STUDIES IN NEUROLOGY

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STUDIES IN NEUROLOGY

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PART III

THE SPINAL CORD

THE GROUPING OF AFFERENT IMPULSES WITHIN THE SPINAL CORD

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CHAPTER I

INTRODUCTION

It would seem reasonable to suppose that the mechanism of sensation ·as arranged in such a way that, from the skin to the sensorium, there was ne system of end-organs, fibres and cells for each sensory quality appreciable y man. On this supposition, every application of heat to the skin would ause a disturbance in the activity of a special set of end-organs, which reacted o this form of stimulation only. From these end-organs the impulse would e transferred by specialised fibres to the spinal cord, and thence by a single ract, directly or through the intermediation of cell-systems, to the final centres n the brain. On this hypothesis, similar organs must exist for cold, for pain, or pressure and for touch. With the discovery of the heat- and cold-spots, nd with von Frey's [36] further development of the doctrine of punctate ensibility, a mechanism seemed to have been found which would reasonably xplain the phenomena of sensation.

But recent work has shown that, as far as the peripheral nerves are con- cerned, the afferent nervous system is not arranged on so simple a plan. Rivers, n conjunction with one of us, has been able to show that between the sparsely scattered heat-spots lies some other mechanism, capable of responding to stimulation by warm objects. Similarly, the work with Sherren upon divided peripheral nerves has demonstrated the existence of two afferent systems in the skin, each of which has its own distribution. To explain the nature and distribution of the sensory mechanism in the peripheral nerves, we are compelled to fall back upon a hypothesis of evolution, from a simple apparatus to something higher but still imperfect; we cannot assume the immediate development of a system logically and specifically complete.

The conception, which we have reached, of the afferent mechanism in the peripheral parts of the nervous system, accords more clearly with what might be expected from our present knowledge of comparative anatomy and physiology. For it is extremely unlikely that, out of the primitive sense-organs of lower animals, independent systems could be developed in man, specifically fitted to receive all those impulses which lead to the development of the sensations of heat, of cold, of pain, of touch, or of pressure. But our doctrine of three peripheral systems developed in all probability at different phylogenetic periods, each system reacting differently to the mass-stimuli of daily life, accords better with the known processes of evolution.

We concluded from our examination of the phenomena which follow division of peripheral nerves, that the afferent mechanism at this level of the nervous system consisted of three systems.

(1) A system corresponding to the group of impulses we have called deep sensibility. The end-organs of this system respond to the stimulus of pressure and to the movement of joints, tendons and muscles. Painful impulses can also arise within this system in consequence of injury to a joint, or excessive pressure. This sensory mechanism is capable of responding in such a way that the patient appreciates both the locality of the stimulus and the direction of movement in any joint which lies within an area innervated solely by this system; and yet the integrity of deep sensibility carries with it no power of appreciating a stimulus, such as that of cotton wool, even over hairy parts. Nor does it permit of the discrimination of two compass points applied simultaneously to the skin, even when widely separated.

The fibres which conduct these sensory impulses run mainly with the muscular nerves, and are not destroyed by division of all the sensory nerves to the skin.

(2) The protopathic system, capable of responding to painful cutaneous stimuli and to the more extreme degrees of heat and cold. Its end-organs are grouped in points on the surface of the body, sensitive to one only of these stimuli. Their response is diffuse, and unaccompanied by any definite appreciation of the locality of the spot stimulated.

(3) The epicritic system. To the impulses of this system we owe the power of cutaneous localisation, of discriminating two points and of recognising the finer grades of temperature, called cool and warm.

A knowledge of this grouping of afferent impulses was gained by studying the consequences which followed division of peripheral nerves and posterior nerve roots in man. But, on comparing the loss of sensation produced by injury and disease of the spinal cord with that caused by division of peripheral nerves, fundamental differences at once became apparent. For if, in consequence of disease of the spinal cord, sensibility to the pain of a prick was lost, the pain caused by excessive pressure was also abolished, even though the parts remained otherwise normally sensitive to pressure. Similarly when a part became totally insensitive to stimuli which usually evoke a sensation of warmth, it was found to be also insensitive to all temperatures which normally cause a sensation of heat.

It is evident, therefore, that, as soon as a sensory impulse reaches its first junction in the spinal cord, it becomes shunted into tracts devoted to the conduction of impulses, grouped in a way different from that found in the peripheral nerves. It is no longer a question of protopathic, epicritic and deep sensibility; each tract in the central nervous system is devoted to the conduction of one of the specific impulses, such as pain, touch, heat and cold.[1]

In the present paper, we are concerned more directly with this grouping of sensory impulses in the spinal cord, rather than with the position of the tracts by which they pass to the higher centres. We hope to demonstrate, not only that a change takes place in the grouping of the afferent impulses but also to show at what point this transformation occurs.

[1] For the nature of the posterior columns *vide* Chapter VII., p. 400.

CHAPTER II

THE NATURE OF THE LOSS OF SENSATION PRODUCED BY A LESION OF THE SPINAL CORD, COMPARED WITH THAT DUE TO DIVISION OF PERIPHERAL NERVES

AFFERENT impulses pass from the periphery to the spinal cord along three systems of fibres, those of protopathic, epicritic, and deep sensibility.

The protopathic system is essentially one of punctate sensibility. For heat, for cold and, probably, for pain, there are definite spots, from each of which a specific sensory impulse can alone be released. The hairs are also innervated partly from this system; and, when the skin is endowed with protopathic sensibility only, exquisite pain is produced by plucking the hairs, and a curious diffuse tingling or formication occurs when they are brushed with cotton wool.

Elimination of epicritic sensibility from any part of the body makes it impossible to distinguish two points of the compasses applied simultaneously, cutaneous localisation is perverted and light touch over hairless parts abolished. Whenever epicritic sensibility is destroyed, the power of appreciating intermediate degrees of heat and cold ("warm" and "cool") will also be lost. We believe that there is a separate cutaneous mechanism which reacts to temperatures we call warm (34° C. to 40° C.). It is also possible that coolness is due to impulses from end-organs other than the cold-spots; the evidence for this view forms the subject of a communication by one of us in conjunction with Dr. Rivers. But it is also conceivable that the sensation of "coolness" might be produced by the combined stimulation of this mechanism and the cold-spots which belong to the protopathic system. According to this view an appreciation of "warmth" would be necessary for the production of the sensation of "coolness," and therefore destruction of epicritic sensibility would remove the power of appreciating the intermediate degrees of temperature, whether they normally give rise to a "warm" or a "cool" sensation.

The existence of both these forms of sensibility depends upon the integrity of fibres in the sensory nerves to the skin. But, even after the complete division of all nerves to the skin, the denervated part remains sensitive to pressure, and pain can be produced as soon as this pressure exceeds a certain measurable amount. Each pressure touch can be localised with fair accuracy, and any movement of the joints is at once recognised. But no degree of temperature produces any sensation, and the part may be burnt or frozen with impunity; not even the pain of the extremes of heat and cold can produce a reaction in this system, which is so exquisitely sensitive to the pain of increasing pressure. The two points of the compasses applied simultaneously cannot be discriminated, but the vibrations of a tuning fork beating 128 to the second can be perfectly recognised.

As this form of sensibility remains after all cutaneous afferent nerves have been destroyed, it is obvious that the fibres by which its impulses pass to the central nervous system must run, at any rate to a considerable extent, with the muscular nerves. But it must not be supposed that we deny the existence of fibres in the superficial structures of the body, which belong to this deep system, and are capable of reacting to pressure in all forms.[1] Sherren, Rivers and Head were compelled to neglect them, because their only opportunities for investigating the properties of this deep system arose after division of all the nerves to the skin. But, in consequence of the peculiar dissociation of sensibility which we shall study in this paper, we see reason to believe that this system of afferent fibres running in great part with muscular nerves, also sends some fibres to the skin, particularly of such parts as the palm of the hand and the sole of the foot.

These statements can be summarised in the following table :—

Loss of *epicritic sensibility* abolishes—
- Recognition of light touch over hairless parts or parts that have been shaved.
- Cutaneous localisation.
- Discrimination of compass points.
- Appreciation of differences in size, including the accurate discrimination of the head from the point of a pin apart from the pain of the prick.
- Discrimination of intermediate degrees of temperature from about 26° C. to about 38° C.

Loss of *protopathic sensibility* abolishes—
- Cutaneous pain, especially that produced by pricking, burning, or freezing, together with that of stimulation with a painful interrupted current. Over hair-clad parts, plucking the hairs ceases to be painful.
- Sensations of heat from temperatures above about 45° C.
- Sensations of cold from temperatures below 20° C.

After destruction of all cutaneous afferent fibres the part is still endowed with *deep sensibility*.
- Pressure can be recognised, and its gradual increase appreciated.
- Pain is produced by excessive pressure (measured by the algometer).
- Movements of muscles can be recognised.
- The point of application of pressure can be localised.
- The patient can recognise the extent and direction of movement produced passively in all the joints within the affected area.

This grouping of the afferent impulses on their way from the periphery to the central nervous system is probably determined by reasons of phylogenetic development. But as soon as the first intramedullary cell-system is reached, these impulses become shunted into paths along which they travel in new combinations, and in this chapter we shall discuss the forms assumed

[1] *Cf.* p. 196.

by the loss of sensation, due to a lesion interfering with afferent impulses, after this new grouping has occurred.

§ 1.—Pain

Nowhere is this difference of grouping more evident than in the behaviour of those impulses associated with the pain produced by deep pressure. After division of a peripheral nerve, or of posterior roots, those parts only become insensitive to the pain of deep pressure which are at the same time totally insensitive to the tactile element of this stimulus. Unless all forms of deep sensibility are abolished, pain will still be caused by excessive pressure.

But, if the lesion lies within the spinal cord, sensibility to pain is abolished as a whole, whatever the form of painful stimulation. The patient will be insensitive both to the pain of excessive pressure and to that of a prick or of the interrupted current; yet, at the same time, he may be able to recognise the

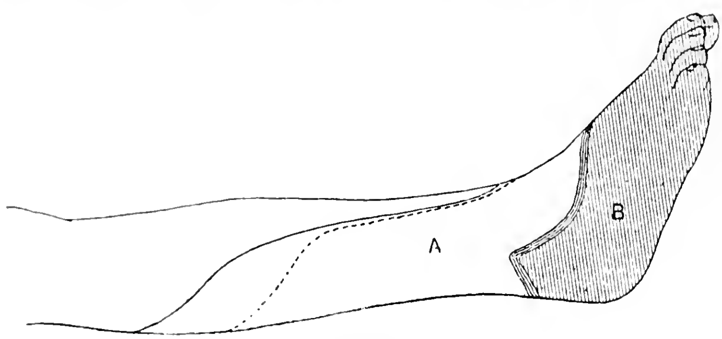

Fig. 74.

To show the loss of sensation in William B., produced by destruction of the sacral plexus.

The extent of the loss of all forms of sensation, including pressure, is shaded and marked **B**.

Those parts which were insensitive to all cutaneous painful stimulation but were sensitive to the pain of deep pressure are enclosed within a broken line and marked **A**.

Sensibility to light touch was lost below the single dark line.

position of the spot pressed upon, and can appreciate the gradually increasing pressure.

The following case is an excellent instance of the condition produced by destruction of several nerve-trunks.

William B. (originally reported by Sherren and Head, p. 223, and later by Sherren [107]) was shot through the buttock on October 4, 1901. This produced loss of sensation over the region supplied by the great and by the small sciatic nerves, together with paralysis of all the muscles below the knee supplied by the latter nerve. He was seen by Mr. Sherren and one of us on several occasions from 1902 onwards. Finally, in May, 1905, he came under the care of Mr. Sherren at the London Hospital, and at the exploratory operation the following condition was found. The sciatic plexus was divided below the point at which it was joined by the second sacral nerve; the third sacral had been destroyed in the wound of the sacrum and the nerves were bound up in a dense mass of fibrous tissue. Mr. Sherren sutured the lumbo-sacral cord and the second sacral nerve to the stump of the sciatic. As soon as the wound of this operation was healed, the sensibility of his leg was again tested and was found to correspond exactly to that before the operation. The extent of the loss is shown on Fig. 74, taken from a series of photographs. It will be seen that over the greater part of the foot, deep sensibility was lost (area B): here he was insensitive to the painful and tactile elements of pressure and failed to appreciate the vibration of a tuning-fork. But on the outer aspect of the leg was an area of considerable extent (A) over which he was entirely insensitive to the prick of a pin or to the pain of an interrupted current. Within this area, the same amount of pressure was painful as on the sound side within similiar limits. Thus a part of the leg completely insensitive to

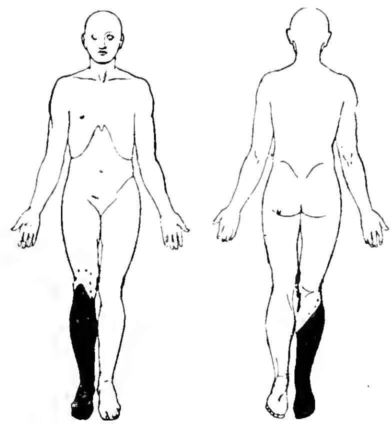

FIG. 75.

To show the loss of sensation in Case 17, due to an injury to the spinal cord.

The dark area represents the parts insensitive to cutaneous painful stimuli, and also to the pain of excessive pressure; and yet over this area light touch and the tactile element of pressure were appreciated.

cutaneous painful stimulation was sensitive to the pain of excessive pressure. The only parts where pressure could not be made to produce pain, were those devoid of all forms of deep sensibility.

	Algometer Reading in Kilograms.	
	Right (affected).	*Left.*
Outer Aspect of Shin.		
Anterior portion (*a*)	Pain at 2 (within the area of cutaneous analgesia) ...	Pain at 2.
Posterior portion (*b*)	Pain at 3 (within the area of cutaneous analgesia) ...	Pain at 3.
Sole of foot	No pain at 10 (deep sensibility abolished)	Pain at 2.
Below external malleolus ...	No pain at 10 (deep sensibility abolished)	Pain at 1·5.

Compare with this dissociated analgesia the condition of the following patient (Case 17), who suffered from a lesion within the spinal cord. He was injured by the overturning of a truck of concrete on May 9, 1905, and was brought to the London Hospital paralysed from the hips downwards. By May, 1906, he had partly recovered and showed a condition that was so sharp a contrast to that of the previous patient (Fig. 75).

He walked, dragging the left leg like a man with hemiplegia, and this leg was stiff and spastic. All movements could be performed by the various parts of the limb, but they were slow, especially dorsiflexion at the ankle. Both knee-jerks were exaggerated, ankle clonus was obtained and the plantar reflex gave an extensor response on both sides.

The right leg below the knee was insensitive to prick and to all degrees of temperature. But, over the whole of this area, he could appreciate all tactile stimuli and could localise accurately the spot touched or pressed upon. Yet it was not possible to produce pain anywhere over the right leg and foot by excessive pressure, although he fully recognised its gradual increase.

	Right.		*Left.*
Outer aspect of leg	No pain at 16	..	Pain at 5
Inner aspect of leg over tibia	No pain at 10	..	Pain at 4.
Front of thigh above the limits of the analgesia	Pain at 5	..	Pain at 5

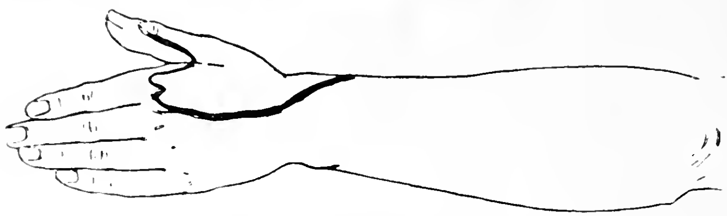

FIG. 76.

To show the loss of cutaneous sensibility on the dorsum of the hand produced by experimental division of the radial (r. superficialis n. radialis) and external cutaneous nerves in the neighbourhood of the elbow.

Thus, in the former case, where the analgesia over the leg was produced by division of nerve-trunks, a large area of skin was sensitive to the pain of deep pressure, although insensitive to all painful cutaneous stimuli. Only over the foot, where deep touch evoked no response, was the pain of pressure abolished.

But, where the loss of sensation was produced by a lesion of the spinal cord (Case 17), the pain of pressure was absent over parts insensitive to prick, in spite of the complete integrity of the sensations of deep touch, and of the power of recognising the gradually increasing pressure.

These two patients were chosen as examples, because the site of the loss of sensation was so nearly alike in the two cases. An equally striking contrast is given by comparing the sensory condition of a part to which all the cutaneous nerves have been divided, with the loss of sensation produced by a pure lesion of the spinal cord.

On April 25, 1903, the radial and external cutaneous nerves were divided at the elbow in one of us. The area on the hand, which became entirely nsensitive to all cutaneous stimuli, including the pain of a prick and of the nterrupted current, is shown on Fig. 76. But pressure was appreciated and, when increased, caused pain even more readily than over a similar part of the sound hand. The readings given by the algometer in kilograms were as follows :—

	Left (affected).	*Right (sound).*
Over the dorsum of the hand	3·5	3·5
In first interosseous space	2·0	3·5
	2·0	4·0

Compare with this dissociated sensibility to painful stimuli, the sensory condition of the hands in Case 13, a patient suffering from syringomyelia. The whole of the area marked on Fig. 77 was insensitive to prick and to the

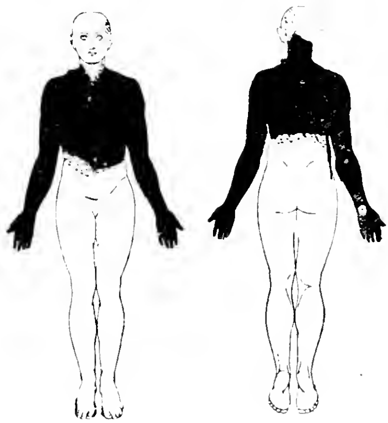

Fig. 77.

To show the loss of sensation to cutaneous painful stimuli in a case of syringomyelia (Case 13). The whole of the area marked black was insensitive to the pain of excessive pressure.

painful interrupted current. Tactile sensibility was everywhere perfect; he could localise accurately the spot touched, or pressed upon, and appreciate passive movements of all the joints. But pain could not be produced by pressure anywhere within the area of cutaneous analgesia, although he recognised the gradually increasing stimulation.

	Right.	*Left.*
Palm of hand	No pain at 15	No pain at 15.
Thenar eminence..	No pain at 15	No pain at 15.
Sole of foot	Pain at 4 ..	Pain at 4.

Thus, in conclusion, we have found that, when sensibility to pain is abolished in consequence of an intramedullary lesion, all forms of painful stimuli are simultaneously affected. But, if the lesion be situated in the peripheral nerves or posterior roots, the painful impulses produced by excessive pressure are not interrupted, unless deep sensibility is abolished as a whole.

§ 2.—Heat and Cold

Great as is the contrast between the grouping of painful afferent impulses in the peripheral and central nervous system, those for sensations of heat and cold undergo an even more complete redistribution. Destruction of either the epicritic or the protopathic fibres interferes with the afferent impulses, both for heat and for cold. If epicritic sensibility is abolished, the patient cannot discriminate intermediate degrees of heat and cold, but remains sensitive to the more extreme temperature stimuli. After a peripheral nerve has been divided, the protopathic system recovers first; this recovery endows the part with sensibility to cold below about 20° C. and heat above about 40° C.

Injury to peripheral nerves or posterior roots abolishes, to some degree,

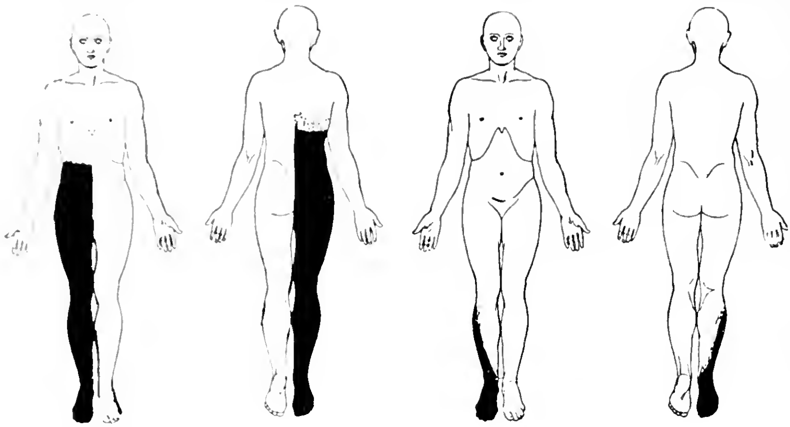

Fig. 78. Fig. 79.

Both figures show the loss of sensation produced in Case 8, by disease of the cervical region of the spinal cord. Fig. 78 shows the extent of the loss to prick. Fig. 79 that of the loss to all degrees of cold. Sensation was everywhere present to all degrees of heat.

sensibility both to heat and cold; recovery restores to the part sensibility to both forms of thermal stimulation.

But, when the lesion is situated within the spinal cord, areas may be found insensitive to heat but sensitive to cold, or *vice versa*. An intramedullary lesion may even destroy all sensibility to one form of thermal stimulation, leaving the parts completely sensitive to the other. Evidently the whole arrangement of thermal impulses has undergone a change within the spinal cord. All impulses which subserve sensations of heat, whether they arrive by way of the epicritic or protopathic systems, become a single intramedullary group. In a similar manner all thermal impulses, whatever their source, which can produce sensations of cold, are brought together within the spinal cord.

G. G. A. (Case 8) was a good example of this condition. Sensation was disturbed down the right half of the trunk and over the right leg, whilst the left leg was stiff and spastic. The right knee-jerk was brisk, but the left was exaggerated, and clonus was obtained from the left ankle. He was analgesic below the level of the nipple on the right side (Fig. 78). Cold was appreciated everywhere above the right knee; but the outer aspect of the right leg and the whole of the right foot were insensitive to stimulation by cold in all degrees (Fig. 79). Heat from 35° C. to 56° C. was everywhere appreciated correctly, except that, over the parts insensitive to prick, he did not experience the usual sensation of burning pain when the temperature rose above 50° C.; and yet he could clearly appreciate the increasing heat when the stimulus changed from 50° C. to 60° C.

Here no cold stimulus produced a sensation over parts of the leg, where

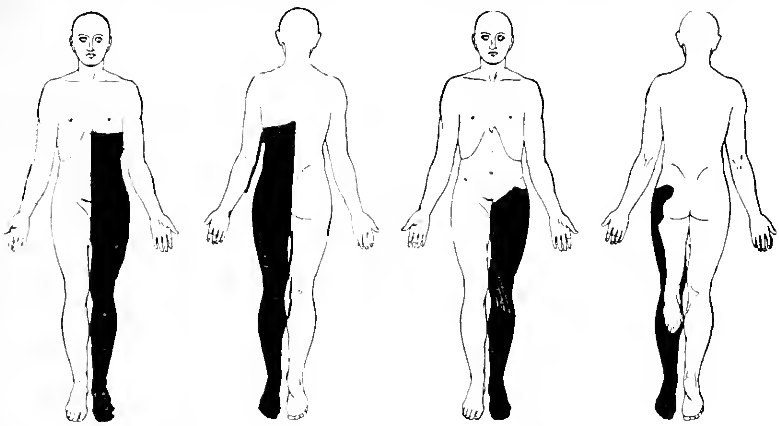

Fig. 80. Fig. 81.

To show the loss of sensation to heat (Fig. 80) and to cold (Fig. 81) due to injury to the cervica spinal cord (Case 7).

all temperatures from 30° to 60° C. caused a sensation of heat. Such a total dissociation of the sensations of heat and cold never occurs from division of peripheral nerves.

A similar dissociation of sensibility to heat and cold, but in the reverse direction, was seen in Cyril W. F. (Case 7). In consequence of an injury to the neck, due to diving into shallow water, this young man produced weakness of the right arm, accompanied by loss of sensibility to pain, heat and cold over the left half of the body, each area of loss of sensation having a different extent (Figs. 80 and 81). From the level of the ensiform cartilage downwards to the penis, he was insensitive to all degrees of heat only; temperatures between 30° and 60° caused no sensation of warmth. But, over this area, he was sensitive to all cold stimuli, recognising them at once.

Here, again, the sensibility to heat and to cold were dissociated. Moreover, those parts insensitive to heat were insensitive to all degrees from 30° C. to 60° C., a condition which never occurs from any lesion of peripheral nerves.

In the case of Mrs. G. (No. 3), the loss of sensation to various thermal stimuli was tested with extreme care on many occasions, and she was found to be insensitive on the left leg to all degrees of temperature between 0° C. and 60° C. As she was also insensitive to pain over the same parts, it might have been urged that in this case both protopathic and epicritic sensibility had been abolished. The falsity of such a supposition is at once evident from the fact that she was everywhere sensitive to light touch, and that the compass test gave normal results over the affected areas. This condition can never occur from a lesion of peripheral nerves or posterior roots.

An exactly similar loss of sensation to all grades of heat and cold appeared in Case 2, in consequence of an injury to the cervical spine. This completely abolished sensibility to pain, heat and cold over the left leg and left half of the body, leaving all forms of tactile sensibility entirely unaffected.

In conclusion, we find that the afferent impulses produced by thermal stimuli are differently grouped in the peripheral nerves and in the spinal cord.

(1) Sensibility to heat may be abolished without coincident disturbance of that to cold, and *vice versa*.

(2) When sensibility to heat is disturbed in consequence of an intramedullary lesion, the patient no longer appreciates any thermal stimulus between 30° C. and 60° C. That is to say, insensibility is absolute to both intermediate and extreme degrees.

(3) Insensibility to heat and cold may be absolute, and yet the patient may be able to recognise the lightest tactile stimulation and to discriminate the two points of the compasses. Such conditions can never occur from a lesion of peripheral nerves only.

§ 3.—Light Touch and Deep Touch

One of the most characteristic features of the loss of sensation following division of peripheral nerves, is the frequency with which light touches are not appreciated, although deep touch and pressure are immediately recognised.

But, when the lesion is purely intramedullary, all these sensory impulses come and go together. Thus, in a characteristic instance of Brown-Séquard paralysis (No. 1), the patient was unable to recognise either light, touch or pressure, applied within the affected area on the right half of the body. The whole of the right leg was insensitive to stimulation with cotton wool. No reaction could be obtained to any of the graduated tactile hairs, although No. 5 was promptly recognised over the left leg. Pressure, even of many kilograms, produced no sensation, unless the position of the muscles was shifted. Yet this patient recognised accurately any alteration in position, or any movement produced passively in the insensitive leg. Such a condition cannot possibly arise from a lesion of peripheral nerves.

Thus, whenever sensibility to touch is abolished on the opposite half of the body, in consequence of an intramedullary lesion, we believe that all forms of tactile stimuli will be found to be affected. The peripheral afferent impulses for touch and pressure, arriving by way of the epicritic and deep systems, become combined in the spinal cord, so that the lightest perceptible touch produces a minimal tactile impulse, which passes up the spinal system among the tactile impulses evoked by the severer stimulus of pressure.[1]

§ 4.—Passive Position and Movement

After division of peripheral nerves, the recognition of passive movement, and of the position into which any part of the limb has been placed passively, is strikingly associated with the integrity of that system of nerves concerned with the maintenance of deep sensibility. So long as the cutaneous afferent nerves only are divided, the patient can appreciate all movements of the joints, is sensitive to pressure, and complains of pain when this pressure is increased. There is a close association in the peripheral nervous system between sensibility to pressure, the pain of excessive pressure and the power of recognising passive movement and position. All three forms of sensibility are present or absent together after lesions of the peripheral nerves, and all three depend upon the integrity of those afferent fibres which run with muscular nerves.

With an intramedullary lesion, on the other hand, all recognition of the position assumed passively by a limb is entirely dissociated from the afferent impulses produced by pressure. Both groups are equally dissociated from those impulses which underlie the recognition of the painful nature of excessive pressure.

In fact, Case 1 shows that the patient may be able to appreciate passive position and movement, although totally insensitive to every other sensory stimulus. This man was suddenly seized with loss of power in the left hand and leg, accompanied by absolute loss of sensibility to pain, heat and cold over the opposite half of the body. His power of movement was gradually restored, but the loss of sensation remained. Insensibility to touch and pressure accompanied the analgesia and thermo-anæsthesia, and excessive pressure produced no pain. But, in spite of this profound loss of sensation, the sense of passive position and movement remained undisturbed in both lower extremities. The most careful testing failed to show a difference between any parts of the two legs in the power of recognising movement or position passively assumed. Here, in spite of the absence of all sensibility to deep touch and pressure, the sense of passive position was not disturbed.

In the case of James Y. (No. 10) an exactly converse condition was present: sensibility to touch and pressure was present, but he was unable to recognise the position into which his limbs had been placed, and failed to perceive even the most extensive movement. In consequence of a metastatic growth within the spinal cord, this man had rapidly lost power in both legs. When seen by us a month after the onset, both legs were flaccid and paralysed, and sensibility to painful and thermal stimuli was abolished below the knees and diminished over the area shown in Figs. 82 and 83; light touch and pressure

[1] For a further consideration of the relation between sensations of light and deep touch, *cf.* p. 356.

could be recognised everywhere. But he was unable to tell the position into which his legs had been placed; he could not recognise even the grossest movements at the hip, the knee, or the ankle. With this loss of appreciation of passive position and movement was associated a complete absence of discrimination of two points, even when separated to a distance of 20 cm.

This dissociation of the sense of passive position from the impulses of all other forms of sensation, except the discrimination of two points, is peculiarly well illustrated by the case of Charles B. (No. 2). At the time he was first seen, motion was impaired in the left leg, and sensibility to pain and temperature abolished in the right leg and right half of the body. He could appreciate passive movement and the position of all his limbs perfectly. But, in consequence of the operation for the removal of the fractured portion of the spine,

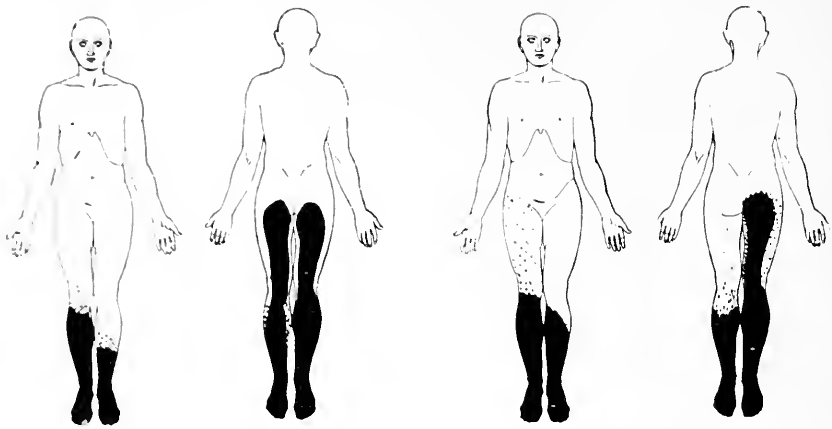

Fig. 82. Fig. 83.

To show the loss of sensation produced by a metastatic growth within the spinal cord in Case 10.
Fig. 82. Shows the extent of the loss to pain.
Fig. 83. Shows the extent of the loss to heat and cold.
The extent of the loss of sensation to painful and thermal stimuli varied considerably from day to day, and the areas of total loss were bounded in every case by parts of diminished sensibility.

he lost the power of recognising passive movement and position of the left leg, *i.e.* the leg in which all other sensory functions were perfect.

Such loss of the sense of passive movement and position on the opposite side of the body to the analgesia and thermo-anæsthesia is the rule in Brown-Séquard paralysis, and is illustrated by several of our cases.

In conclusion, we have been able to show that, in consequence of an intramedullary lesion, every other form of sensibility may be abolished in a part which still remains sensitive to passive movement. (Case 1.)

Secondly, we have shown that the patient may be unable to recognise even the grossest passive movements, and be entirely unaware of the position of his legs, although they are sensitive to all tactile and pressure stimuli. (Case 10.)

Thirdly, we can bring forward a number of instances where the sense of passive position and movement was disturbed in one leg, whilst every other loss of sensation was to be found in the leg of the opposite side. (Case 2.)

Such dissociation of the impulses underlying the recognition of passive position and movement from the impulses of the other forms of deep sensibility cannot occur in consequence of injury to peripheral nerves.

§ 5.—The Compass Test

One of the most remarkable differences between the loss of sensation produced by division of a peripheral nerve and that due to a lesion within the spinal cord is revealed by the compass test. When a nerve has been injured, sensibility to light touch is the first to be disturbed; with this failure to appreciate careful stimulation with cotton wool over hairless parts, the compass test will be invariably found to give results considerably below the normal accuracy. In fact, from the point of view of the peripheral nervous system, the compass test is an accurate measure of tactile sensibility of the skin. For this purpose Head and Sherren found it most useful, when carried out by the modified method described in their paper.

But, when the lesion is situated within the spinal cord, sensibility to light touch and the power of discriminating two points may be strangely dissociated.

In order to demonstrate this characteristic dissociation, all forms of tactile sensibility must be preserved. For it is obvious that, if the part to be tested is insensitive to touch and pressure, the compass test will fail from want of afferent impulses. A diminution of tactile sensibility will produce a less accurate compass record, not because the special power of discriminating two points is lessened, but on account of the diminished acuity of the tactile impressions that are to be discriminated.

We have, therefore, selected those cases only where all forms of tactile sensibility were perfect, and yet the power of discriminating two points was gravely disturbed.

In Case 10, a man, aged 61 years, had become rapidly paralysed in both legs in consequence of a growth within the spinal cord (Figs. 82 and 83). With this paralysis, he had lost the power of appreciating the position of his limbs to an unusual degree, and was unable to discriminate the two points of the compasses, when widely separated. Over the external surface of the leg, he failed entirely at 15 cm. and at 20 cm. over the front of the thigh; over the palm of the left hand, a part unaffected by paralysis of motion or sensation, he gave correct answers at a distance of 1·5 cm. At this time, there was no part over which he did not at once respond to light touches, or to pressure, and this grossly defective power of discriminating two points cannot, therefore, have been due to altered tactile sensibility.

This dissociation is shown in a peculiarly striking manner by Case 16. The patient, a man, aged 32 years, had suffered for four years from symptoms of a growth within the cervical portion of the spinal cord. This produced a loss of sensation over the arms and trunk shown on Figs. 84 and 85: but both legs remained sensitive to all painful, thermal and tactile stimuli. With the finest tests, no difference could be discovered in the tactile sensibility of the two legs. With von Frey's hairs, No. 5 could be appreciated everywhere over the soles of both feet; No. 4 produced no sensation on either limb. And yet the power of discriminating two points was gravely diminished over the left foot and leg. Over the sole of this foot, he answered badly when the points were separated to a distance of 8 cm.

8 cm. 1 | 10 R.
2 | 5 W. 5 R.

whereas, over the right sole, his answers were perfect at 4 cm.

4 cm. 1 | 10 R.
2 | 10 R.

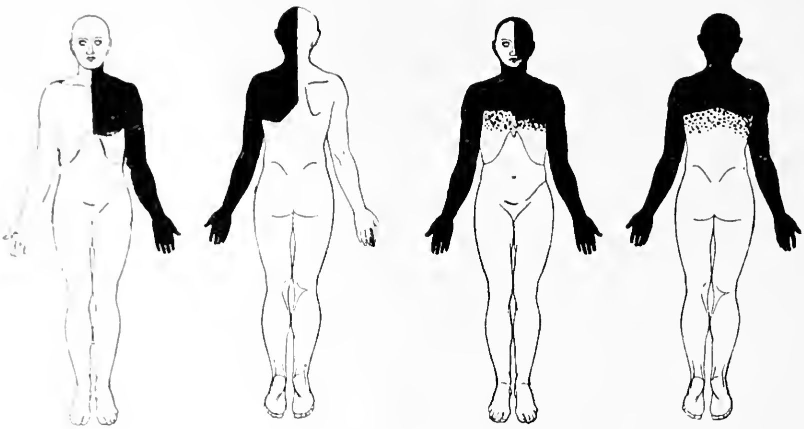

FIG. 84. FIG. 85.

To show the loss of sensation in a case of disease of the medulla oblongata and cervical portion of the spinal cord (Case 16).

Fig. 84. Shows the loss of sensation to painful stimuli. Fig. 85, the loss to heat. To cold, the anæsthesia was slightly less extensive.

The only loss of sensation in the lower extremities consisted of profound loss of the sense of passive position and movement, and of defective sensibility to the compass test in the left leg.

Over the outer aspect of the left leg, he failed with the points separated to

15 cm. 1 | 4 W. 6 R.
2 | 5 W. 5 R.

15 cm., but over a similar part of the right leg, his answers were uniformly correct at 8 cm.

These two cases show that, within the spinal cord, the impulses which underlie the power of discriminating two points are separated from those of tactile sensibility. Having passed up in the epicritic system, they become dissociated in the spinal cord from the remaining forms of epicritic sensibility. Within the spinal cord, they pass on in close association with the impulses which underlie the recognition of passive movement and position of the limbs, impulses which have reached the cord by means of the system of fibres subserving deep sensibility.

CHAPTER III

THE INTERRELATION OF AFFERENT IMPULSES IN THEIR PASSAGE UP THE SPINAL CORD

In the previous chapter, we have shown that afferent impulses, which reach the central nervous system by way of the peripheral nerves, undergo rearrangement within the spinal cord. We shall now attempt to trace their course upwards, indicating as far as possible the relation of each set of impulses to the others.

More than fifty years ago, Brown-Séquard stated that division of one half of the spinal cord caused loss of sensibility to pain on the side opposed to the lesion, and that motion was affected on the same side.

Led by the results of his experiments on animals, he examined more carefully the condition of sensation in patients suffering from what was called spinal hemiplegia. He attempted to show that this condition was the result of disease or of injury to one half of the spinal cord, which produced paralysis of voluntary movement on the one side, and anæsthesia on the other side of the body.

" Experiments on animals and a great many clinical facts," he says [19], " show that an injury, destroying a small zone, or dividing the whole lateral half of the spinal cord in the cervical region, produces the following symptoms—

" 1st.—Paralysis of the volunatry motor conductors on the same side.

" 2nd.—A paralysis also of the vasomotor conductors on the same side, and, as a consequence, a greater afflux of blood and a higher temperature. . . .

" 5th.—There is anæsthesia of all kinds of sensibility, excepting the muscular sense, in the side opposite to that of the lesion in the spinal cord, owing to the fact that the conductors of sensitive impressions from the trunk and limbs decussate in the spinal cord, so that an injury in the cervical region of that organ in the *right* side, for instance, alters or destroys the conductors from the *left* side of the body.

" 6th.—There is some degree of anæsthesia also on the side of the lesion, in a very limited zone, above the hyperæsthetic parts, and indicating the level of the lesion in the cord. This anæsthesia is due to the fact that the conductors of sensitive impressions reaching the cord through the posterior roots, at the level or a little below the seat of the alteration, have to pass through the altered part to reach the other side of the cord."

This admirable summary is followed by the narration of two cases, observed by Brown-Séquard himself, with a fulness rarely equalled in the present day [19].

TABLE

Case	Disease.	Motor Disturbance.	Sensory: At Level of Lesion.	Sensory: Remote (Due to Interference: Light Touch.	Sensory: Remote (Due to Interference: Pressure
No. 1. F. C. p. 406.	Probably hæmorrhage into the spinal cord. Sudden onset, Dec. 13, 1903	At first weakness of L. arm. No spasticity	None ...	R. leg and R. half of body below level of umbilicus	R. leg and R. half of body below level of umbilicus
No. 4. A. H. p. 416.	Fracture of fourth cervical vertebra in 1901	Spasticity and weakness L. leg and L. arm	None ...	Slightly diminished over R. foot	Slightly diminished over R. foot
No. 2. C. B. p. 410.	Fracture of third cervical vertebra in 1904	*Before operation*—Weakness of R. arm and leg	None ...	None ...	None ...
	Operation June 25, 1905	*After operation*—Increased weakness of R. arm and leg	None ...	None ...	None ...
No. 3. G. G. p. 412.	Probably hæmorrhage into the spinal cord. Sudden onset, Feb. 18, 1898	Spasticity and weakness R. leg	None ...	None ...	None ...
No. 5. W. M. p. 420.	Fracture of cervical spine in 1904 (Radiograph shows disintegration of sixth and seventh cervical vertebra)	*Local*—R. hand, wasting of small muscles *Remote*—R. arm and R. leg, spasticity	None ...	None ...	None ...
No. 6. J. M. p. 423.	Injury to cervical spine from diving into shallow water in 1886	*Local*—L. hand, wasting of small muscles *Remote*—Spasticity of L. leg	None ...	None ...	None ...
No. 7. C. W. F. p. 426.	Injury to cervical spine from diving into shallow water in 1905 (Radiograph shows changes in body of sixth cervical vertebra)	*Local*—R. hand, slight wasting small muscles *Remote*—None	None ...	None ...	None ...
No. 8. G. G. A. p. 429.	Disease of the cervical cord, possibly syphilitic. Onset 1904. Seen by us 1906	*Local*—L. hand, slight wasting small muscles *Remote*—Spasticity L. leg	None ...	None ...	None ...

I.

DISTURBANCE. REFLEXES.

with Long Sensory Paths).

Pain.	Cold.	Heat.	Passive Position and Movement	Compasses.	
R. leg and R. half of body below level of umbilicus	R. leg and R. half of body below level of umbilicus	R. leg and R. half of body below level of umbilicus	No loss ...	L. no loss. R. no response.	Knee-jerks equal. No ankle clonus. Plantars flexor.
R. leg and R. half of body	R. leg and R. half of body	R. leg and R. half of body	No loss ...	No loss ...	L. knee-jerk + +. R. knee-jerk normal. L. ankle clonus. R. no ankle clonus. L. plantar extensor. R. plantar flexor.
L. half of body and greater part of L. arm	L. half of body and greater part of L. arm	L. half of body and greater part of L. arm	No loss ...	No loss ...	R. knee-jerk + +. L. knee-jerk normal. R. ankle clonus. L. no ankle clonus.
Same ...	Same ...	Same ...	Profound loss. R. arm and R. leg	Not tested ...	R. plantar extensor. L. plantar flexor.
L. lower extremity up to groin	L. lower extremity up to groin	L. lower extremity up to groin	R. foot ...	R. foot ...	R. knee-jerk + +. L. knee-jerk normal. R. ankle clonus. L. no ankle clonus. R. plantar extensor. L. plantar flexor.
L. leg, L. half of body and strip on L. arm	L. leg, L. half of body and strip on L. arm	L. leg, L. half of body and strip on L. arm	No loss ...	No loss ...	R. knee-jerk greater than L. R. ankle clonus. L. no ankle clonus. R. plantar extensor. L. plantar flexor.
R. half of body below umbilicus, and R. leg, except over sacral areas	R. half of body below umbilicus, and R. leg, except over all sacral areas	R. half of body below umbilicus, and R. leg, except over all sacral areas	No loss ...	No loss ...	L. knee-jerk + +. R. knee-jerk normal. L. ankle clonus. R. no ankle clonus. L. plantar extensor R. plantar flexor.
Front of L. leg and thigh. All sacral areas unaffected	L. leg, except all sacral areas	L. leg and L. half of body to level of ensiform and angle of scapula	No loss ...	No loss ...	R. knee-jerk greater than L. No ankle clonus. R. plantar doubtful. L. plantar flexor.
R. leg and R. half of body to level of ensiform	R. foot and outer aspect. R. leg below knee	No loss ...	No loss ...	No loss ...	Left knee-jerk + +. R. knee-jerk normal. L. ankle clonus. R. no ankle clonus. L. plantar extensor. R. plantar flexor.

His results have been attacked from two points of view. It was pointed out that the lesions produced by disease were crude and ill defined, and commonly affected both halves of the spinal cord. Moreover, post-mortem examinations on those who had suffered from Brown-Séquard paralysis are uncommon, except in cases complicated by grave general disease, which renders difficult an accurate investigation of sensibility.

Physiologists attempted to solve the question by means of animal experiments, carried out with all modern surgical precautions. Some (especially Turner [126]) supported the original view of Brown-Séquard, others (Schiff, Mott [85], Rothmann [98], Schuster [104]), concluded that afferent impulses did not cross in the diagrammatic manner he described. Moreover, many experimenters have shown that hemisection in the dorsal region produces ascending degeneration in both the same and the opposite half of the spinal cord. It is therefore certain that to afferent impulses, arriving by way of the posterior roots, both crossed and uncrossed paths are open.

But of the nature of the afferent impulses passing by these paths, experiments on animals can tell us little. It is difficult to conclude whether they are non-sensory afferent impulses, concerned with what may be called the higher reflexes, or whether they are ultimately concerned with some form of sensation. For every examination of sensation is in reality a psycho-physical experiment, where the extent of the mental error can entirely obscure the physical result. The nature and extent of these errors we can estimate only in man. Moreover, it is not sufficient to note the response to a stimulus; we must hear from the lips of the patient his experiences under stimulation. Supposing he starts and withdraws his foot when pricked, we cannot conclude that he experiences pain. It may be that his withdrawal is the reflex response to pressure with a pointed object. He alone can tell us the nature of his sensations.

Thus, we are compelled to fall back upon the results of disease. But the destruction produced by disease is greatly wanting in precision compared with an experimental lesion. Moreover, on account of lack of time, or forethought, or the progressive nature of the disease, many clinical records are wanting in necessary fulness and precision. Thus, on the one hand, are those who, for the sake of the definiteness of the lesion, cling to the results of animal experiment, which can demonstrably lead to elementary conclusions only concerning sensation; on the other stand the clinicians, with their imperfect records and ill-defined terms.

We do not attempt to base our conclusions on the verification of the position of the lesion by post-mortem examination. For, in most cases where a microscopical examination was possible, the general condition of the patient had been unfavourable to that rigid and repeated examination by which alone the condition of sensibility can be established.[1] We shall assume that an

[1] We have rejected two cases in which a complete microscopical examination was made on account of faulty sensory records.

intramedullary lesion disturbs the motor functions, and alters the reflexes on the same side of the body. This no one has doubted. Then we shall examine the effect produced by an intramedullary lesion upon the patient's answers to a series of sensory tests. From these we shall deduce the manner in which the sensory impulses are grouped in their passage up the spinal cord, and correlate the loss of sensation with the motor disturbance.

Such study of the nature and relation of sensory impulses, when disturbed by an intramedullary lesion, has led to more fruitful results than the anatomical method, which demands in every instance that the lesion should be demonstrated to be unilateral. For a complete unilateral lesion, especially if it be the result of progressive disease, will certainly cause functional and even microscopical changes in the opposite half of the cord.

We have arranged on Table 1, eight cases of Brown-Séquard paralysis observed by ourselves. In every instance the motor disturbance was limited to the one half of the body, and in no case was the same form of sensation disturbed on the two sides.

In this chapter we shall deal with the disturbances of sensation remote from the level of the lesion. As Brown-Séquard pointed out, a lesion of the spinal cord not uncommonly produces some degree of anæsthesia on the side of the lesion, due to an interruption of sensory impulses at the level of the disease. These local manifestations will be reserved for Chapter IV, while in the present chapter we shall deal with the disturbances of sensation in parts remote from the level of the lesion.

§ 1.—Pain, Heat and Cold

The close relation between the impulses for sensations of pain and temperature has long been universally recognised. Easily investigated and clearly defined, the loss of sensibility to pain, heat and cold is well described in most cases of disease of the spinal cord, however insufficient may be the remainder of the record. Petrén [90] has gathered together records of 137 unilateral lesions of the spinal cord in a monograph on this subject. He concludes that, in 128 cases where the condition was adequately recorded, sensibility to pain, heat and cold was abolished on the side opposite to the lesion.

Thus, whatever may happen to the impulses which underlie other forms of sensibility, there can be little doubt that, in man, those for pain, heat and cold cross to pass up the opposite side of the spinal cord.

To these cases may be added the eight instances of Brown-Séquard paralysis in the Table on pp. 350 and 351. In all it will be found that the motor disturbance was strictly unilateral, and the remote loss of sensation was confined to one side: in all, sensibility to pain, heat and cold was disturbed on the side opposed to that of motion.

We have already described the character of this loss of sensation in Chapter II. When sensibility is abolished to pain, from an intramedullary lesion, no normally painful stimulus, whether it be a prick, the interrupted current, or excessive pressure, will produce a painful afferent impulse. In the same way, sensation is lost to all degrees of heat or of cold, except at the edges of an ill-defined area of thermo-anaesthesia. Here the more extreme degrees of heat or of cold may produce a sensation, because they are a more intense thermal stimulus than the intermediate degrees; but, if the insensitive area has well-defined borders, all forms of the specific sensibility to heat or to cold are abolished altogether.

Although the impulses for pain, heat and cold are so closely associated in their passage up the spinal cord on the side opposed to their point of entry they do not travel inextricably intermingled. Not only can the three forms of sensibility be destroyed over different skin areas, but it is possible that one may even escape entirely.

In Case 8, it is almost certain that at one time sensations of pain, heat and cold were lost over the right half of the trunk and over the right leg. But, when the patient was first seen, the dissociation was pronounced. He could not appreciate a prick, or the pain of excessive heat, or the painful faradic current, over the right half of the body below the costal margin. But sensibility to all degrees of cold was lost over the right leg below the knee only, whilst temperatures between 35° C. and 65° C. could be everywhere recognised. (Figs. 78 and 79.)

It is particularly in lesions of the cervical portion of the spinal cord that the three forms of sensation tend to be unequally affected. In August, 1905, C. W. F. (Case 7) injured his neck from diving into shallow water; when seen by us in November, the loss of sensation was more extensive to heat than to cold, to cold than to pain (Figs. 86, 87 and 88). Moreover, this patient showed another phenomenon not uncommon in lesions of the upper part of the cord; the analgesia occupied the front of the thigh and leg, but did not extend on to the sacral area. To a less degree, this was the case also with the loss of sensation to cold. Thus, a lesion in the cervical region abolished sensation over the opposite leg, without interfering with the impulses from the terminal portions of the spinal cord. This was extremely well shown in the case of J. M. (No. 6), who, twenty years before we first saw him, had injured his cervical spine by diving into shallow water. In this instance, the extent of the loss to pain was greater than that to cold and to heat.

When the loss of sensation produced by an intramedullary lesion occupies the opposite half of the body only, the boundary between parts of normal and abnormal sensibility is usually ill defined. This might have been foretold from our knowledge of the irregular distribution of such lesions.

But, occasionally, the upper border of the loss of sensation to pain, to heat and to cold can be determined with unusual certainty. Such definiteness of outline must signify that all impulses passing upwards have been interrupted completely at a certain level.

Now it would seem from some of our cases that, even when the impulses for pain, heat and cold are interrupted after they have crossed the cord, the situation and shape of the border between parts of normal and abnormal sensibility point to a segmental arrangement.

In conclusion, we believe—

(1) That afferent impulses for pain, heat and cold cross the spinal cord to pass up the opposite side.

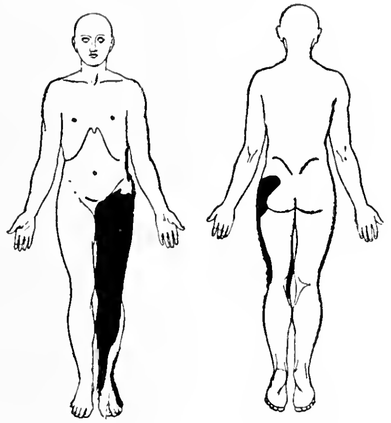

Fig. 86.

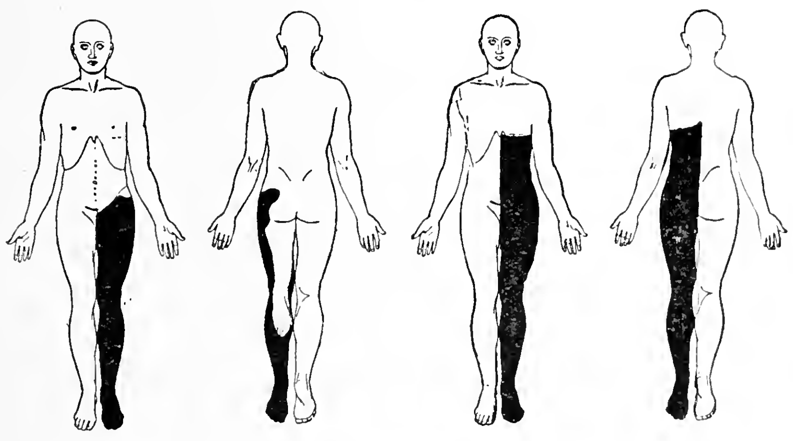

Fig. 87. Fig. 88.

To show the loss of sensation in Case 7.
Fig. 86 shows the extent of the loss of sensation to painful stimuli.
Fig. 87 shows the loss to cold.
Fig. 88 shows the loss to heat.

(2) That the remote loss of sensation may affect to a varying degree the impulses for the three forms of sensibility.

(3) The borders of this remote loss of sensation on the opposite side of the body to the intrameduallary lesion usually merge gradually into parts of normal sensibility. But, occasionally, they correspond to the borders of intramedullary segments.

§ 2.—Touch and Pressure

In a previous chapter, we showed that the disturbance of tactile sensibility, due to an intramedullary lesion, differed fundamentally from that produced by injury to a peripheral nerve, or posterior nerve root. For, when a peripheral nerve has been divided, a considerable extent of the anæsthetic area remains sensitive to pressure, but insensitive to light touch. But, if the lesion lies within the spinal cord, tactile sensibility is diminished, or abolished as a whole, whether the touch be caused by the lightest movement of hairs, by stimulation with cotton wool, or by pressure. Occasionally, it is true, pressure produces the sensation of touch, when the less insistent forms of tactile stimulation fail to be appreciated. If an intramedullary lesion has destroyed the impulses associated with the sensation of light touch, it will also interfere with those that underlie sensibility to pressure; that pressure can still be appreciated is due solely to the fact that it is a greater tactile stimulus, not to any difference in path between the impulses for light touch and for pressure.

In the previous section, we showed that the impulses for pain, heat and cold crossed the spinal cord to ascend on the opposite side. Here we shall consider the intramedullary course of tactile impulses.

The clinical records of cases of Brown-Séquard paralysis are more especially defective with regard to the condition of tactile sensibility; most of the stimuli that have been employed for touch are, in reality, tests for the recognition of pressure. Fortunately, however, the impulses for light touch and pressure are combined into one tactile group during their passage up the spinal cord; pressure is only an extreme form of touch. We may, therefore, assume that if, in any case of Brown-Séquard paralysis, it is recorded that pressure was not appreciated, sensibility to light touch was also abolished.

Sensations of touch and pressure are much less frequently disturbed in cases of Brown-Séquard paralysis than those of pain, heat and cold. In the two cases observed with unusual care by Brown-Séquard himself, tactile sensibility was greatly diminished, or lost, over the same parts that were insensitive to pain, heat and cold, on the opposite side of the body to the disturbance of motion. Among 128 cases collected from the literature by Petrén, the anæsthesia to pressure reached the same development as that to pain, heat and cold in 39 only. In every instance the loss of sensibility to pressure was found on the same side as the analgesia.

This in no way proves that a unilateral lesion of the cord produces loss of tactile sensibility. It demonstrates only that, if this form of sensibility is abolished, as the remote effect of an intermedullary lesion the loss of sensation will be found on the opposite side of the body to the motor disturbance.

We are able to add an excellent instance of this comparatively rare loss of tactile and pressure sensibility in a case of Brown-Séquard paralysis.

F. C. (Case 1) went to bed perfectly well on December 13, 1903. When he tried to get out of bed he found he "could not use his legs," and fell to the ground. On the afternoon of December 14 he found his left arm was weak. By Easter, 1904, his left arm and his left leg had recovered, and he returned to work. He had noticed little wrong with the other side, but within three weeks of the onset, during his stay in the National Hospital, Queen Square, complete analgesia and thermo-anæsthesia had been discovered over the right half of the trunk and right leg.

He first came under our care in August, 1905, for an attack of acute rheumatism. During this time we discovered the condition of sensation, which has remained substantially unaltered up to the present time.

He now shows the following disturbance of sensation. All sensibility to cotton wool is abolished over the right leg and right half of the trunk, as high as the level marked on Fig. 89. Within this area he is totally insensitive to

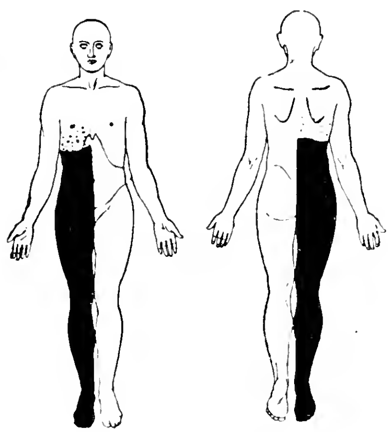

Fig. 89.

To show the loss of sensation to all forms of tactile, painful and thermal stimuli in Case 1. The frontal border was not sharply defined, but merged gradually into parts of normal sensibility.

pressure steadily applied; but, if the muscles are rolled from side to side during the act of pressure, he sometimes says, "You are rolling the front of my leg," or, "You are pressing me." This loss of sensation is associated with inability to distinguish the head of a pin from the point, or to appreciate difference in size.

All sensibility to pain is abolished over the same parts, whether the stimulus be a prick, an interrupted current or extreme pressure. Even a pressure of 20 kgms., applied to the outer aspect of the right knee, produces no pain, although, on a similar part of the left leg, the patient complains of pain with a pressure of 4·5 kgms.

The recognition of passive position is perfect in both legs from the toes to the hip.

All loss of motor power has now disappeared; his grasps are equal and there is no stiffness of either leg. The knee-jerks are brisk but equal, and ankle clonus cannot be obtained. On neither side does the plantar reflex give an extensor response.

Thus we conclude, that sensibility to touch and pressure is rarely disturbed in Brown-Séquard paralysis. But, if such a change exists,

(1) It is found on the opposite side of the body to the motor disturbance. (Case 1 and Case 4.)

(2) The impulses of light touch (cotton wool, von Frey's tactile hairs), deep touch and the tactile element of pressure are lost together. If the borders of the loss of sensation are ill defined, pressure can be appreciated over parts insensitive to stimulation with cotton wool, in consequence of the greater intensity of pressure as a tactile stimulus. There is no evidence pointing to a separation of sensibility to light touch from that to the tactile aspect of pressure, such as is found in lesions of peripheral nerves.

§ 3.—Sense of Passive Position and Movement

Throughout this paper, in almost every section, our investigations have borne their tribute to the acumen and accuracy of Brown-Séquard. He stated that the impulses for the sensations of pain, heat and cold crossed to the opposite side of the cord; ultimately, the impulses for touch, though more rarely disturbed, followed a similar course. Not only our cases, but the whole of the work of the past, when analysed, supports this view.

Much controversy has arisen regarding the further statement of Brown-Séquard, that appreciation of the position into which a limb has been passively placed is affected on the same side of the body as the disturbance of motion and reflexes. Nothing could be more convincing than a perusal of the beautifully recorded cases that came under his personal observation.

Among our observations, the following case (No. 2) is a striking corroboration of the view, that the impulses which underlie knowledge of the position into which a limb has been placed are interrupted on the same side as the motor disturbance. It is a peculiarly unequivocal instance, because the patient was examined when all sense of passive position was perfect; yet the right leg was spastic, and sensibility to pain, heat and cold was abolished over the left half of the body and left leg. After the operation upon his spine, these signs remained unaltered, but he lost all power of recognising the position into which his right leg had been placed.

His history was as follows: On April 11, 1904, he was thrown out of a dog-cart onto his head. He became unconscious for a few seconds and, when he recovered his senses, found he was completely paralysed down the right side. From the moment of the accident he has been unable to appreciate pain, heat and cold applied to the left leg and left half of the trunk.

In May 1905, when first seen by one of us, a little more than a year after this accident, he walked with a hemiplegic gait, swinging his right hip, so that the toes of the right foot might clear the ground.

Over the left half of the body and the whole of the left leg below the level of the seventh cervical segment, he was insensitive to all forms of pain, heat and cold. Light touch with cotton wool, deep touch and pressure were recognised everywhere, and were well localised. The sense of passive position was perfect in all four limbs, and he could recognise the position assumed by parts of the limb under electrical stimulation.

On the right side the knee-jerk was greatly exaggerated, ankle clonus was easily obtained and the plantar reflex gave an extensor response. The left knee-jerk was diminished and no clonus could be obtained in the left ankle; the plantar reflex on this side gave a flexor response.

Thus at this time the patient showed all the signs of that form of Brown-Séquard paralysis where motion is disturbed on the one side, sensibility to pain, heat and cold on the other, touch and pressure and the sense of passive position being entirely unaffected.

On June 25, 1905, Sir Victor Horsley exposed the laminæ of the cervical vertebræ and found that the third neural arch was fractured. All went well until a fortnight after the operation, when the patient noticed that the right side and right leg seemed stiff and cramped and he thought he had lost power.

But, when he was again seen by one of us, the only further change that could be discovered was a loss in the right arm and leg of the sense of position assumed passively. He could not touch his nose with his right forefinger if the eyes were closed. He could not tell into what position the thumb and fingers of the right hand had been placed, unless the movement was violently performed, and movements of the right wrist were badly appreciated. No movement of the toes of the right foot could be recognised.

At the same time, he was sensitive everywhere to stimulation by light touch and pressure, and the point touched was well localised. Thus, the operation had added loss of sense of passive position and movement on the right side to the loss of sensibility to pain, heat and cold, which previously existed over the left half of the body.

Case 16 also illustrates the loss of the sense of passive position and movement on the same side of the body as the disturbance of reflexes and of motion. R. A. H. suffered from a long-standing intramedullary lesion of the bulb and cervical region of the spinal cord, which had paralysed the left vocal cord and left half of the palate. The left knee-jerk was exaggerated, clonus was obtained from the left ankle and the left plantar reflex gave an extensor response. On the right side, the reflexes were normal and no ankle clonus could be obtained.

Sensibility to all painful and tactile stimuli was disturbed over the whole of the left fore-quarter, but to heat and cold the loss of sensation occupied both upper extremities.

The legs remained normally sensitive to all forms of tactile, painful, and thermal stimulation, but the sense of passive position was profoundly disturbed in the left lower extremity, *i. e.*, on the side of the alteration in motion and reflexes. Out of twenty movements, ten of which were dorsiflexion and ten plantar extension of the left ankle, he gave eleven false answers—

Dorsiflexion	7 W. 3 R.
Plantar extension	4 W. 6 R.

On the right side he made no mistake under similar conditions—

Dorsiflexion	10 R.
Plantar extension	10 R.

Sense of passive position was even more grossly affected in the toes of the left foot, but his answers were faultless and quick from those of the right foot.

Case 3 is another striking instance of a similar inability to recognise the position assumed passively by the toes: this loss was also found in the limb opposite to that insensitive to pain, heat and cold. This patient has been under observation for eight years, and we have therefore had ample opportunity of confirming our observations.

In March, 1898, she was suddenly seized with paralysis of the right leg accompanied by loss of sensation to pain, to heat and to cold in the whole of the opposite limb. Since that time, her condition has remained materially unchanged.

When walking, she drags the right leg, which she holds stiffly, saying she dare not relax this leg, or she would fall. The whole leg is spastic, and voluntary movement is impaired by its rigidity; but, in addition, there is some loss of power, especially in the movements of the right hip. There is no wasting, and the electrical response is everywhere normal.

Light touch and pressure are everywhere appreciated and accurately localised. Repeated examination failed to reveal any difference between her answers on the two sides. But the whole of the left leg and thigh below the level of the eleventh dorsal segment is absolutely insensitive to all forms of pain, heat and cold.

In this leg, every movement produced passively is quickly and easily recognised. She made no mistake when the left great toe was moved twenty times into a flexed or extended position. But on the right side, the side of the muscular rigidity and weakness, she failed repeatedly to recognise the position of the great toe. Here, our method of recording the results shows the difference between the condition of the two feet with remarkable distinctness.

Left Great Toe (Analgesia and Thermo-anæsthesia).

Flexion	I.	III.	II.	II.	II.
Extension	II.	II.	I.	III.	II.

Right Great Toe (Motor Loss).

Flexion	II.	X.	IIIX.	III.
Extension	XX.	I.	XI.	XXIXX.

No difference could be observed between her power of appreciating movements of the ankles, knees or hips. Exactly similar results were obtained as far back as 1898.

Here, again, the loss of the sense of a position assumed passively by part of the limb was found on the side of the motor disturbance, and not on the side insensitive to pain, heat and cold.

Thus, we conclude that, with regard to the impulses which underlie our power of recognising the passive position of a limb, Brown-Séquard's original statement was correct.

(1) The sense of passive position and movement is abolished on the same side as the motor disturbance, provided that the loss of motion is entirely unilateral and no single form of sensation is disturbed on both halves of the body.

(2) The loss of the sense of passive position and movement is independent of the tactile impulses and of those which underlie the power of cutaneous localisation. But, as will be shown in the following sections, it is closely associated in Brown-Séquard paralysis with inability to discriminate two compass points.

§ 4.—The Relation between the Power of Discriminating Two Points and the other Forms of Sensibility

In a previous chapter, we cited two cases to show that tactile sensibility might be perfect and yet the patient might be unable to discriminate two points applied simultaneously to the skin. Both of these cases revealed incidentally the close association between the loss of the sense of position assumed passively, and the power of discriminating two points.

Now, we have already ample evidence, that the power of recognising the passively assumed position of any limb tends to be disturbed on the same side as motion in Brown-Séquard paralysis. We should therefore expect that the compass test would also show a diminished accuracy of discrimination on the same side.

But it must be remembered, that the compass test depends upon two entirely separate factors. In order that the test can be applied, the patient must be able to recognise that he is being touched. If sensibility to touch and pain is lost, the test is obviously inapplicable, because of the total absence of sensation, and not because of any necessary inability to discriminate two points. A diminution of tactile sensibility alone will affect the results of the compass test, by decreasing the certainty with which the patient knows when he has been touched. This was the reason Brown-Séquard stated that, in two of his cases, the compass points were not normally discriminated over the non-paralysed limb. In both of these cases, tactile sensibility was profoundly affected on that half of the body opposite to the motor paralysis.

For the same reason Spearman [115], in his careful report, found that the compass test gave bad results on both legs. We venture to suggest that on the right leg, which was analgesic and thermo-anæsthetic, this was mainly due to the grave defect in contact sensibility; on the left leg, which was spastic and paretic, the inability to recognise two points was associated with the loss of sense of position. The probability of this explanation is increased by the remarkable raising of the threshold for the compass test which occurred on the left leg as the result of muscular fatigue, a condition scarcely noticeable in the right leg, where the cutaneous sensory loss was profound.

Since the compass test depends upon two factors, which may be separated in disease of the spinal cord, it is necessary to choose cases where one of these factors alone is demonstrably unaffected. It is obvious that a diminution of tactile sensibility will diminish the ease with which two points are discriminated; but we have other less elaborate tests for touch, and the true interest and value of the compass test lies in the revelation of a loss of power of discriminating two points, although tactile sensibility is perfectly maintained.

Case 3 is an instance of such a condition. Over the left leg, sensibility to pain, heat and cold was abolished, whilst in the right foot the patient was unable to recognise the position into which her toes had been placed. To the finest tests all forms of touch were everywhere perfect.

When the compasses were applied longitudinally to the sole at a distance of 2·5 cm., it was found that she was more accurate in her answers on the left foot (sensory loss) than on the right (motor loss).

Left 2·5 cm.	1	9 R. 1 W.
	2	10 R.
Right 2·5 cm.	1	8 R. 2 W.
	2	8 R. 2 W.

For some hours before these tests, she had been resting in bed, and she was therefore tested again after walking about 150 metres without a stick. The result was striking. For whereas at 4 cm. distance the test gave perfect results on the dorsum of the left foot, her answers failed grossly over a similar part of the right foot.

Left 4 cm.	1	10 R.
	2	10 R.
Right 4 cm.	1	6 R. 4 W.
	2	6 R. 4 W.

This brings out the considerable raising of the threshold for the compass test which follows exertion, a fact first pointed out by Spearman [115].

On account of the stationary condition of her symptoms and her great quickness and trustworthiness, this patient forms a good instance of the close connection between delicacy in discriminating two points and a recognition of the position of the limb.

When discussing disturbances of the sense of passive position and movement, we cited the case of R. A. H. (No. 16), where an intramedullary lesion of the bulb and cervical spinal cord had produced locally loss of sensibility in both upper extremities, whilst motion and the reflexes were disturbed on the left side only.

In this patient, the remote loss of sensation consisted of a profound disturbance of the sense of passive movement and position in the left foot and ankle.

Together with this loss, it was found that his power of discriminating two points was profoundly affected over the left foot and leg. Thus, over the sole of the left foot his answers were bad when the points were separated to 8 cm.

8 cm.	1	10 R.
	2	4 R. 6 W.;

whilst over the right sole they were perfect at 4 cm.

4 cm.	1	10 R.
	2	10 R.

Over the outer side of the left leg he answered badly at 15 cm.

15 cm.	1	6 R. 4 W.
	2	5 R. 5 W.

although his answers were perfect at 8 cm. over a similar part of the right leg

8 cm.	1	10 R.
	2	10 R.

This difference in the sensibility of the two legs to the compass test could not have been due to any alteration in tactile sensibility. For stimulation with cotton wool was appreciated equally when applied to both feet and to the outer side of both legs; over both soles, von Frey's hairs produced sensations of equal intensity. Stimulation with No. 8 and No. 5 was well appreciated; but stimulation with No. 4 applied to the soles could not be appreciated over either foot.

In conclusion, we believe that, if all forms of tactile sensibility are perfect in Brown-Séquard paralysis, (1) the power of discriminating two points may be found to be diminished over the side of the motor disturbance; (2) there is a close relation between loss of the sense of passive position and movement and the power of discriminating two points; loss of the one is usually associated with grave disturbance of the other.

CHAPTER IV

LOCAL EFFECTS OF AN INTRAMEDULLARY LESION

So far we have neglected the local effects produced by a lesion of the spinal cord, and have dealt solely with its remote results on sensation. A skilled operator can now produce, with the help of rigid asepsis, an experimental division of one half of the cord, of such precision that the sensory effects at the level of the lesion, on the same side as the section, may be negligible. The sensory consequences of a stab in the back, producing a wound of the spinal cord, may also under favourable conditions be entirely remote. Even those remarkable cases of Brown-Séquard paralysis, arising suddenly and presumably due to spontaneous hæmorrhage, may show no permanent sensory changes at the level of the disease.

But, whenever interference in the conducting paths is due to a growth or to a large hæmorrhage, such as not uncommonly follows fracture of the spine, the disease manifests itself by local disturbances which will form the theme of this chapter. The greater the extent of the lesion longitudinally in the spinal cord, the wider will be the area upon the surface of the body affected by these changes: and of all local lesions, the most widely extended is that of syringomyelia. At any rate in its early stages, this disease manifests itself by sensory changes on the same side of the body as the disturbance of motion; its signs and symptoms are essentially the local manifestations of a lesion of vast longitudinal extent.

In some cases of syringomyelia, the central growth reaches such proportions that long afferent paths are destroyed, and parts at a distance from the focus of disease become insensitive: but, in essence, syringomyelia is a local disease, producing sensory changes at the level of the lesion.

§ 1.—The Local Sensory Effects of an Intramedullary Lesion occur on the Same Side as the Disturbance of Motion

Every disturbance of cutaneous sensibility, due to the local effect of disease of the spinal cord, lies on the same side as the muscular wasting and loss of motor power, that is, on the side of the maximum lesion. This forms a fundamental difference between the local and remote effects of intramedullary disease.

This rule is well illustrated by the following case of glio-sarcoma of the spinal cord (Case 9). In November, 1904, Joseph F. noticed a slight weakness of the left arm; soon afterwards, his neck became stiff, and he complained of tingling sensations in the fingers of the left hand. The weakness of the left arm gradually increased until February, 1905, when it became completely paralysed. During March and April, he became progressively weaker, and his legs began to give way.

In July, 1905, when admitted to the London Hospital, his left arm lay motionless on the bed by his side, completely paralysed for voluntary movement. The small muscles of the hand and, to a less degree, those of the forearm were wasted, but reacted in the normal manner to both the constant and interrupted currents. The grasp of the right hand was weak and its small muscles were somewhat wasted; all movements were well performed by the remaining muscles of the limb.

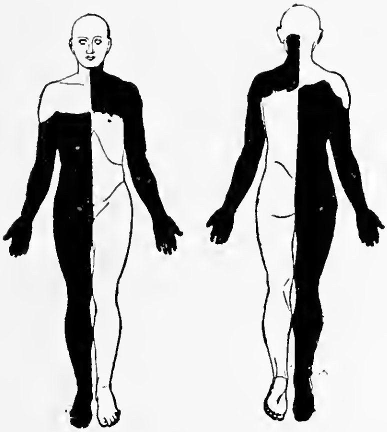

Fig. 90.

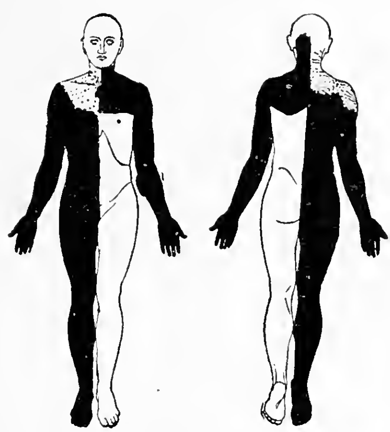

Fig. 91.

To show the loss of sensation to painful (Fig. 90) and thermal (Fig. 91) stimuli produced by a glio-sarcoma of the spinal cord (Case 9). In the cervical region the growth destroyed mainly the left half of the cord. The condition in the left upper extremity represented the local, that on the right half of the body the remote effect of the lesion.

Sensation was profoundly disturbed over the whole of the left upper extremity. All sensibility to pain, to heat and to cold was lost over the areas shown in Figs. 90 and 91, extending as high behind as the occipital crest and occupying the whole of the arm, excepting only a small patch on its inner aspect.

Light touches and pressure were everywhere appreciated and well localised, but two points of the compasses could not be discriminated, even at a distance of 5 cm., anywhere over the left hand. Over the right palm, his answers were perfect when they were 2 cm. apart, and he made two mistakes only in twenty applications, when the points were separated by a distance of 1 cm.

All sense of passive position and movement was lost in the left upper limb. When his eyes were closed, he was unable to indicate the position of his fingers in space or the direction in which they had been moved; and this was also the case with the wrist, the elbow and the shoulder-joint. The contrast in the condition of the two arms in this respect was striking; the patient recognised that he was entirely ignorant of the position of his left arm in space, whereas every movement of any part of the right arm was immediately recognised.

Such were the local effects produced by a tumour growing in the left half of the spinal cord. The remote effects were shown by profound sensory changes in the right half of the body, the right leg and right arm below the level of the fourth cervical segment. Within this area, he was insensitive to pain, to heat and to cold, but light touches and pressure were everywhere appreciated, and localised with accuracy. The sense of passive movement and position was disturbed in the left foot, that is, on the same side as the maximum lesion, but on the opposite side to the analgesia and thermo-anæsthesia.

This case shows, that a growth which destroyed the whole of the left half of the spinal cord produced complete analgesia and thermo-anæsthesia in the left arm at the level of the lesion. The remote loss of sensation to pain and temperature lay over the right or opposite half of the body. Moreover, the sense of passive position and movement was disturbed in the left or analgesic arm, in consequence of the local effect of the growth; whereas its remote effect was manifested by a loss of the sense of passive position and movement in the left foot. This was accompanied by total analgesia and thermo-anæsthesia of the right half of the body, below the level of the fourth cervical segment. Sensibility to touch and pressure remained unaltered until late in the disease. Finally, even this form of sensation was disturbed in the left arm.

Syringomyelia rarely disturbs all forms of sensation at the level of the lesion, but, as far as it occurs, the loss of sensation follows the rules that can be deduced from Case 10. So long as the symptoms remain unilateral, the loss of sensation will be found on the same side as the muscular wasting. This is so well recognised, that we need only mention shortly some cases among our collection which illustrated this rule.

In April, 1905, Walter J. H. (Case 12) was an excellent instance of syringomyelia with unilateral manifestations. Sensibility to pain and temperature was lost over the whole of the right forequarter, but no other form of sensation was disturbed. Neither hand was wasted and there was no loss of motor power. By August, 1906, wasting and loss of power had appeared in the right hand.

Similarly, Florence R. (Case 14), when first examined in 1899, showed distinct wasting and loss of power of the left hand, accompanied by thermo-anæsthesia, confined to the preaxial half of the left forearm and hand. Shortly afterwards, wasting of the right hand was noticed; but even as late as March, 1902, the loss of sensation was still confined to the left forearm and hand; but in November, 1902, part of the right hand also became insensitive to heat and cold. Here, again, the loss of sensation appeared on the same side as the loss of motor power and muscular wasting.

Such cases are examples of the rule that the local manifestations of intramedullary disease are found upon the same side as the disturbance of motion and the wasting of muscles.

§ 2.—The Nature of the Local Disturbances of Sensation produced by an Intramedullary Lesion.

In Chapter III we contrasted the nature of the loss of sensation due to destruction of peripheral nerves with that caused by a lesion of the spinal cord, choosing as an instance the phenomena of Brown-Séquard paralysis. From such a comparison, it became possible to formulate certain fundamental differences between the sensory loss in the two cases. We shall now attempt the more difficult task, and compare the characteristics of the loss of sensation, due to the local activity of an intramedullary lesion, with its remote sensory effects. The manner of response to each particular stimulus will be detailed in order, and we shall indicate the similarity and differences in the loss of sensation produced by the two conditions.

(*a*) *Heat and Cold.*

As is well known from the phenomena of syringomyelia, sensibility to pain, heat and cold may be lost without any other sensory defect. Any one of these forms of sensation may be disturbed separately, or to a varying amount, and it is a commonplace of neurology that thermo-anæsthesia may be the only sensory concomitant of this disease. Moreover, sensibility to heat is not infrequently more widely destroyed than that to cold. It is certain, therefore, that the local manifestations of an intramedullary lesion may disturb sensibility to heat, and leave sensibility to cold unaffected. C. H. (Case 11) was an instance of this condition; at one period of his illness, a large portion of his face was insensitive to heat though sensitive to stimulation with cold.

The converse condition may also be present, and the extent of the loss of sensibility to cold may exceed the loss to stimulation with heat.

But, ultimately, if the disease extends, the borders of the loss of sensation to heat will generally become coterminous with those of the loss to cold. The isolated anæsthesia to one form of temperature stimulation is of interest, solely as showing that a local lesion can disturb the one form of sensibility over parts that remain sensitive to temperatures at the opposite end of the scale. In this, the local manifestations of an intramedullary lesion agree with its remote effects described in Chapter III, and differ fundamentally from the loss of sensation caused by destruction of peripheral nerves.

With regard to the character of this loss of sensibility to heat, it is important to discover whether sensation is simultaneously disturbed for all temperatures we call warm or hot. This is frequently difficult to determine. For the borders of an area insensitive to thermal stimulation frequently merge gradually into parts of normal sensibility; here a temperature of 50° C. will cause a sensation of heat, although the weaker stimulus of 40° C. cannot produce an impulse of sufficient intensity to reach the sensorium. In the same way, temperatures of 22° C. may produce no sensation, although coldness is easily evoked by stimulation with ice. Here the sensibility of the part to heat and to cold is lowered, and the intermediate degrees of temperature therefore become stimuli of insufficient intensity.

We have never been able to assure ourselves in any instance that, in consequence of a pure intramedullary lesion, the patient was sensitive to intermediate degrees of heat and cold but insensitive to extremes.

When the thermo-anæsthesia has remained stationary for a long period, so that this border of partial loss of sensation has disappeared, it is not difficult to show that sensibility to heat is destroyed as a whole. In a similar manner, it can be shown that over areas insensitive to cold, no temperature between ice and 24° C. produces any sensation of coldness. In Case 14, careful experiments, made on September 10, 1906, and on many previous occasions, showed that sensibility to all degrees of heat and cold was destroyed over the left half of the face bounded by the middle line. Ice, water at 22° C., at 38° C., at 40° C., and at 50° C. were all called "a touch" over the left half of the face; whereas, when the middle line was passed, they were accurately discriminated and rightly named.

A similar condition was seen in W. J. H. (Case 12) at the frontal border of the loss of sensation. On a photograph taken in April, 1905, this border corresponded exactly in shape and position with that marked out in September, 1906, showing that the loss of sensation had ceased to extend in this direction. At this border, no temperature at any degree between ice and 60° C. produced any other sensation but that of touch. In this case, the abruptness of the boundary between parts of normal and abnormal sensibility made it unusually easy to determine this fact.

But it is not only in syringomyelia that the local manifestations of an intramedullary lesion may produce a thermo-anæsthesia, which conforms to this description. A rapidly advancing growth may cause a similar loss of sensation. Parts become insensitive to heat which are sensitive to cold, and no response may be evoked by stimulation with any degree of temperature which normally produces a sensation of heat. This was well shown by the case already cited (No. 9), where a tumour growing mainly in the left half of the spinal cord disturbed sensation in the left arm and right half of the body. Here we had the opportunity of comparing the local thermo-anæsthesia on the side of the lesion with that on the opposite half of the body due to its remote manifestations: and in both cases, the character of the loss of sensation was the same. The left arm, equally with the right leg, was insensitive to all temperature stimuli.

To sum up, therefore: (1) the local action of a lesion within the spinal cord may produce a more extreme thermo-anæsthesia to heat than to cold, or *vice versa*. Parts sensitive to the one end of the scale may be insensitive to temperatures at the other end.

(2) We have found that an area insensitive to heat will also be insensitive to all temperatures that produce a warm sensation on the normal skin. Towards the edges of the thermo-anæsthetic areas, water at 40° C. may produce no

sensation, although 50° C. is recognised as hot. This is due solely to the greater intensity of the stimulus of the higher temperature over parts of defective sensibility; it does not occur when the loss of sensation has remained stationary for long periods.

(*b*) *Pain.*

In every instance of Brown-Séquard paralysis where the patient was insensitive to cutaneous painful stimuli, he was also insensitive to the pain of deep pressure, although its gradual increase could be perfectly recognised. This characteristic association between cutaneous analgesia and loss of sensibility to the pain of deep pressure, is also found as one of the local manifestations of an intramedullary lesion.

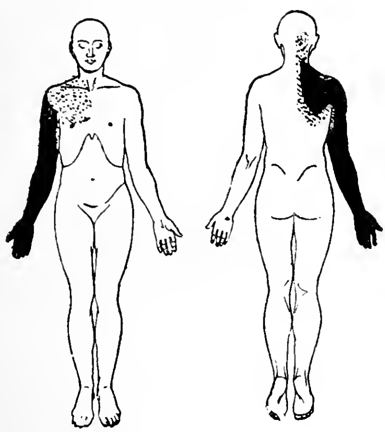

FIG. 92.

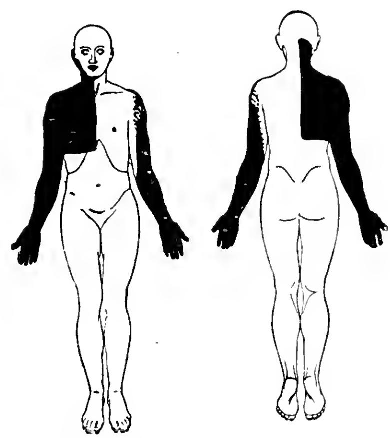

FIG. 93.

To show the loss of cutaneous sensibility to painful stimuli in Case 12. Fig. 92 shows the extent of the analgesia in 1905, Fig. 93 the parts affected in 1906.

Thomas B. (Case 13) is an excellent instance of this association. He was insensitive to the pain of a prick and of the interrupted current over both upper extremities and the upper half of the trunk (Fig. 77). Over the whole of this area, pressure failed to cause pain, even when raised to 15 kgm.; and yet he was nowhere insensitive to deep touch, and recognised the gradually increasing pressure. Elsewhere, outside the analgesic area, a pressure of from 3 to 5 kgm. invariably caused pain.

A similar condition was found in Case 12. Here the whole of the right upper extremity and the right half of the cervical and thoracic regions of the trunk were insensitive to the pain of a prick and the painful interrupted current (Figs. 92 and 93). Sensibility to touch, both superficial and deep, was everywhere perfect; but, over the whole of the right upper extremity, an increase of pressure up to 15 kgm. caused no pain. When we first saw him, the right upper extremity only was analgesic (Fig. 92). But later, the left hand and forearm also became insensitive to prick, and the loss of sensation is evidently advancing in this limb (Fig. 93). Here his behaviour when tested with the algometer was instructive. The loss of sensation to prick and to the interrupted current extended to the left elbow and at times even above that point. Over the palm, a pressure of 4·5 kgm. was painful, and he complained when the pressure over the flexor aspect of the forearm reached 5 kgm. Although the forearm and hand were insensitive to prick and to the pain of an interrupted current, pain could still be produced by pressure little in excess of the normal.

Thus, over parts where the cutaneous analgesia has been recently acquired, increasing pressure not uncommonly produces a painful sensation. But, over an old-standing area of cutaneous analgesia produced by the local effects of an intramedullary lesion, pressure no longer produces pain; and yet sensibility to the tactile element of pressure remains entirely unaffected.

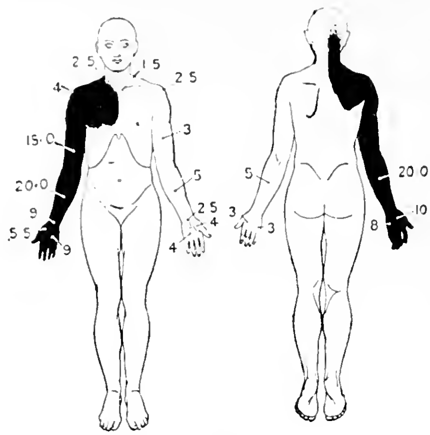

Fig. 94.

To show the loss of painful sensibility in Case 11.

The area marked in black corresponds to the extent of the cutaneous analgesia. At various points are placed numbers corresponding to the pressure which caused pain. Thus 5·5 means that pain was caused by an algometer pressure of 5·5 kilograms. But such a number as 20 = 0 means that no pain could be caused even by a pressure of 20 kilograms.

This persistence of sensibility to the pain of pressure over parts that correspond to the outworks of an advancing lesion, can lead to the following anomaly. The skin of the whole upper extremity may be insensitive to all painful stimuli, although pain can be produced by pressure over the palm of the hand. In Case 11, this phenomenon was the more striking in that the right arm and hand were entirely unaffected, and could be used for comparison with the analgesic extremity. On Fig. 94 is shown the extent of the cutaneous analgesia, and at each point is given the pressure in kgm. which produced pain. It is at once evident that the whole forearm, back and front, was insensitive to both cutaneous and deep pain. But, over the right palm, a pressure of 5·5 kgm. still produced pain; over a similar part of the normal palm, pain was evoked by a pressure of 4 kgm., a difference within the range of experimental error. Here the whole of the forearm on the extensor and flexor surfaces was insensitive both to painful cutaneous stimuli and to the pain of deep pressure; but, to the latter, the palm remained sensitive, though insensitive to cutaneous painful stimulation. This is evidently due to a difference in the segmental distribution of the afferent mechanism employed in the conduction of painful impulses produced by cutaneous and by deep stimulation. The pain produced by deep pressure on the palm is conducted by fibres which run with the muscular nerves. It probably enters posterior roots other than those which receive the afferent impulses from the skin of the same parts. If this were so, the impulses from the termination of the limb would probably enter those segments which correspond to the motor supply of the part. Now, the hand receives its motor innervation from the first thoracic and eighth cervical. In the case we have quoted, these segments, judging by the cutaneous loss of sensibility, would lie at the edge of the active lesion in the cord, and the hand would remain sensitive to the pain of deep touch, because it was represented by parts not in the focus of destruction.

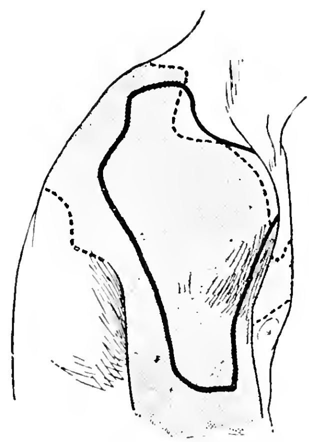

Fig. 95.

To show the relation of the deep hyperalgesia to the cutaneous analgesia in Case 11 (p. 440). The area of cutaneous analgesia is coloured grey and enclosed by a broken line; the area hyperalgesic even to the lightest pressure is enclosed by a heavy black line.

This want of correspondence between the extent of the cutaneous and deep analgesia, produced by the local manifestations of an intramedullary lesion, led to the following extraordinary condition, in the case we have just considered (No. 11, Fig. 95). The skin of the whole upper extremity was analgesic to the prick of a pin and to the painful interrupted current. This man, however, suffered from a neuropathic destruction of the right shoulder-joint (Charcot's joint). This joint was excessively painful, and, over a considerable area, enclosed within the thick black line on Fig. 95, he was profoundly hyperalgesic to even the lightest pressure; even pressure with the head of a pin caused him to cry out. At the time when this area of deep hyperalgesia could be marked out, the whole of the parts tinted grey on Fig. 95 were insensitive to all cutaneous painful stimuli. That is to say, there was a large area of the arm and shoulder abnormally tender to pressure, though the skin was entirely insensitive to the prick of a pin. Ultimately this hyperalgesia disappeared with the gradual advance of the loss of sensation. (For further details, vide p. 442.)

In conclusion, we find that the analgesia, produced by the local manifestations of an intraspinal lesion, consists essentially of insensibility to the pain of both cutaneous and deep stimulation. This loss of sensation to painful pressure exists without any disturbance of sensibility to its tactile element: the patient not only knows he is pressed, but recognises the gradually increasing pressure.

In these characters, the analgesia produced by the local manifestations of intramedullary disease corresponds exactly with that due to its remote effects.

(c) Touch and Pressure.

One of the most striking differences between the form assumed by the loss of sensation in Brown-Séquard paralysis and that which follows injury to peripheral nerves, lies in the behaviour of the patient to the stimuli of superficial and deep touch. If sensibility to touch is disturbed in Brown-Séquard paralysis, the patient no longer responds to either form of stimulation.

Loss of tactile sensibility is a rare local manifestation of syringomyelia; but we are able to bring forward two instances from our collection. From these cases, it would seem that the form assumed by the loss of tactile sensibility

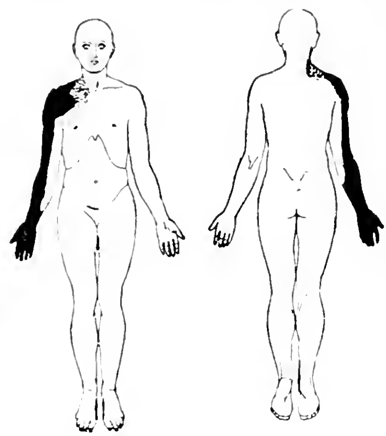

Fig. 96.

To show the loss of tactile sensibility in George B. (Case 15, p. 453). Over the area marked black he was insensitive to all forms of tactile stimuli, superficial and deep; over the dotted area he was insensitive to light touch, but sensibility to deep touch, though present, was certainly somewhat diminished.

corresponds exactly with that of the remote tactile anæsthesia in Brown-Séquard paralysis. Sensibility to light touch and sensibility to pressure were lost over almost exactly the same extent.

Fig. 96 shows the area insensitive to light touch and to pressure in the case of George B. (No. 15). For seven years he had lost sensation in the right hand, accompanied by a gradually increasing inability to write. In October, 1906, the sensations of pain, heat and cold were lost over the right upper extremity and the greater part of the right half of the head and neck. Sensibility to pressure was destroyed over the area marked in black on Fig. 96; over this area, together with the dotted parts, he was entirely insensitive to light touch. These two areas corresponded closely, except at the extreme frontal border, where the extent of the loss of sensation to light touch somewhat exceeded that of the loss to pressure. But, since stimulation with No. 8 of von Frey's hairs no longer produced any sensation when the border of loss to light touch was passed, we may assume that deep sensibility was also diminished. Pressure caused a sensation only by its greater intensity as a tactile stimulus. On the inner aspect of the arm, the borders of the anæsthesia to the two forms of tactile stimulation coincided almost exactly.

The second case where tactile sensibility was disturbed as a local manifestation of intramedullary disease, is that of R. A. H. (No. 16, p. 458). When this man was first seen in March, 1904, all loss of sensation was confined to the left arm and neck, except that to cold, which was bilateral. Tactile sensibility was completely abolished over the whole of the left upper extremity. The motor disturbance was represented by paralysis of the left vocal cord and the left half of the palate. The left knee-jerk was greatly increased, clonus was obtained from the ankle and, on the same side, the plantar reflex gave an extensor response.

Thus it would seem that, in those rare instances where syringomyelia produces loss of sensation to touch, it also causes corresponding anæsthesia to the tactile element of pressure.

More rapid growths, starting within the spinal cord, frequently spread to the posterior roots, or produce secondary metastases which become extramedullary. This makes the results obtained from such malignant growths extremely unsatisfactory. Many of the sensory phenomena they cause are of mixed origin, and not due solely to intramedullary disease.

As far as our material goes, we believe that, when tactile sensibility is disturbed at the level of the lesion in consequence of intramedullary disease, the part becomes insensitive to stimulation with touch, both superficial and deep. Towards the extreme edges, pressure may be appreciated, but the skin may be insensitive to the lighter stimulus; this is due solely to difference in the intensity of the stimulus, and accurate tests will show that, even over this borderland, sensibility to deep touch is diminished.

Thus, the condition of tactile sensibility at the level of the lesion closely resembles that due to its remote effects.

(*d*) *Passive Movement and the Discrimination of Two Points.*

Among the distant manifestations of an intramedullary lesion, any loss in the sense of passive position and movement was always found to be associated with defective answers to the compass test. (Chapter III., §§ 3 and 4.) A similar relation is found, when this form of sensation is disturbed at the level of the lesion. So long as the disease remains purely intramedullary, there is not that close association between the discrimination of two points and sensibility to light touch usually found after lesions of peripheral nerves or posterior roots; nor is the power of recognising passive movement and position associated with the integrity of deep touch.

Of this we can bring forward one unusually perfect example. Joseph F. (Case 9) suffered from a glio-sarcoma, which destroyed the spinal cord in the cervical region more extensively on the left side than the right. He was unable to recognise the position of any part of the left upper extremity, and no passive movement of the joints, however extensive, produced any sensation. And yet, at first, sensibility to both superficial and deep touch was unaffected.

Over the left hand, he was unable to discriminate two points of the compasses when separated for a distance of 5 cm.; over the right hand he made two false answers only at 1 cm., and at 2 cm. he was invariably correct.

Right hand 1 cm.	1	9 R. 1 W.	Left hand 5 cm.	1	10 R.
	2	9 R. 1 W.		2	10 W.
2 cm.	1	10 R.			
	2	10 R.			

Here the power of discriminating two points was profoundly impaired, although tactile sensibility was at that time unaffected, and the sense of passive movement and position was lost, in spite of the retention of sensibility to pressure.

Thus, it would seem that, when the loss of sensation at the level of an intramedullary lesion includes disturbance of the sense of passive position and movement, the discrimination of two points is also affected.

(c) *Summary.*

A survey of the character assumed by the loss of sensation at the level of a pure intramedullary lesion of the spinal cord has led to the conclusion, that this loss follows the central rather than the peripheral type, although it is situated in those parts which lie on the same side as the disease. If sensibility to heat is disturbed, the patient no longer recognises temperatures between 30° C. and 60° C. But, over the same parts, he may be sensitive to all temperatures which normally produce a sensation of cold. Where the skin is insensitive to painful stimuli, deep pressure will no longer be painful. Sensations of light touch and the tactile aspect of pressure are linked together, so that the former is a less, and the latter a more intense, degree of tactile stimulation. When the patient becomes unable to recognise the position of his limb, assumed passively, it will be found that he is also unable to discriminate two points at distances much in excess of that normally requisite.

CHAPTER V

AFFERENT SEGMENTATION WITHIN THE SPINAL CORD

WHENEVER several observers, working on the same problem, bring out results which differ greatly, in spite of fundamental similarity, it is certain they have adopted different methods. The present state of text-book knowledge on segmentation of the central nervous system is an instance of the confusion which may arise from an attempt to combine the results of different observers, without recognising the significance of the methods by which they have been obtained. (Seiffer [106], Lewandowsky [68], Oppenheim [88].)

Those who have worked on the segmentation of the afferent nervous system from their own observations, and by original methods, can be classified into the following groups.

(A) DISTRIBUTION OF THE POSTERIOR ROOTS

(1) Sherrington [108 and 109] determined the total afferent distribution of each posterior root, by the method of residual sensibility. By dividing a number of posterior roots above and below the one nerve root under examination, he left a sensitive area surrounded on all sides by anæsthesia. This sensitive area must have been innervated by the one remaining posterior root. But, of the specific function of these afferent nerve fibres, he remained of necessity ignorant. His areas correspond to the maximal extent of the fibres of one posterior root, whether they be those of epicritic, of protopathic or of deep sensibility. We shall therefore speak of the areas worked out by Sherrington as maximal root areas.

(2) Head and Campbell [45] recorded the areas on the surface of the body mapped out by the eruption of herpes zoster. They then determined in seventeen instances by post-mortem examination which posterior root ganglion was the seat of the disease. Now, it is obvious that, if the whole of one ganglion is affected, the extent of the eruption will correspond to the distribution of those fibres only which, when irritated, can cause vaso-dilatation and destructive lesions on the skin. Head and Sherren have shown reason to believe that such fibres are closely associated with the protopathic system. (*Cf.* also Bayliss [4].)

It is therefore probable, that the areas marked out by herpes zoster correspond to the segmental arrangement of the protopathic fibres as they pass through the posterior root ganglion.

(B) Segmentation within the Spinal Cord

(1) As revealed by irritation (Hyperalgesia).

Head [14] worked out a scheme of intramedullary segmentation based on the hyperalgesic zones which arise in consequence of visceral irritation. Disease of an internal organ produces impulses which pass into the spinal cord by the white rami. The segment upon which they impinge is excited, and pain is produced. But, at the same time, all potentially painful impulses passing into this segment from the somatic afferent nerves are exaggerated, and ultimately the body wall may become tender.

These hyperalgesic zones represent the extreme projection on the surface of the body of those segments within the spinal cord which receive painful impulses from the periphery.

(2) As revealed by loss of sensation due to intramedullary lesions (Kocher [59], Allen Starr [118 and 119], Thorburn [121 and 122], Wichmann [134]).

Of these observers, Kocher alone faced the difficulty and determined to record the upper level of the analgesia in a large number of cases of verified spinal lesions. That part of Wichmann's valuable monograph which deals with the spinal cord is also based on the loss of sensation, produced by intramedullary disease; but, in his general scheme, he attempts to combine the results obtained by other means. Thorburn assumed that the areas of loss of sensation corresponded to the form and extent of the supply of segments within the spinal cord, and failed to appreciate that they represented those parts only, which were not supplied from the lowest intact segment. Moreover, he failed to differentiate between the loss of sensation due to destruction of roots as they enter the spinal cord and that of intramedullary segments.

A want of appreciation of the different methods employed by these observers, and the non-recognition of the diverse significance of their results, have led to endless confusion.

The appearance of Sherrington's work on the posterior roots caused clinicians to revise their views with regard to the distribution of sensory disturbances in certain well-known diseases such as tabes dorsalis. Max Laehr [64] was the first to recognise that the loss of sensation in syringomyelia was distributed segmentally, at a time when most observers believed that its arrangement more nearly corresponded to that found in hysteria. Since then, many clinicians have acknowledged the truth of his observations and have amplified his statement in various directions.

Clinical observers have relied on the extent of the loss of sensation in their attempts to prove the segmental distribution of a lesion within the spinal cord. All would have been well, had they correlated their results solely with the borders of the loss of sensation in verified cases of interruption of the cord at various levels. But the attempt to compare these areas of loss of sensation from intramedullary disease with the maximum supply of posterior roots led to nothing but confusion.

No clinician seems to have recognised that the complete cutaneous distribution of a nerve, of a posterior root or of a segment of the spinal cord, could only be discovered by observing how much of the skin was sensitive, when that afferent path alone remained intact. If we wish to know how much of the palm is supplied by the median nerve, we cannot do so by observing the extent of the loss of sensation caused by its division. A case must be selected where the ulnar, the radial and the external cutaneous nerves have been divided: then, any part of the hand which remains sensitive must receive its innervation from the median. This is the method of residual sensibility invented by Sherrington, and so ably employed by him to discover the maximum afferent distribution of each posterior root.

If we wish to determine the exact level of the affected intramedullary segment, we are compelled to adopt an indirect method. For lesions within the spinal cord, such as those produced by fracture of the spine or rapidly spreading growths, lead to widespread destruction. However well defined may have been the disturbance of sensation, some disease will be found corresponding to parts beyond its limits. Moreover, the opportunities are too limited for correlating these areas of residual sensibility with the extent of intramedullary disease.

Head [44] showed that there is a close correspondence between the distribution of the tenderness caused by irritation of the segments within the spinal cord, concerned with the reception of painful impulses, and the areas marked out on the skin by the eruption of herpes zoster. Now, herpes zoster is due, in most cases, to acute inflammation of a posterior root ganglion, whereas the tender areas in visceral disease are due to the irritation of intramedullary segments. But, though all the cells and the fibres peculiar to them must be affected by the profound inflammation of the ganglion, one system only, as far as we know, can produce an antidromal effect upon the skin. These are the fibres shown by Bayliss [4] to have their cells of origin in the ganglion of the posterior root. Bayliss, in conjunction with one of us, has been able to show, that these antidromal fibres are capable of excitation in the divided nerve of a cat, five weeks after it has been reunited to the central nervous system. In the time and manner of their regeneration, these fibres closely resemble those of the protopathic system. Thus, it is probable that this power of producing acute changes in the skin of the periphery is a function of fibres, which run in the protopathic system.

On this hypothesis, the eruption of herpes zoster would correspond to the distribution of the fibres and cells of the protopathic system in the ganglion of the posterior root.

Now Head and Sherren showed, that division of several posterior roots never caused a more extensive loss of protopathic than of epicritic sensibility. Expressed crudely, sensibility to painful cutaneous stimuli was lost over a larger area than sensibility to light touch. From this fact alone it is certain, that the protopathic fibres in the posterior roots supply areas which overlap one another to a less extent than those of the epicritic system.

It is therefore not surprising to find a comparatively close correspondence between the form and extent of the areas marked out by herpes zoster, and the hyperalgesic zones of visceral disease. They belong, it is true, to different levels of the nervous system; the herpetic zones correspond to the distribution of those fibres which conduct all the cutaneous painful impulses, whilst the others represent the segments of the spinal cord into which those impulses impinge.

Since it is impossible to obtain enough material to determine the enumeration of the segments by means of destructive lesions of the spinal cord, it is justifiable to turn to the known levels in herpes zoster. For, since the seventeen postmortem examinations by Head and Campbell, it has become possible to determine the site of the lesion with precision, in most cases of this disease. Even should it ultimately turn out that the likeness between the areas of tenderness in visceral disease and those of herpes zoster has been exaggerated, we can still determine the numerical level of an intramedullary segment, by comparing the extent of the residual sensibility with the areas marked out by herpes zoster.

(*a*) *The Sensory Disturbance at the Level of the Lesion shows signs of Intramedullary Segmentation.*

By applying this method of residual sensibility to cases where the sensory impulses have been interrupted by disease within the spinal cord, it would be possible to arrive at a notion of the caudal borders of the intramedullary segments for touch, for pain, for heat and for cold. In every case, the border must be determined at which sensation to each of these stimuli ceases.

But, unfortunately, in an overwhelming majority of cases, the boundary between parts of normal and abnormal sensibility is ill defined. The upper border of the anæsthesia for any one stimulus may differ in position according to the method of testing. If, for instance, we start from parts of normal sensibility, the patient's attention is awakened, and he will respond to the stimulus even within areas which would appear to be insensitive if the testing began in the reverse direction. The border obtained by passing from normal to abnormal parts may differ greatly from that at which sensation is present, when we travel in the reverse direction. If so, it is certain that the specific sensation we are testing is diminished, but not absolutely lost, over an area which extends between the two borders. Such cases are useless for determining the form and position of intramedullary segmental borders.

In order that an area of disturbed sensibility can be used to investigate intramedullary segmentation, the position of the border of residual sensibility must remain constant from day to day. Moreover, the border at which the specific sensibility ceases must correspond closely with that at which it begins when testing in the opposite direction.

Unfortunately, such well-defined areas of total loss of sensation are rare

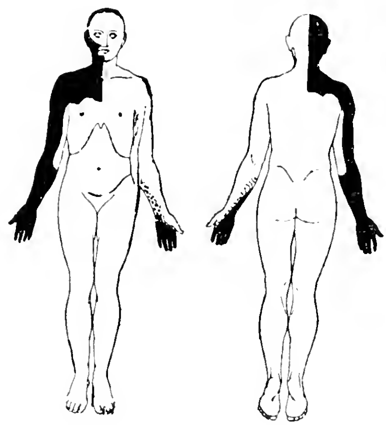

Fig. 97.

To show the loss of sensation to cutaneous painful stimuli in Case 15 (p. 453).
Note the area of residual sensibility on the inner aspect of the right arm; its frontal border corresponds to that of the second thoracic segment.

manifestations of intramedullary disease. But they occur sufficiently frequently for us to be certain that the boundary between sensitive and insensitive parts corresponds to the border of an intramedullary segment. For instance, in Case 15, an area on the inner aspect of the right arm alone remained sensitive

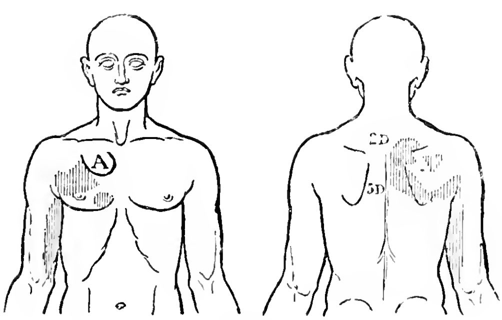

Fig. 98.

To show the area of superficial tenderness due to an aneurysm of the aorta. The frontal border of this area corresponds to that of the second thoracic segment.

to cutaneous painful stimuli (Fig. 97). The border of this residual sensibility should correspond to an intersegmental boundary.

Now, the only scheme of intramedullary segmentation based on any method except loss of sensation is that of the hyperalgesic zones in visceral disease. Compare the area of residual sensibility on Fig. 97 with the tenderness found in a case of aortic disease (Fig. 98). It will be seen how closely the extent of the one corresponds with that of the other.

From a case of herpes zoster examined after death (Head and Campbell,

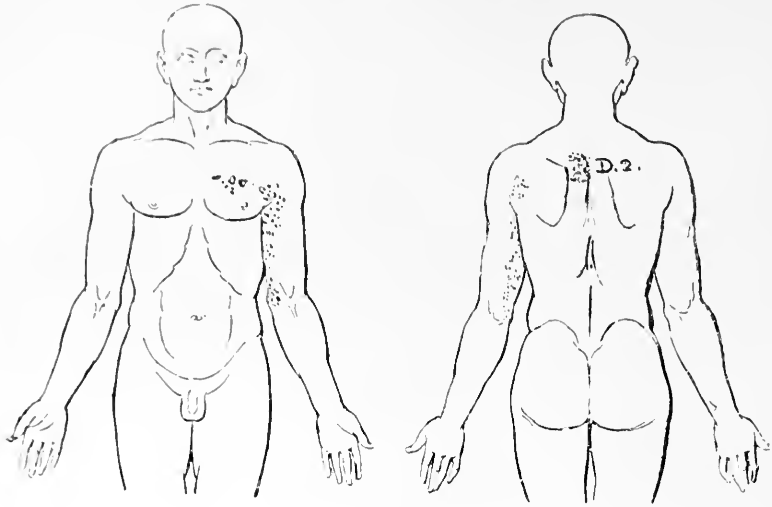

Fig. 99.

To show the distribution of the eruption in a case of herpes zoster, proved by postmortem examination to be due to inflammation of the ganglion of the second thoracic posterior root. (Head and Campbell [45], Case 7.)

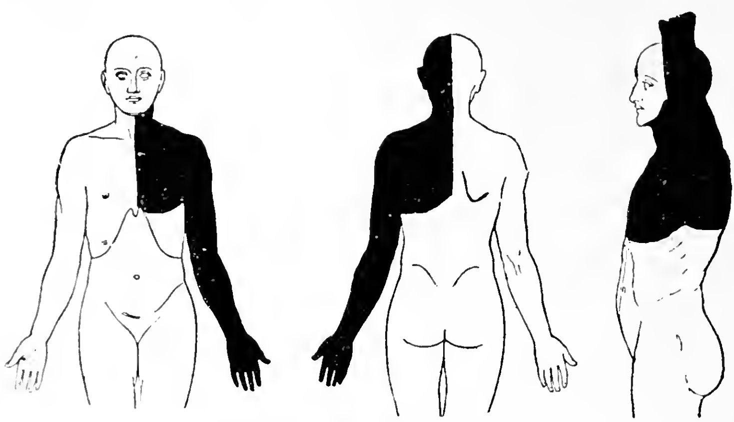

Fig. 100.

To show a well-defined boundary between parts insensitive to prick and those of normal sensibility. Case 16, p. 458.)

The boundary of the residual sensibility corresponds to the frontal border of the seventh thoracic segment.

Case 7), we know that this area of residual sensibility must have corresponded to the distribution of the second thoracic segment (fig. 99).

Another boundary, which remained over a considerable period constant to cutaneous painful stimuli, is shown on Fig. 100. This was taken from a case of syringomyelia (Case 16), where the disease affected mainly the medulla and cervical spinal cord.

Compare this intramedullary segmental area with the distribution of herpes zoster in a case where the ganglion of the seventh thoracic posterior root was diseased (Fig. 101). It will be seen how closely the frontal border of this eruption corresponds to the boundary of residual sensiblity to painful stimulation in Fig. 101.

We have compared the border of an area of residual sensibility with the border of a zone of hyperalgesia, due to the disturbance of an intramedullary segment by visceral irritation. But a glance at Figs. 97, 100, will show that the segmental nature of the disturbance in the two instances of syringomyelia could have been deduced even from an examination of the extent of the analgesia, for the boundaries of the area insensitive to painful stimulation corresponded

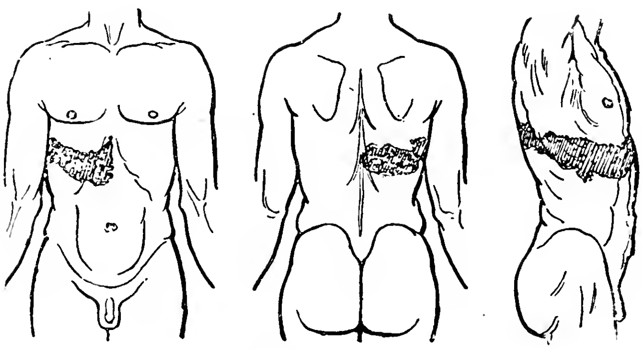

Fig. 101.

To show the distribution of the eruption in a case of herpes zoster proved by postmortem examination to have been due to inflammation of the ganglion of the seventh posterior root. (Head and Campbell, Case 2.)

closely with that of the parts sensitive to the same stimuli. Thus, neighbouring segmental zones cannot overlap one another extensively on the trunk. The amount to which the distribution of one segment encroaches on that of its neighbours is probably less than one half its own extent. Thus it comes about that even the loss of sensation to prick, to heat and to cold may closely represent the true segmental distribution of the intramedullary centres.

The frontal border of the loss of sensibility to pain, produced by cutting off all these segments below a certain level, will cause a loss of sensation, that is only slightly lower than the caudal border of the same segment shown by residual sensibility.

For this reason, those observers who have fixed their attention on the cutaneous analgesia and thermo-anæsthesia produced by lesions of several segments of the cord have come closer to the true segmental distribution than would have been the case, had their contention been correct that these segments overlapped greatly.

But this is true only for the loss of sensation to cutaneous painful and thermal stimuli. An intramedullary lesion may manifest itself locally by an area of cutaneous analgesia and thermo-anaesthesia whose borders correspond almost exactly to those at which sensation to pain, heat and cold ceases. But much of this area may be sensitive to deep painful stimuli, such as excessive pressure.

Moreover, tactile sensibility is usually disturbed over a considerably smaller extent, and the borders of this loss of sensation do not correspond to those of the cutaneous analgesia.

It is therefore of fundamental importance, in every case, to test each form of sensation separately, and to record the border at which it ceases and the border at which it begins, when the stimulus travels from sensitive to insensitive areas. If these two borders correspond closely, and if the same borders are obtained on several different occasions, it is possible to say that this area may be a segmental border. The form and extent of the boundary of the residual

Fig. 102. Fig. 103. Fig. 104.

Fig. 102.—From Case 12 (p. 444). To show the extent of the residual sensibility to painful and thermal stimulation in 1906.
Fig. 103.—From Case 16 (p. 458.) To show the extent of the residual sensibility to painful cutaneous stimuli.
Fig. 104.—From Case 14 (p. 450). To show the extent of the residual sensibility to painful cutaneous stimuli, taken from a series of observations made between November, 1903, and February, 1905.

sensibility only will determine if the disturbance of sensation is the expression of intramedullary segmentation.

We have brought sufficient evidence to prove the truth of Max Laehr's [64] original statement, that the phenomena of loss of sensation, caused by intramedullary disease, pointed to a segmental arrangement of the afferent mechanism at the level of the lesion. But it will be well in the light of this knowledge to examine some of those remarkable borders on the face between parts of normal and abnormal sensibility, so commonly found in cases of syringomyelia.

We shall bring forward such cases only, where these borders remained unaltered for considerable periods. For, when the extent of the loss of sensation is spreading, a single examination may yield results which are transitory, due to the want of adjustment of the higher sensory mechanism to shifting structural changes. But, when a sensory border has remained constant over a long period, as occurs not infrequently in cases of syringomyelia, we can assume that it represents the division between those parts of the central nervous system still capable of function and those in which this power has been destroyed.

The disturbances of sensibility to heat and to cold follow the same segmental arrangement as those for pain. In cases of syringomyelia, it is sometimes possible to find one segmental border marked out by the sensory disturbance to heat, another to cold and a third to pain. Such borders are not, however, usually fixed, and do not therefore come within the subject of this section.

In Case 12, the area insensitive to heat and cold, when passing from normal to abnormal parts, was bounded above by the line on Fig. 102. This was no transitory border, for it has persisted from April, 1905, until October, 1906.

A similar border on the face, associated with a completely different loss of sensibility on the scalp, is seen in Fig. 103. Here the loss of sensibility to cold extended almost as far forwards as the frontal border of the hairy scalp.

Another remarkable area is shown on fig. 104, taken from Case 14. This was worked out by each of us independently on many separate occasions, between November, 1903, and February, 1905. At this border, all sensibility to cutaneous painful stimuli was lost, and the area over which sensation was present to these stimuli was sharply defined.

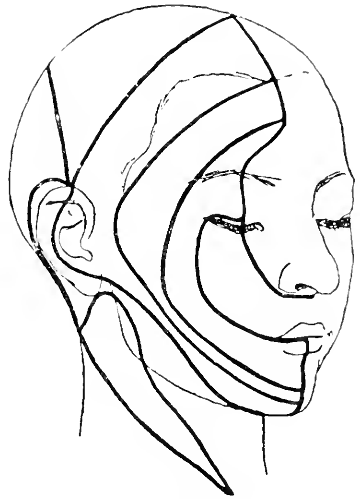

FIG. 105.

Taken from Schlesinger [103] to show the method by which, according to this author, the loss of sensibility advances in lesions of the upper part of the spinal cord and medulla oblongata. Note how closely these borders correspond to those of the tenderness in visceral disease of the organs of the head and face.

We have already shown that on the trunk the residual sensibility to pain, heat and cold tends to follow the distribution of intramedullary segments. It is therefore probable, that these areas on the face are also distributed segmentally. They certainly do not correspond to the peripheral divisions of the trigeminal nerve.

The line on Fig. 102 can scarcely represent the posterior border of residual sensibility of the third divison of this nerve, and it certainly does not correspond to that of its second division. On Figs. 103 and 104, the areas of residual sensibility are inexplicable from the point of view of the peripheral branches of the trigeminal.

The clue to the significance of these areas of residual sensibility is given by the tenderness which accompanies disease of the organs of the head and neck. Fortunately, most of these areas upon the face can be worked out from diseases of the teeth; and, as one tooth only is not infrequently diseased in patients otherwise in perfect health, single areas make their appearance on the face more often than in any other part of the body.

Compare the diagrammatic representatives of these areas of tenderness on Fig. 106 with the parts that remained sensitive to pain, to heat, or to cold on Figs. 102, 103, 104. It will be obvious, that here lies the key to the otherwise inexplicable distribution of the sensory disturbances of the head and neck, produced by a local intramedullary lesion.

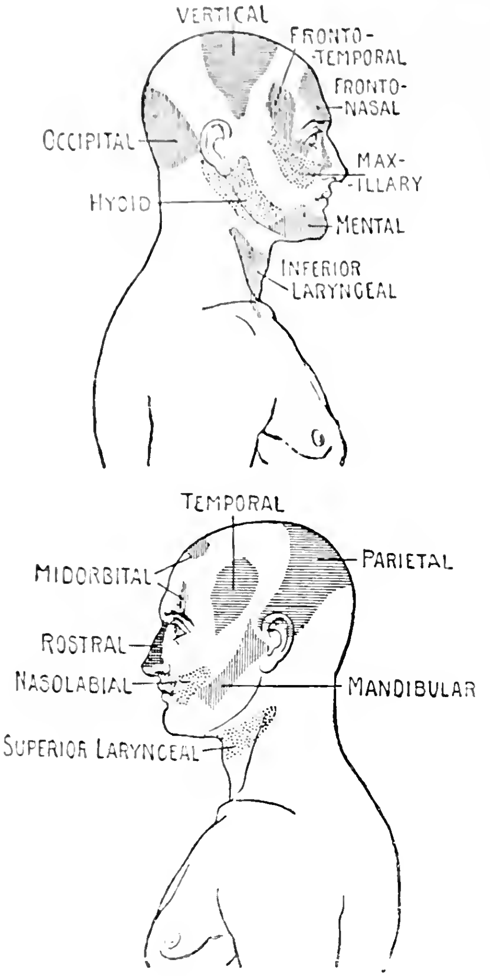

FIG. 106.

To show the extent and distribution of the tender areas which may accompany reflected visceral pain due to disease of the organs of the head and neck. (Taken from Head [14, Part II].)

Fig. 102 shows that all segments anterior to the third cervical and hyoid areas were unaffected: but in Fig. 103, the vertical parietal and occipital areas were added to those insensitive in the previous case.

On Fig. 103, it is evident that the only sensitive parts remaining corresponded to the segments in front of the vertical, the temporal and maxillary areas.

Thus, in spite of the difficulties which surround the determination of these tender areas accompanying reflected pain, we find that their distribution alone enables us to understand the forms assumed on the face by the sensory disturbances due to intramedullary disease.

(*b*) *The remote disturbance of sensation on the side opposed to the lesion may show signs of intramedullary segmentation.*

Sensory changes at the level of the lesion might be expected to show signs of segmental arrangement. But we believe it is also possible to show that, even when the impulses are interrupted after they have passed to the opposite side of the spinal cord, traces of a segmental arrangement can still be discovered.

Thus, in Case 3, the border between parts of normal sensibility and those insensitive to pain, heat and cold was well defined on the side opposed to the lesion. This border resembles the caudal limit of the eruption in a case of herpes zoster due to the destruction of the ganglion of the eleventh thoracic posterior root (Fig. 107). Thus, we must assume that in this case the lesion in the left half of the cord interrupted all the painful and thermal impulses which entered on the right side by the twelfth thoracic posterior root, but allowed all those of the eleventh thoracic root to pass unimpeded.

In the same way, in Case 4, an injury of the cervical portion of the spinal cord produced complete loss of sensation to pain, heat and cold over that half of the body opposite to the paralysis of motion. Here also the boundary between parts of normal and disturbed sensibility was well defined, following

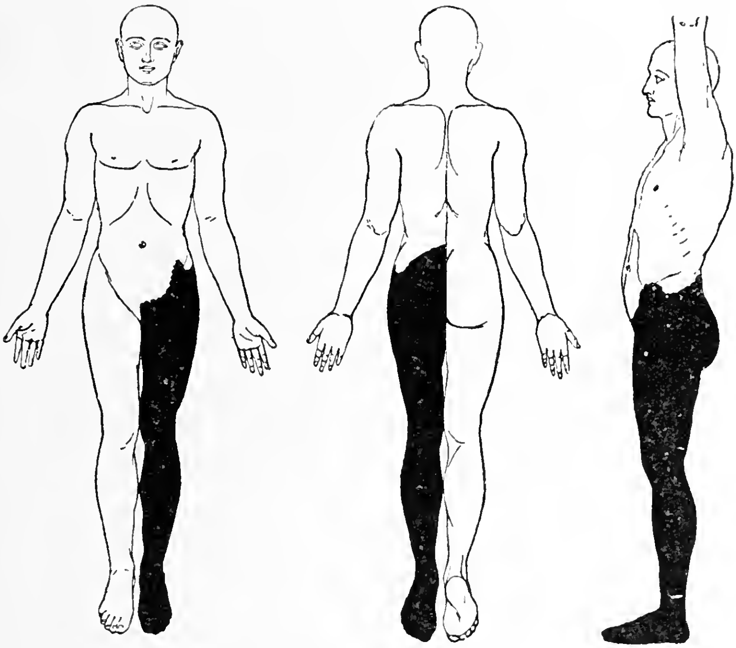

Fig. 107.

To show the disturbance of sensibility to painful and thermal stimulation produced by a lesion which interfered with motion and increased the reflexes in the right leg. (Case 3, p. 412.)

The border between the normal parts and those which were completely insensitive was unusually well defined, corresponding to the caudal border of the eleventh thoracic segment.

closely the caudal border of the first thoracic segment. The injury must therefore have destroyed the paths for all those impulses for pain, heat and cold which crossed the cord in the second thoracic segment, and must have destroyed them after the crossing had occurred.

A similar result was produced by a fracture of the third cervical vertebra (Case 2). Motion was disturbed in the right arm, whilst sensibility to heat and cold was entirely abolished over the left leg, left half of the trunk and part of the left arm. The boundary between parts of normal and abnormal sensibility corresponded to the posterior border of an area frequently marked out by herpes zoster, which Head and Campbell attributed to disturbance of the ganglion of the seventh cervical posterior root.

Now, in this case an exploratory operation proved that the neural arch of the third cervical vertebra had been fractured; and yet the anterior border of the remote loss of sensation on the opposite side corresponded to that of the eighth cervical segment. In the same way, the frontal border of the loss of sensation in W. M. (Case 5) corresponded to the parts which we should expect to become analgesic from destruction of the segments below the second thoracic. But there can be little doubt that the upper, rather than the lower, part of the cervical spine was injured by his fall.

Thus, it would seem that, when the loss of sensation (remote) on the opposite side to the lesion shows evidence of segmentation, it indicates an interruption

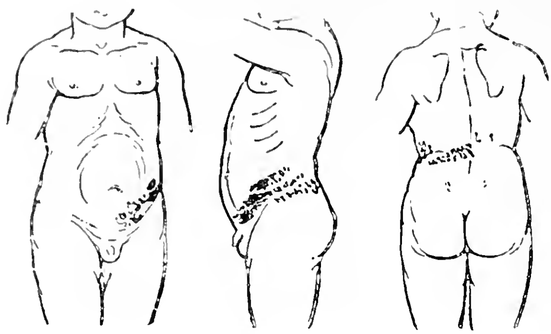

Fig. 108.

To show the distribution of the eruption in a case of herpes zoster proved by postmortem examination to be due to inflammation of the ganglion of the eleventh thoracic posterior root. (Head and Campbell, Case 5.)

of the spinal cord, several segments below the point of injury. This was first shown by Piltz [93], whose statements are borne out by our cases of Brown-Séquard paralysis, as far as they go.

(*c*) *The remote analgesia and thermo-anæsthesia produced by lesions of the cervical spinal cord, point to a lamellar arrangement of sensory impulses in this region.*

Any one who has studied a long series of cases of spinal cord disease will have been struck with the occasional retention of sensation over the sacral areas, in spite of the complete insensibility of the remainder of the trunk. It would seem that the impulses from the caudal end of the body may escape an interruption which has overtaken all other sensory impulses.

Sometimes this phenomenon also appears in cases of Brown-Séquard paralysis, and it is particularly well seen in the following instances from our collection. The first of these was a man of 41 years who had injured his neck by diving into shallow water, twenty years before he first came under our care. The motor disturbance was represented by distinct wasting of the muscles of the left hand. All loss of sensation was confined to the right leg and right half of the body (Figs. 109 and 110). But, in spite of the widespread cutaneous analgesia, it will be seen that the genitalia with part of the buttock and back of the thigh remained sensitive to prick. The retention of sensibility to heat and cold was even greater, extending to the soles of the feet.

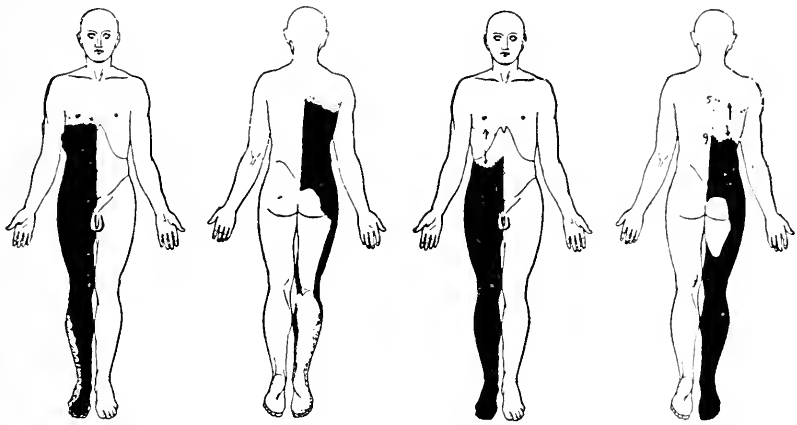

FIG. 109. FIG. 110.

To show the disturbance of sensation produced by injury to the cervical spine in Case 6.

Fig. 109. Shows the extent of the loss to thermal stimuli. Sensation remained intact over the sacral areas.

Fig. 110. Shows the extent of the loss to cutaneous painful stimuli. Sensation was present over an area corresponding to the lower sacral segments only.

Cyril W. F. (Case 7) showed a similar condition, also produced by diving into shallow water. But, in this case, the loss of sensation was most extensive to heat and of smallest extent to prick (Figs. 80 and 81, p. 343).

It is therefore probable that in the cervical region the impulses from the caudal end of the body (sacral segments), after crossing the cord, pass up in paths separate from those for the sensory impulses from the lumbar and thoracic regions. These paths must be arranged in a lamellar manner, since an injury may interrupt the one set of impulses, leaving the others intact.

CHAPTER VI

THE PASSAGE THROUGH THE SPINAL CORD OF AFFERENT IMPULSES CONCERNED WITH THE SPACIAL ASPECTS OF SENSATION

No question has led to greater difference of opinion than the means by which we recognise the position of our limbs in space, and localise a spot stimulated. Fortunately, in the present paper, we are concerned with the passage through the spinal cord of certain elementary afferent impulses, and not with the question of spacial perception as a whole. This remains a function of the nervous system at a level higher than that with which we are now occupied.

But, throughout this paper, we have spoken of the power of recognising passive position and movement. Recognition of voluntary movement is a more complex process, based upon impulses grouped differently from those which fall within the range of that part of the nervous system we are now considering. We have also examined the power of naming and indicating the position of a spot touched, and, in every case, we have investigated the capacity for discriminating two points at varying distances. These three tests, the recognition of passive position and movement, the discrimination of compass points and the localisation of a spot touched, have been chosen, because experience shows that they are affected in lesions of the spinal cord.

We have not only avoided all terms relating to the perceptual aspects of localisation, but also those that express the ultimate sum of many streams of diverse sensory impulses, co-ordinated at a higher level than that with which we are now concerned. We shall use the term "tactile localisation" for the power of discovering the spot to which a stimulus is applied. For those impulses which enable us to recognise the two points of the compasses, we shall use the term "tactile discrimination." Of all those impulses which are concerned in the recognition of articular movement, we shall deal with those of passive movement and position only.[1] These are the three spinal afferent elements which at a higher level of the nervous system, together with many other factors, lie at the foundation of spacial localisation.

§ 1.—The Impulses concerned with the Recognition of Passive Position and Movement

After division of peripheral nerves, it is found that the power of recognising passive movement and position is closely associated with the integrity of those

[1] Two of these three terms correspond to the groups classified by German authorities "Raumsinn" (tactile discrimination); "Hautlocalisation" or "Ortsinn" (tactile localisation (*Cf.* Spearman [116].)

afferent fibres which run mainly with muscular nerves. It is these fibres which innervate the joints, the tendons and the muscles. So long as they remain intact, all cutaneous nerves may be destroyed, and the patient will still be able to recognise the position into which his joints have been placed. As soon as these fibres are destroyed, this power is lost. But, in the same path as the impulses for the sense of articular movement and position, travel those which underlie the recognition of deep touch, as far as all subcutaneous structures are concerned. The close association between sensibility to deep touch and the recognition of passive movement and position, is best seen by dividing all the cutaneous nerves to any part, without injury to the muscular trunks. The skin is thus rendered totally anæsthetic, and any sensibility which may remain must be due to impulses which travel in the afferent fibres of the deep system running with muscular nerves. It will then be found that the patient can recognise the tactile and painful elements of pressure, and remains sensitive to passive movement and position of every part of the affected limb, although he is insensitive to every other form of stimulation. Injury to peripheral nerves cannot disturb one of these impulses, without simultaneously affecting others of the group.

But, in consequence of lesions within the spinal cord, these impulses can be separately affected. The patient may be sensitive to a deep touch, but at the same time all sensations of articular movement and position may be destroyed. This was the case in J. Y. (No. 10). A secondary growth within the spinal cord had entirely withdrawn from him all knowledge of the position of his legs. So great was the loss of sensation that he was ignorant even of the grossest changes in their position ; and yet he was able to recognise pressure everywhere over both legs.

Conversely, in Case 1, all tactile sensibility and all power of recognising differences in pressure were destroyed over the right leg ; and yet, there was no part of the limb where he could not recognise passive position and movement. Passive movements were equally well appreciated, whether the joints moved belonged to one limb or the other ; and yet, the right leg was totally insensitive to every other form of stimulation.

With cases of intramedullary disease, it is particularly easy to show that the power of recognising passive articular movement depends upon impulses which are uncrossed and therefore even more elemental than those for pain, heat and cold. For the power of appreciating articular movement and position is always lost on the same side as the disturbance of motion. In Grace G. (Case 3), the left leg was insensitive to all painful and thermal stimulation, but the sense of passive position and movement was perfect. On the right side, sensibility to touch, pain, heat and cold was perfect, but the sense of passive position and movement was disturbed in the right foot. A similar condition existed in Case 2. In consequence of an injury to the cervical spine, this man became insensitive to all painful and thermal stimulation over the left leg and left half of his body. When first seen, the sense of articular movement and position was perfect. But, after an attempt to rectify the condition of his spine, he could no longer recognise the position of his right leg; the surgical operation had destroyed the sense of articular movement and position on the opposite side of his body to the analgesia and thermo-anæsthesia.

This rule, that the sense of articular movement and position is lost on the side of the disturbance of motion, leads to a curious difference between the remote and local sensory phenomena of intramedullary disease. The remote effects consist of loss of sensibility to pain, heat and cold and perhaps to tactile stimuli over the side opposed to the loss of motion; any loss in the sense of articular movement and position will be found in the limbs on the side of the motor disturbance, where the sensibility is otherwise unaffected.

But the local effect of intramedullary disease disturbs cutaneous sensibility on the same side as the motor disturbance, in consequence of an interference with the afferent impulses before they have crossed the cord. The sense of articular movement and position will also be abolished in the same limb, since it is always disturbed on the side of the loss of motion. This difference is excellently exhibited by the case of Joseph F. (No. 9). This man was analgesic and thermo-anæsthetic over the right leg, in consequence of disease of the cervical spinal cord. The sense of articular movement and position was disturbed in the toes of the left foot, that is, on the opposite leg to the remote loss of sensation to pain, heat and cold. But the growth in the left half of the spinal cord produced a local loss of sensibility to all forms of touch, pain and temperature in the left arm, and, in addition, he was entirely unable to recognise any movement of this arm, however gross.

In conclusion—

(1) The sense of passive position and movement may be destroyed as a consequence of intramedullary disease, although sensibility to deep touch remains perfect. Conversely, the patient may be insensitive to all tactile stimulation, both superficial and deep, and yet may be normally sensitive to passive movements.

(2) Any loss of the sense of passive position and movement will be found on the same side of the body as the disturbance of motion and reflexes.

Thus, the remote effects of intramedullary disease may be manifested in loss of the sense of passive position and movement, disturbance of motion and changes in the reflexes on the one side of the body associated with analgesia, and thermo-anæsthesia of the opposite half.

The local effects of an intramedullary lesion will all be found on the same side; paralysis and wasting of muscles, loss of the sense of passive position and movement, analgesia and thermo-anæsthesia, may all exist together in the same limb.

§ 2.—The Impulses concerned with Tactile Discrimination

E. H. Weber [132] first employed simultaneous contact with the two points of the compasses as a sensory test. According to him, the power of recognising that a stimulus had an existence external to the body was the highest quality of sensation: sensations grouped together under the name of "common sensibility" (Gemeingefühl) did not carry with them this quality. He showed that, when the discrimination of two points was used as a test, some parts were many times more sensitive than others: for instance, the two points could not be distinguished over the back, until they were separated to a distance sixty times greater than was necessary for a sensitive surface, such as the tip of the tongue. He believed that, in the compasses, he had discovered a means of measuring the sensibility of the skin, but fully recognised that the test he employed depended upon something apart from crude tactile sensibility.

For, throughout, he speaks of the fineness of the "Ortsinn," and the chapter in which he introduces his experiments is headed "Ortsinn der Haut." His work was imperfectly understood by those who subsequently used the compass test. Brown-Séquard frankly accepts it as a method of measuring the fineness of tactile sensibility. He does not discuss the method; but, when he wishes to demonstrate the obtuseness to touch of the non-paralysed leg in a case of crossed paralysis, he states that the two points appeared to be one, even when separated to a distance of 13 cm.; on the paralysed leg, the patient discriminated the two points, when they were 1·2 or 1·3 cm. apart. Evidently, in this patient, tactile sensibility was gravely diminished, for Brown-Séquard states that "it was necessary to press very hard" on the left leg, "while the patient was able to distinguish the two points, even when they touched but very slightly the paralysed leg." (Brown-Séquard [19].)

Now it will be obvious, that tactile sensibility may be so gravely diminished, that contact may cause little or no sensation. Under such circumstances, the patient would be unable to recognise the two points, because the contact of one or both failed to produce a sensory impulse. The compass test would then fail from lack of tactile sensibility.[1]

But early in our research on the sensory results of intramedullary lesions, we found that the power of discriminating two points of the compasses might be disturbed over parts which were sensitive to every other form of cutaneous stimulation. One leg might be insensitive to painful and thermal stimuli, but remain sensitive in a normal degree to the compass test; the opposite leg might show a gravely defective sensibility to the compasses, although sensitive to every other form of cutaneous stimulation. We also found that, if tactile sensibility was disturbed, the anæsthesia was found over the leg which was also insensitive to pain and temperature. Three facts stood out clearly before us:—

(1) The power of discriminating two points can be diminished over a limb completely sensitive to all cutaneous stimuli.

(2) If, as a consequence of the remote effects of an intramedullary lesion, the compass test shows a diminution of sensibility, whilst touch is perfectly appreciated, the part so affected will lie on the same side as the disturbance of motion.

[1] *Cf.* Case 4, p. 416.

(3) Whenever tactile sensibility is abolished, in consequence of the remote effects of an intramedullary lesion, this loss of sensation will be found on the side opposed to the loss of motion, over the limb insensitive also to painful and thermal stimuli.

It was therefore evident that, although the compass test depends upon the integrity of tactile sensibility for its existence, it can reveal a disturbance in sensation which, as far as intramedullary impulses are concerned, is entirely separate from sensations of touch. Throughout this work, we have used the compasses as a means of revealing defects in the impulses, which underlie the power of tactile discrimination, apart from a loss of tactile sensibility. That is to say, we have restored this test to the use originally prescribed by E. H. Weber. We have not used it as a test for tactile sensibility as was done by Brown-Séquard, and, by this strict differentiation, we have been able to reconcile the discrepancies which have so puzzled recent observers. A clear understanding of this use of the compass test is necessary for the comprehension of the results produced by disease within the spinal cord. For if, among the instances where this test showed some loss of sensation, are included those where tactile sensibility was otherwise defective, the loss of sensation revealed by the compasses will appear, sometimes on the side of the disturbance of motion, sometimes on the opposite side. But, if we confine ourselves to those cases only, where tactile sensibility was perfect, any defect in discriminating two points will be found to lie invariably on the same side as the disturbance of motion and reflexes. (*Cf.* Case 3, p. 412. Case 16, p. 458.)

§ 3.—Tactile Localisation

We have already considered in this chapter, the effects of an intramedullary lesion on the impulses which underlie the recognition of passive position and movement, and of tactile discrimination. Although they pass to the spinal cord along two afferent paths, these paths become associated within the spinal cord. Not only are the two sets of impulses usually disturbed together by intramedullary lesions, but the loss of sensation to both forms of stimulation is uncrossed, on the same side as the disturbance of motion.

We shall now bring forward evidence to show, that the faculty of tactile localisation is due to impulses which, within the spinal cord, run separately from those of tactile discrimination.

This view was held by Volkmann [128], who first investigated the matter. But the question has been much obscured of late by a misapprehension of the significance to be attached to the compass test. Some have accepted this test as a measure of tactile localisation, although it was pointed out in 1858, that the compasses tested the "sense of space" (*Raumsinn*) only. In 1901 Förster [30] went so far as to assert, that tactile localisation depended entirely upon sensations of movement (*Bewegungsempfindungen*). However much we may differ from this observer in his general conclusions, he was the first to examine a series of pathological cases from this aspect.

Recently, Förster's challenge has been taken up by an experimental psychologist (Spearman [115]). But from a clinical point of view, Spearman's case was not completely satisfactory, because the symptoms were evidently bilateral, and sensibility to touch was diminished. We have, however, frequently alluded to this paper, because of the admirable thoroughness of the methods employed.

Before describing in detail the results we have obtained, it is necessary to discuss shortly the methods employed in testing a patient's power of recognising the locality of a spot touched.

First, the patient's eyes are closed and he is asked to say where he is touched. This is the simplest of all methods, and is usually spoken of by us as "spot-naming." If the patient can answer correctly every time he is touched on his great toe, on the heel, on the dorsum of the foot, or on the knee-cap, it is certain that his power of tactile localisation cannot be greatly affected.

If he is asked to point to the spot where he has been touched, he usually errs considerably. But when allowed to grope with the finger he comes closer, and may ultimately touch the very spot. Many observers have pointed out, that this method implies two faculties: a knowledge of the spot touched and of the position in space of the part upon which that spot lies. It requires a combination of the sense of passive position and movement with the power of tactile localisation.

Suppose, however, that the sense of passive position and movement is destroyed, and yet the patient can name correctly every spot touched on the limb. It will then be found, that, if he is allowed to grope for the spot, he fails entirely at first to find the limb, but gradually, as testing proceeds, becomes increasingly able to approximate his finger to the spot. That is to say, by means of the touch and movements of his indicating hand, he has partly corrected his defective knowledge of the position of the limb. When this knowledge has been reacquired, move the limb without allowing him to open his eyes. Then he will grope for the spot touched as badly as ever he did, although he still names it correctly.

Spearman devised the following method for overcoming this reacquisition of knowledge by means of groping touch. A hole is pierced in a piece of cardboard held one centimetre from the surface to be tested. Through this hole the patient is touched, and he attempts to point out the spot with a pencil. This marks the card, and the distance of the pencil-mark from the hole can be measured. Since the skin is never touched, except by the stimulating object thrust through the hole by the observer, the patient has no opportunity of correcting his defective knowledge by means of touch. This method is an excellent one, where the one limb is affected, and that of the opposite side shows none of the sensory defects with which we are concerned in this chapter. But it only emphasises the double nature of the groping test, which can never be simple so long as we have to deal with the sensory defects produced by an intramedullary lesion.

The power of tactile localisation may remain good over parts where the sense of passive position and movement is entirely absent. In J. Y. (Case 10), who had entirely lost all knowledge of the position of his limbs, we performed the following experiments: His legs were extended in the bed, and he was allowed to see the position into which they had been placed. Then his eyes were closed and he was touched over the sole, instep and just below the knee-cap: in every instance his answers were correct, even though the touch was made with cotton wool. With his eyes still closed, the leg was moved into an entirely different position, and his answers were equally correct, although he was entirely ignorant that the leg had been moved, and believed it lay extended before him.

Directly he was asked to point out the spot that had been touched, the double nature of the groping-test was apparent. In the attempt to find the spot he had named correctly, he beat the bed idly, entirely unable even to find his limb.

With the profound disturbance of the power of recognising the position of his limbs was associated an inability to discriminate the compass points; over the outer surface of the left leg, he failed when they were separated to 15 cm.—

15 cm.	1	8 W. 2 R.
	2	3 W. 7 R.

and over the front of the left thigh at 20 cm. distance—

20 cm.	1	7 W. 2 R.
	2	6 W. 4 R.

But, in spite of this failure to discriminate the two points, he could name accurately the spot touched.

Thus, it is evident that, although the impulses underlying tactile discrimination and the sense of passive position are closely associated in the spinal cord, they must be separated from those of tactile localisation as revealed by the power of naming the spot touched.

R. A. H. (Case 16) also showed that the impulses, which underlie the power of naming the spot touched, pass by paths within the spinal cord, separate from those for the impulses of tactile discrimination. This man showed signs of chronic intramedullary disease affecting the bulb and cervical spinal cord. The motor disturbance was represented by paralysis of the left vocal cord and left half of the palate, with a spastic condition of the left leg.

There was profound loss of the sense of passive position and movement in the left foot and ankle, and tactile discrimination (compasses) was gravely affected. This case was particularly favourable for such tests, because the sensation of the right lower extremity was unaffected and, on the left leg, painful, thermal and tactile sensibility was normal even to the finest tests. On the sole of the right foot his answers were perfect, when the compass points were separated by a distance of 4 cm. Over the left sole, he gave six false answers at 8 cm.

1	10 R.
2	4 R. 6 W.

In the same way, when he was tested by moving his left ankle passively, he failed to give a correct answer in thirteen instances out of twenty.

Dorsiflexion	3 W. 6 O. 1 R.
Plantar extension	1 W. 3 O. 6 R.

But, with the right ankle, his answers were quick and uniformly accurate.

And yet in spite of these grave defects in tactile discrimination, and in appreciation of passive position and movement, he named a spot touched as accurately on the left leg as on the right. A number of definite spots on both lower extremities, such as the ball of the great toe, the heel, the external malleolus, were touched with cotton wool; in no instance did he fail to answer quickly and correctly. Whilst his eyes remained closed, the left foot was placed into an entirely different position. Although he could not tell the situation of the foot, he still named all the points touched as correctly as on the sound side.

But, as soon as he was asked to point out the spot, the difference between the two legs was at once obvious. When tested by Spearman's method, he deviated to the following extent.[1]

	Right (normal).	*Left (affected).*
Sole of the foot	5·7 cm.	7 cm.
Outer aspect of leg	4·3 cm.	6·8 cm.
Front of thigh	2·5 cm.	4·3 cm.

A further series of experiments were made by stimulating the same spot on the dorsum of the foot four times before and four times after movement, the patient's eyes remaining closed throughout. The results were as follows :—

	Right (normal).	*Left (affected).*
Before movement	9·7 cm.	9 cm.
After movement	9·7 cm.	13 cm.

It will be seen that the deviation on the sound side remained the same, but on the affected foot had increased greatly after movement.

From these experiments it is evident, that, at the spinal level, the impulses underlying spot-naming run independently of those for tactile discrimination and the recognition of passive position and movement. But, as soon as an attempt is made to indicate the point stimulated, it is necessary that the patient should recognise the position into which his limbs have been placed passively.

At the spinal level, the impulses for tactile localisation seem to be intimately associated with those of tactile sensibility; we have seen no instance where an intramedullary lesion has produced defective localisation of touch without a demonstrable reduction of tactile sensibility.

[1] In this series he was touched six times at each spot; the numbers represent the average deviation.

§ 4.—Summary

A lesion within the spinal cord can interrupt the afferent impulses which subserve the spacial aspects of sensation in such a way, that the patient fails to answer to one or more of three simple tests. He may not be able to recognise passive position and movement, he may be unable to discriminate two points separated to a distance far in excess of normal, or he may be unable to name the position of a spot stimulated.

We showed reason to believe, that the impulses induced by the first two tests pass up the same side of the spinal cord as that by which they had entered. The remote sensory loss, produced by the interruption of these impulses, even in the cervical region, is found on the side of the motor disturbance.

In this peculiarity, the impulses underlying the recognition of passive position and movement and of the discrimination of two points, differ from every other sensory impulse passing up the spinal cord. Even the impulses for spot-naming ultimately cross to the side of the spinal cord opposite to their point of entry.

But with lesions of the cortex and subcortical systems, the loss of appreciation of passive position and movement is found on the opposite side to the lesion. It is obvious, therefore, that all afferent impulses, which reach consciousness and are manifested as a disturbance of sensation, ultimately cross to that half of the nervous system opposed to their point of entry. Some cross quickly; but with some, like those which underlie the sense of passive position and movement, the crossing is delayed until the spinal cord has passed into the medulla oblongata and pons varolii.

Now, sensory impulses which pass up the same side of the spinal cord have not reached the second level of the sensory nervous system. For the most distinctive feature of the impulses at a secondary sensory level is the fact that the remote results caused by interference with them is manifested on the opposite side of the body.

Thus, it is evident that the impulses underlying the appreciation of passive position and movement and tactile discrimination have not attained, within the spinal cord, to the chief characteristic of sensory impulses at the second or intramedullary level of the nervous system.

Each of these two sets of impulses reaches the spinal cord in combination with others. The fibres of the epicritic system conduct, not only the impulses underlying tactile discrimination, but also those for the appreciation of light touch. The peripheral system, associated with deep sensibility, conducts impulses for pressure, for the pain of excessive pressure, as well as those impulses which underlie the sense of passive position.

Thus, by the time the impulses, which pass up in the epicritic system, have reached the cervical region, those for tactile discrimination have parted company with all the others, which have passed to the opposite side of the spinal cord.

In the same way, of all the sensory impulses which reach the cord by way of the deep system of nerves, those concerned with the sense of passive position and movement alone remain uncrossed. Those associated with the pain of excessive pressure and with the appreciation and localisation of deep touch, have all crossed to the opposite side of the nervous system within the spinal cord.

Among the many sets of impulses poured into the spinal cord by way of the epicritic and deep systems, a gradual filtering off takes place. At last, in the upper cervical region, none from the epicritic system remain uncrossed, except those concerned with tactile discrimination: none from the deep system, but those which underlie the appreciation of passive position and movement.

When we turn to the impulses underlying tactile localisation, we find that, although they have crossed to the opposite side within the spinal cord, they still remain intimately associated with the impulses for tactile sensibility. The epicritic system brings to the spinal cord the impulses for light touch and cutaneous localisation; the deep system carries those concerned with the recognition and localisation of pressure touch (deep touch).

These are immediately transformed and combined into a single group of tactile impulses, which ultimately cross to the opposite half of the spinal cord. Those impulses, associated with tactile localisation, might have been split off to run a course of their own apart from those for tactile sensibility. But this is not the case at the spinal level. Here these two groups of impulses seem to be still intimately associated together. Their fate, at a higher level than that with which we are now concerned, will be the subject of a further communication.

In conclusion, we believe that among the impulses concerned with the local aspect of sensation, which can be interrupted by intramedullary lesions, the three groups do not all belong to the second sensory level. Those concerned with tactile localisation cross the cord and show evidence of recombination; they have, therefore, become sensory impulses of the true intramedullary level. The impulses underlying tactile discrimination and the recognition of passive position and movement show no evidence of recombination, and are interrupted on the same side as motion by intraspinal lesions. From a study of disease higher up the nervous system, above the spinal cord, we know that these impulses ultimately cross, and become recombined. Thus, we believe that a lesion of the spinal cord interrupts these impulses before they have reached the second sensory level. Throughout the spinal cord, they still remain impulses of the primary sensory level.

CHAPTER VII

GENERAL CONCLUSIONS

For fifty years physiologists and clinicians, stimulated by the work of Brown-Séquard, have attempted to trace the upward paths of afferent impulses through the spinal cord. But, in spite of the many admirable experiments on animals and a certain number of well-observed cases of intramedullary disease in man, the latest writers either confess to ignorance, or believe that every impulse passes by at least two paths.

This widespread scepticism arises from the nature of the methods employed. On the one hand, although the experimenter can produce a lesion of the spinal cord in a healthy animal, which can be killed at any desired period after the operation and the secondary ascending degenerations be traced with exactitude, yet it is impossible to say certainly how sensation is affected by the lesion, even when the animal has been long under observation.

On the other hand, the clinician may expend much time and trouble in determining the nature of the loss of sensation; but it is especially in these well-observed cases that it is usually impossible to verify the anatomical nature of the lesion. Most of the instances, in which a careful microscopical examination has been possible, have been cases where the lesion has been progressive, or where the patient has died from complications which greatly detracted from his suitability for psychophysical examination.

No one who has read our paper will think we do not value the experimental or clinical work of our predecessors. If we may seem to pay less detailed attention to it than is customary, it is solely because we have attacked the problem from a different aspect. We accept the experimental result that in animals it is impossible to abolish the upward passage of all afferent impulses from one limb by hemisection of the spinal cord, and fully recognise that the majority of clinical reports are anatomically unsatisfactory.

Recognising the inherent difficulties of both methods, we determined to attack the problem from a different aspect. All previous workers have assumed that afferent impulses reach the spinal cord in the same combinations as those ultimately received by the centres in the brain. Whatever psychical sorting might take place among sensations, it has been assumed that the sensory impulses pass from the periphery to the highest physiological centres, unchanged in quality and in unaltered combinations.

But Head, Rivers and Sherren showed that this could not be the case; for the afferent impulses passed up the peripheral nerves in combinations entirely foreign to those familiar to the investigators of normal sensibility. They showed that sensory impulses reach the spinal cord by way of the fibres of the posterior nerve-roots in the same remarkable combinations. It was, therefore, certain that the grouping of these impulses must have changed in some way. Where this change occurred, and how the sensory impulses were combined anew, was the problem we set before us.

(*a*) *Results obtained by the Physiological Method.*

Our method has been to trace known sensory impulses, arriving by way of normal peripheral nerves and posterior roots through a diseased spinal cord to higher centres that are entirely unaffected, and we have attempted to indicate how sensation is modified under such conditions.

We showed in Chapter II, how the disturbance of sensation produced by an intramedullary lesion differed from that due to division of peripheral nerves. Impulses arrive by three main streams, along the fibres of the protopathic, epicritic and deep systems. We compared this grouping of impulses at the primary, or peripheral, level with the changes in sensation produced by a purely intramedullary lesion; and for this purpose, we chose the loss of sensibility on the opposite half of the body to that on which motion and reflexes were affected.

All sensory impulses which have crossed the cord show signs of recombination. The form assumed by the loss of sensation shows that the tactile elements have become united into a single group, by whatever peripheral path they may have reached the spinal cord. In the same way, the impulses started by cutaneous painful stimulation arriving by the protopathic fibres, and those due to painful pressure arriving by the deep system of nerves, become combined, parting company with all other sensory impulses that may have travelled with them in peripheral paths. The thermal impulses of the epicritic and protopathic systems become recombined, so that an intramedullary lesion can interrupt all those subserving the sensation of heat, without interfering with the impulses underlying sensations of cold. Or, in some cases, the patient may be insensitive to cold over parts completely sensitive to heat of all degrees. In passing from the peripheral to the intramedullary, or secondary, level, the impulses change from a regional and developmental grouping to physiologically specific combinations.

Finally, we analysed the loss of sensation caused by intramedullary disease at the level of the lesion, and showed that, in character, it agreed with that remote loss on the side opposed to the lesion where the sensory impulses had been interrupted after they had crossed the spinal cord. Thus, the change must have occurred on the same side of the cord as that by which the sensory impulses entered.

(b) The Nature of the Impulses in the Posterior Columns of the Spinal Cord.

Tactile, painful and thermal impulses, and those associated with tactile localisation, cross in their passage through the spinal cord, and show evidence of recombination. But the sensory impulses which underlie the recognition of passive position and movement and tactile discrimination do not cross within the limits of the spinal cord. Lesions of the higher centres show that, ultimately, even these impulses cross and are grouped anew; but this change cannot be demonstrated by a pure intramedullary lesion.

Injury and disease of the cervical region of the spinal cord prove that an impaired tactile discrimination and loss of appreciation of passive position and movement may form the only remote loss of sensation on the same side as the disturbance of motion. Thus, although these impulses show no signs of recombination and are still impulses of the lowest sensory level, they are no longer associated with the sensory companions with which they travelled in the peripheral nerves. The impulses underlying tactile discrimination, which reached the spinal cord by way of the epicritic fibres, have parted company with the impulses for light touch, for tactile localisation and for intermediate degrees of heat and cold. The deep system of afferent fibres running with muscular nerves, carried to the spinal cord, not only the impulses associated with the recognition of passive position and movement, but also those for the appreciation and localisation of deep touch and for the pain of excessive pressure. Of epicritic impulses, those for tactile discrimination alone remain uncrossed and uncombined in the cervical spinal cord; similarly, of all those which passed into the spinal cord by way of the deep system of fibres, the impulses underlying the appreciation of passive position and movement alone remain uncrossed and uncombined.

For these impulses we must therefore seek some path in the spinal cord, which is the direct continuation of the posterior roots and which remains uncrossed, until we have passed beyond the limits of the spinal cord. Such a path is found in the long extrinsic tracts of the posterior columns. Fibres from the fifth lumbar and first sacral posterior roots can be shown to degenerate up to the nucleus of the postero-internal column, and degeneration can be traced up the complete length of the postero-external column, after division of the posterior roots supplying the hand. But the number of fibres which can be found degenerated in the upper part of the cervical region is but a small fraction of those which show evidence of destruction, as a consequence of division of any one posterior root. All the way up, the posterior columns are giving off fibres to other parts of the cord.

On tracing the sensory impulses throughout their course in the spinal cord, an exactly analogous filtering off occurs. Painful, thermal, tactile impulses ultimately pass from the point of entry to the opposite side of the spinal cord.

But, before they pass across, they have undergone characteristic recombination. That this change occurs in the same half of the spinal cord by which the impulses enter, is shown by the fact that the local loss of sensation produced by a pure intramedullary lesion closely resembles, in character and grouping, that of the remote sensory disturbance which lies over the opposite half of the body.

The rapidity with which the sensory impulses cross to the opposite side varies greatly. Some, such as those associated with pain, heat and cold, seem to have passed completely to the opposite side in the space of five or six segments (Piltz [93], *vide* also Chapter V, p. 384). Thus, in man, an intramedullary lesion may interfere completely with sensory impulses for pain, heat and cold from the opposite half of the body, without disturbing any other form of sensation. With tactile impulses, the crossing is evidently less rapid; for it is rare to find a remote disturbance of tactile sensibility. But, ultimately, even tactile impulses pass completely to the opposite side of the cord, and a lesion in its upper part may, if sufficiently severe, produce loss of tactile sensibility over the same parts that are analgesic and thermo-anæsthetic. But, until this crossing is finally completed, it is obvious that two paths will be open for tactile impulses. They will continue to pass up the fibres of the epicritic and deep systems in the posterior column, until the highest point in the spinal cord at which those impulses entering by any one posterior root are received by the secondary systems. But, much nearer the point of entry, some impulses will have become transformed and have crossed to the opposite side. Thus, two paths are open for tactile impulses, one in the primary system of the posterior columns, the other in the secondary intramedullary system. In the first of these paths, the impulses travel untransformed, whilst as soon as they enter the secondary path, they will have been recombined into a specific group, associated with all forms of tactile sensibility.

For the impulses associated with pain, heat and cold, a primary and a secondary path coexist for a short extent only within the spinal cord: for those associated with all forms of touch, this double path seems to extend over a considerable length. Finally, the impulses associated with passive position and movement and with tactile discrimination do not, within the limits of the spinal cord, reach the point where they are recombined, but continue uncrossed to pass along the fibres of primary afferent systems in the posterior columns. It is not until they reach the posterior column nuclei (nucleus gracilis and nucleus cuneatus) that they pass from a primary to a secondary sensory system. Here, at last, the impulses associated with tactile discrimination and with passive position and movement undergo recombination, and cross to the opposite side of the nervous system.

Epicritic and protopathic impulses, and those associated with deep sensibility, travel along the fibres of the posterior columns like rubble over a graduated sieve. Stones of small size drop through at once, those that are larger pass on further, and some travel the whole length of the sieve to fall into a heap at the end. So, some impulses cross rapidly, others after a longer course; some do not become sifted off until the cord has terminated above in the nuclei of the posterior columns.

These impulses alone can be completely interrupted by destruction of the posterior columns. We therefore find, that the only definite consequence of destruction of the posterior columns is to produce loss of tactile discrimination (compass test) and of the sense of passive position and movement on the same side as the lesion.

(c) *The Significance of the Delayed Crossing of Sensory Impulses of the Secondary or Intramedullary Level.*

What is the significance of this delayed constitution of the crossed tracts of the secondary or intramedullary level? The impulses which result from all forms of painful stimulation pass to the spinal cord by the protopathic fibres, and by the fibres of the deep system which run with the muscular nerves. The impulses from the skin, arriving by way of the protopathic system, probably become almost at once transformed, and pass into an intramedullary system at the level of their point of entry. It is probable that the fibres of the deep system, carrying impulses produced by painful pressure from the same part of the body, do not enter by the same posterior roots as those carrying the impulses produced by cutaneous painful stimuli. Thus, more than one segment of the cord is required, before all the painful impulses from any one part of the body can be gathered together and recombined.

This is probably the cause of that want of correspondence between the extent of the cutaneous and deep analgesia, produced by the local manifestations of an intramedullary lesion. It also underlies the remarkable condition described on p. 371, where an area of pain and hyperalgesia to the lightest pressure, due to a diseased joint, lay within the limits of total cutaneous analgesia.

Such cases show why a certain extent of the spinal cord must be traversed before the transformed impulses from any part of the body can be gathered up in a path on the opposite side of the spinal cord. Interruption at any point after they have crossed may produce a remote analgesia with a definite upper border, but this border will probably lie several segments below the position of the interrupting lesion.

An even greater extent of the spinal cord must be traversed by the impulses associated with light touch arriving by way of the epicritic fibres, and by those for sensations of pressure conducted along the deep system. For, the extent of the epicritic supply of any one posterior root greatly exceeds that of its protopathic fibres; the overlapping is greater, and the epicritic fibres are less completely segmental in distribution.

The local effects of an intramedullary lesion are produced by interference with the paths of the secondary level before they have crossed the cord, whereas the remote effects are due to interruption of these tracts as they pass up towards the third level after crossing the cord.

Disease of the grey matter as such does not produce loss of sensation, except by interfering with these paths of the secondary intramedullary level as they pass through its substance.

The more nearly segmental the arrangement of a primary sensory system as it enters by the posterior roots, the shorter will be the distance necessary for the complete crossing of the impulses it carries into the spinal cord. Thus impulses for pain and sensations of temperature arising mainly out of highly segmented protopathic impulses have the shortest double path.

(*d*) *The Path of Impulses Subserving the Sense of Passive Position and Movement.*

We have shown that the more nearly a primary sensory system is arranged segmentally as it enters the spinal cord by the posterior roots the more quickly will its impulses cross to the opposite side after recombination.

The fibres which conduct the impulses for passive position and movement are probably arranged on a plan different from that of the remaining sensory segmentation. The greater number start from end-organs in the joints, muscles or tendons of the limbs, and in the leg, chiefly from the foot and ankle. When the sense of passive position and movement is disturbed, the loss of sensation is arranged according to joints.

Thus, we should not expect the crossing of these impulses to occur as rapidly as those subserving thermal and painful sensibility. In fact, we find that complete crossing and recombination does not occur, until after these afferent impulses have reached the posterior column nuclei.

But this delay in crossing and recombination of the impulses subserving the sense of passive position and movement, seems to have another cause. We have investigated those afferent impulses only which reach consciousness; but many afferent impulses pass in by the primary or peripheral systems which never produce sensation.

We wish to emphasise a distinction between the fate of sensory and non-sensory afferent impulses, which has not been insisted upon sufficiently of late years. If a tract is shown to degenerate from below upwards, it probably conducts afferent impulses. These impulses may however never reach consciousness; they may be associated with some higher reflex condition, such as the maintenance of equilibrium, or the tone of muscles. This may be an entirely unconscious process, and sensation may never be evoked, until some disturbance of equilibrium produces impulses which, passing up sensory paths, reach the highest centres concerned with sensation. A disturbance of non-sensory afferent impulses produces an abnormal condition in the organism. This abnormal condition evokes fresh afferent impulses which, passing up sensory paths, causes the organism to become aware of the change that has occurred in a state normally outside consciousness.

Now, the afferent impulses, passing by means of the deep system from tendons and joints, are pre-eminently associated with the higher reflex states, such as equilibrium. Recent work, especially that of Horsley and of Sherrington, has shown that the cerebellum is the afferent centre for these higher reflexes. Any column, therefore, which conducts impulses from the tendons and joints will probably give off collaterals to afferent cerebellar tracts.

One such path, the direct cerebellar tract, lies on the same side as the posterior roots by which the impulses from the deep system enter the spinal cord.

It is therefore probable that, in their passage through the spinal cord, the afferent impulses of deep sensibility, concerned with the position and movement of joints, divide into two groups—those destined after transformation to become the non-sensory afferent impulses of the direct cerebellar tract, and those which continue up the fibres of the primary system in the posterior columns to subserve the sense of passive position and movement. The latter impulses do not become recombined until they reach the nucleus gracilis and nucleus cuneatus; they then cross rapidly to the opposite side like every other sensory impulse.

(e) *The Theory of Intramedullary Specific Receptors.*

All sensory impulses are ultimately recombined, on passing from the peripheral to the intramedullary level. This recombination takes place in the same half of the nervous system as that by which the sensory impulses enter. Impulses from the primary level which have been initiated by painful stimuli of whatever kind, are united into a single group. In the same way, all tactile impulses, whether they arrive by way of the epicritic or deep systems, are gathered up and travel together in the secondary system.

We believe this is due to an arrangement somewhat as follows: each end-organ in the skin is capable of reacting to the mass stimulations of the environment in a specific manner; heat-spots react to certain degrees of heat only, cold-spots to cold or, paradoxically, to heat above 45° C. The end-organs of the deep system react to pressure, whether it be painful or not, but do not respond to stimulation with heat and cold.

When these peculiar impulses reach the spinal cord, they are discharged into the secondary systems, each of which is guarded by specific receptors. These act towards the impulses of the primary sensory level exactly as the end-organs in the skin acted towards the mass-stimuli of the environment. When an impulse, which has originated in the effective stimulation of a heat-spot belonging to the protopathic system, reaches an intramedullary receptor of the secondary system set aside for the impulses of heat, it starts a specific impulse. But the same receptor reacts to the epicritic impulses which are started by stimulation of the skin with temperatures between 34° and 40° C. No reaction, however, occurs if the receptor of the secondary system is exposed to impulses due to any other form of stimulation.

Similarly, the receptors of the secondary system arranged for painful impulses respond to all impulses of this nature, whether they arise from stimulation by a prick, or from excessive pressure.

In the same way, all tactile impulses are gathered up by the receptors of the secondary tactile system, whether they are started by a light touch and arrive by way of epicritic fibres, or by pressure and reach the spinal cord through deep afferent fibres running with muscular nerves.

Thus, we imagine that, at the point where sensory impulses pass from the primary to the secondary level, there is a mechanism capable of responding to one specific sensory impulse, however that impulse may have been originated.

It is as if the gallery of a concert hall were fitted with a series of resonators, each of which was tuned to a certain note. Each resonator would pick up a peculiar tone, whether it was produced by the strings, the brass, or the wood-wind.

(f) Sensory Impulses of the Secondary Level undergo further recombination at the Third Sensory Level.

When sensory impulses pass from the primary or peripheral to the secondary or intramedullary level, they are recombined in such a way that those which have been initiated by painful, thermal or tactile stimuli are brought together into specific groups. Interruption of sensory paths within the spinal cord produces a loss of sensation so nearly specific in character, that it might be thought no further recombination was possible.

Closer examination of the groups of sensory impulses at this level shows that they have still to undergo further sifting; the nature of this change in grouping at the tertiary level will form the theme of a further communication. It must be remembered, that intramedullary tactile impulses are still closely associated with those of tactile localisation, and no case has come under our notice where the patient was unable to name the spot touched, unless at the same time tactile sensibility was distinctly diminished. This is a relic of the close relation of sensibility to light touch with cutaneous localisation, and of sensibility to pressure with the localisation of deep touch. Finally, at the tertiary level, all the impulses subserving localisation are brought together, and the impulses for tactile localisation become separated from those for contact sensibility.

Moreover, at the second or intramedullary level, specific sensory impulses carry with them the factors which determine the feeling-tone of the sensation they ultimately subserve. When a strong interrupted current is applied to the foot, the patient cries out with pain and withdraws the leg. Suppose, however, that the lower extremity is totally insensitive to painful stimulation of all kinds, in consequence of an intramedullary lesion, the current, even when of excessive strength, cannot cause pain. But so long as tactile sensibility remains perfect, he will complain bitterly of the discomfort caused by this form of stimulation.

Careful experiments with G. G. (No. 3, p. 412), and W. M. (No. 5, p. 420), both of whom were unusually trustworthy and willing patients, showed that the movement of withdrawal seemed to be almost as violent when a current of known strength was applied to the analgesic as to the normal leg. G. G. said the sensation produced was a "kind of exaggerated tickling more unpleasant than pain." Both these patients were firm in their assertions that the sensation was not painful; and yet, an observer watching their behaviour would suppose they were undergoing intolerable pain. This reaction was not evoked on the analgesic side by a purely painful stimulus such as the prick of a pin.

Evidently, stimulation with a strong interrupted current normally causes pain, which rising to intolerable limits obscures all other sensations. But, if the painful impulses are interrupted by an intramedullary lesion, the tactile side of this stimulus is revealed, and, when the current is strengthened, can produce a sensation painless, but intensely disagreeable.

Thus, at the second, or intramedullary level, even the impulses of tactile sensibility can subserve a discomforting sensation.

(*g*) *Conclusion.*

In conclusion, we believe that the spinal cord is the seat of the transmutation of most of the impulses of the peripheral into those of the secondary level of the afferent nervous system.

This transmutation and recombination takes place on the same side as that by which the impulses enter the spinal cord. The secondary paths for sensory impulses then cross with greater or less rapidity, so that ultimately all except those subserving the sense of passive position and movement and tactile discrimination have passed to the opposite side within the limits of the spinal cord. Even these sensory impulses cross after reaching the nuclei of the posterior columns.

At the same time, within the spinal cord afferent impulses become separated into sensory and non-sensory. Of the latter, many pass up in the secondary system of the direct cerebellar tract to reach the cerebellum.

Thus, the mechanisms of the secondary or intramedullary level are concerned with the separation of non-sensory from sensory afferent impulses, and with the recombination and transmutation of sensory impulses into specific groups.

SHORT ACCOUNT OF SOME ILLUSTRATIVE CASES

Case 1.—Frederick C.

He was suddenly attacked with weakness of the legs and left arm, December 13, 1903.

On January 4, 1904, he showed weakness of left arm and disturbed sensibility over the right half of the body and right leg.

Seen by us August, 1905. Well compensated mitral regurgitation.

Wasting of small muscles of left hand.

Knee-jerks brisk, no ankle clonus, left plantar reflex gave a flexor response.

Total insensibility to tactile, painful and thermal stimuli was present over the right leg and right half of the trunk (*Fig.* 111).

Frederick C., aged 37, a coal porter, went to bed perfectly well on the night of December 13, 1903. When he tried to get out of bed at six o'clock next morning, he found that he could not use his legs. He fell to the ground and had to be helped back to bed. The same afternoon he discovered that his left arm was useless. He was nursed at home for a fortnight, and the weakness of the legs disappeared; but he was still unable to use his left arm. On January 4, 1904, he was admitted as an in-patient to the National Hospital, Queen Square, where he remained for five and a half weeks. His condition was then as follows: "There was weakness of the left arm and loss of sensation over the right leg and the right side of the trunk; the condition was one of complete analgesia and thermo-anæsthesia, with relative loss of sensibility to touch over this half of the body." [1]

He improved greatly whilst in the hospital, and returned to work on the Tuesday after Easter, 1904. The weakness of his left arm had disappeared to such an extent, that he was able to carry nine tons of coal on the first day he resumed work. Soon, however, he began to notice that

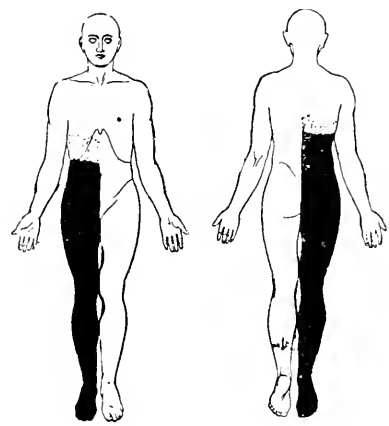

Fig. 111.

To show the loss of sensation to all forms of tactile, painful and thermal stimuli in Case 1. The frontal border was not sharply defined, but merged gradually into parts of normal sensibility.

sensation was lost in the right leg. Pieces of coal falling upon it caused him no pain, and he was often unaware that he had been struck, until he saw bruises on the leg at night. Further, he found that the leg was insensitive to pinching. He did not trouble himself about this loss of sensation, but on August 13, 1905, he began to have pains in his joints, and was admitted to the London Hospital, on August 16, with an attack of acute rheumatism.

When he was 20 years old, and again at the age of 31, he had had attacks of rheumatic fever, and, for the last twelve months, had been a little short of breath on exertion. He denied syphilis and gonorrhœa. He married at 21 years old, had one child, aged 2 years, who is quite healthy. His wife had previously had three miscarriages.

His work was heavy, as he had not only to drive the van, but also to load and unload the coals. He drank about ten pints of beer daily, but no spirits, and smoked about an ounce of shag a day.

There was no family history of nervous or rheumatic disease. He was liable to urticaria; wheals, and factitious urticaria could be produced by pricking or scratching the skin all over the body, both over anæsthetic and over normal parts.

The day after admission, his temperature was 102° F. [38·8° C.], and he had a good deal of pain in the left knee, the left ankle and in both shoulders. He also experienced an uncomfortable

[1] For this note we are indebted to the Registrar of the National Hospital, Queen Square.

sensation in the right knee, and he objected to flexion of the joint, but stated that the sensation was not at all painful; it resembled an itching and was very disagreeable.

The temperature and pain rapidly subsided under the influence of sodium salicylate.

The heart was somewhat enlarged and showed the signs of mitral regurgitation of moderate severity. Compensation was well maintained.

Since this date, the patient has been under frequent observation, and in the following account we shall summarise his present condition.

He is a tall, spare, but very muscular and powerful man, intelligent and answering readily to the various forms of stimulation. His speech is normal, and he has never suffered from fits.

Motion.—The grasp of the left hand was a little weaker than that of the right, but this difference was much increased during the attack of rheumatism, when the dynamometer readings were :—

Right grasp 30 kilograms. Left grasp 7 kilograms.

He was examined on many occasions after the rheumatism had passed away, and the average results were as follows :—

Right grasp 30 kilograms. Left grasp 23 kilograms.

There was slight but distinct wasting of the first dorsal interosseous muscle and of the muscles of the thenar eminence of the left hand. All the movements of the hands, forearms and arms could be readily performed, and no wasting could be detected in the remaining muscles of either arm. The gait was normal. He did not drag either leg, and it could not be said that one leg was held more stiffly than the other. He could stand steadily with both eyes closed, and even balance on either foot with equal ease. There was no wasting or tremor in either leg. He could approximate his great toes with his eyes closed, even when he had not previously seen the position of his limbs.

The electrical reactions of the muscles in both arms and legs were normal.

Reflexes.—The knee-jerks were brisk, normal and equal, and the plantar reflex, although difficult to obtain, seemed to give a normal response on both sides.

Sensation.—F. C. stated that the right leg always seemed to him to be hot, as if it were before a blazing fire. When he placed the left leg upon it, or when he touched the right leg with either hand, the right leg always seemed to be hotter than the left.

Pain.—(*a*) Stimulation by pricking with the point of a pin elicited no reply over the whole of the right leg and over the right side of the body as far as the level of the xiphisternum. The upper border was a soft one and shaded gradually into parts of normal sensibility. The anæsthesia was limited exactly to the middle line and included the skin covering the right half of the penis and the right side of the scrotum.

No pain was produced over the right leg by pressure which would have been unendurable over the left leg. The right side of the body as far up as the level of the cutaneous analgesia was also insensitive to the pain of deep pressure. Not only was the pain of deep pressure lost, but the patient also failed entirely to recognise any increase in pressure even when 15 kilograms were used. The algometer records are given below.

ALGOMETER

	Right.	*Left.*
Sole	15 (no pain)	5 (pain).
Shin	13 (no pain)	2·5 (pain).
Outer side of knee	20 (no pain)	4·5 (pain).
Front of thigh	15 (no pain)	5 (pain).
Outer surface of the ant. sup. iliac spine	15 (no pain)	3·5 (pain).
Lower ribs within the limit of the analgesia	10 (no pain)	1·5 (pain).
Sterno-clavicular joint	3 (pain)	3 (pain).
Temple	2 (pain)	2 (pain).
Elbow	4·5 (pain)	4·5 (pain).

He was insensitive to the interrupted current in all its forms over the whole of the analgesic half of the body and over the right leg. He could appreciate neither the pain nor the vibration of the current. But, as soon as the muscles were contracted so as to produce movement of a joint he said, " You are doing something to me." This occurred every time that any considerable movement of a muscle was induced.

(*b*) *Thermal stimuli.*—He was insensitive to stimulation by water at 50° C., or by ice, over the whole of the right leg and right half of the body so far as the level of the xiphisternum. The upper level of the thermo-anæsthesia was not sharply defined, and there was an area of skin extending upwards for about an inch and a half over which sensibility to temperature was diminished. The thermo-anæsthesia was limited exactly by the middle line. Over this area stimulation with the intermediate degrees of temperature likewise failed to evoke any response.

(*c*) *Tactile Sensibility.*—There was profound loss of sensibility to cotton wool over the whole of the right leg and right half of the body, the upper limit extending to nearly the same level as that of the analgesia and thermo-anæsthesia.

On testing the two legs with von Frey's hairs, it was found that No. 8 (23 grm. mm.[2]) was everywhere promptly appreciated and accurately localised over the whole of the left leg. No contact with any of these hairs could be appreciated anywhere over the right leg as far as the upper limit of the anæsthesia to stimulation with cotton wool.

Pressure steadily applied evoked no response over the whole of the right leg and of the lower half of the trunk on the right side. Over the right thigh and over the lower part of the abdomen on the right side, however, if the instrument by which pressure was made was moved sufficiently violently to displace the muscles, the patient stated that he felt a slight sensation. If the whole of the skin and subcutaneous tissues were picked up between the finger and thumb and violently pinched, he never on any occasion gave any response. The sensation experienced by the patient seemed to depend on the movement of the muscles.

(*d*) *Tactile localisation.*—Localisation of touch was perfect over the whole of the left leg, whether the patient was asked to name the point touched with his eyes closed, or whether he was allowed to grope for the point of contact. The maximum final error was in all cases under 2 cm.

(*e*) *Compasses.*—Over the right leg it was impossible to apply this test, owing to the fact that the patient did not respond at all when touched with the compasses, in consequence of the loss of tactile sensibility.

Over the left leg the results were as follows :—

Outer side of left leg (longitudinal)	10 cm.	1	II. I. II. IIII.
		2	II. II. IXI. XIX.
	12 cm.	1	IIII. I. I. II. II.
		2	IIII. I. III. II.

The answers were given promptly and with decision. On the right half of the abdomen a similar difficulty was encountered, since the patient did not respond at all over this area when touched. Over the left half of the abdomen the result was as follows :—

Left side of Abdomen (longitudinal)	6 cm.	1	III. II. III. II.
		2	II. III. II. III.

On the hands compass sensibility was normal.

(*f*) *Sense of passive position and movement.*—Although there was profound loss of cutaneous and of tactile sensibility in the right leg, the patient was able to recognise any position into which his limb was passively placed. The results obtained on passive movement of the great toe were identical on the two sides.

There is a little stiffening of the great toe joint which prevents the answers being as good when the toe is extended as when it is flexed.

All movements at the ankles and knees were appreciated with equal accuracy.

Although the patient could not appreciate firm, steadily applied pressure, he experienced a sensation if his muscles were seized and moved about. If the muscles were made to contract by an electric current, he appreciated the fact that they were being moved. Moreover, he was able to co-ordinate the movements of the muscles of the right leg quite as well as those of the opposite sound limb.

(*g*) *Recognition of a point and sense of size.*—As might have been expected from the total loss of painful and tactile sensibility, the patient was quite unable to distinguish the head from the point of a pin, or to discriminate between discs of various sizes when applied to the skin of the right leg.

(*h*) *Tuning fork.*—All sensation of vibration was lost over the right leg, the right iliac crest, and the right half of the abdomen. The vibrations were, however, appreciated over the lower ribs and the costal margin on the right side.

Cranial nerves.—The pupils were equal and reacted well to light and accommodation. No cranial nerve was affected.

Sphincters.—There was no abnormality in micturition or defæcation.

Spine.—No deformity.

Case 2.—Charles B.

Fracture of the neural arch of the third cervical vertebra from a fall on to the head.

Loss of sensation to pain and temperature over the left half of the body. (Fig. 112.)

Sensation to all forms of touch undisturbed.

Sense of passive position and movement, tactile discrimination and tactile localisation perfect.

Laminectomy, June 25, 1905.

After the operation the condition of sensation was unaltered, except that all sense of passive position and movement was lost in the right arm and leg.

On April 11, 1904, Charles B., a man of 59, was thrown out of a dog-cart on to his head. He thinks he lost consciousness, but is certain that such loss was momentary only, for he remembers lying in the road, watching all that was going on around him, completely paralysed down the right side. He was carried to bed and was able to move his toes upon the tenth day after the accident. Power gradually returned to the right leg, and in two months the right arm was so far recovered that he was able to write.

From the moment of the accident he has been insensitive to heat and cold over the left half of the body. From the left hip downwards he has suffered from a burning sensation, which seems to lie deep below the surface and is always worse after a good meal. He has also suffered greatly from cramp in the right leg.

Condition in May, 1905.

He was a spare, well-built man, looking fully his age. His vessels were not abnormally thickened, and the heart and lungs showed no disease.

Motion.—He walked like a man with hemiplegia, lifting the right hip, and swinging the right foot, so that the toes cleared the ground. He could stand steadily with his eyes closed even when his feet were placed together. As he lay on a couch, there was very little loss of power in the right foot or right knee, when the movements were made against resistance. He could dorsiflex the right foot at the ankle, but the movement was somewhat slower than on the opposite side.

The grasp of the right hand was decidedly weaker than that of the left; all movements at the right wrist and elbow could be performed, though they were less strong than on the opposite side. He could touch his nose with the forefinger of either hand, even when the eyes were closed, and showed no signs of ataxy. The supraspinatus, the infraspinatus and deltoid muscles were slightly wasted; but it must be remembered that the right shoulder joint was fixed by adhesions. The action of the deltoid was weak, but the biceps and supinator longus contracted strongly;

none of the small muscles of the hand were wasted. All the muscles reacted perfectly to the interrupted current, even those that appeared to be wasted.

Reflexes.—The right knee-jerk was greatly exaggerated. Ankle clonus was easily obtained from the right foot, and the right toe gave a characteristic extensor response on stimulation of the sole. The right wrist-jerk was considerably in excess of the left. The left knee-jerk was diminished. No ankle clonus could be obtained on this side, and the plantar reflex gave a definite flexor response.

Sensation.—He complained of a sensation of burning in the buttock down the left leg, principally on its outer side. A similar sensation troubled him in the left arm, mainly situated in the back of the hand.

Over the left half of the body, below the line marked in Fig. 112, all forms of painful stimulation and all degrees of temperature failed to produce any sensation. The border of this abnormal area seemed to be well-defined on the arm, but towards the periphery of the limb faded into parts of normal sensibility.

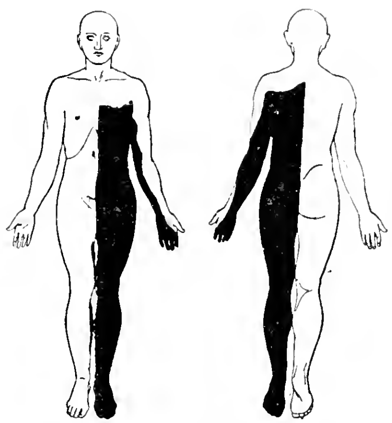

Fig. 112.

To show the loss of sensation to painful and thermal stimuli in Case 2.

The lightest touch with cotton wool produced a sensation in every part of the body, and to this stimulus there was no difference between its two halves. Pressure was everywhere appreciated equally.

Cutaneous localisation was excellent to both light touch and deep pressure, and no difference could be discovered in the accuracy of localisation on the two sides of the body.

He was able to recognise the position into which his limbs had been moved passively, and his answers were quick and accurate, even for movements of the great toes.

The vibrations of the tuning fork were appreciated everywhere.

Over the left half of the body and left leg, the strongest interrupted current produced no pain; but he said that a strong current gave him exactly the same sensation as that produced by holding a hot plate.

Sphincters.—Micturition and defæcation had never been affected in any way. At first, he was impotent without the power of erection, but in May had regained his power, and emission occurred, though more slowly than usual.

Cranial nerves.—The pupils were equal and reacted normally, dilating well to shade. The optic disc showed no hyperæmia and the fundus was normal. The face and tongue were not affected.

Spine.—The spine of the second cervical vertebræ had sunk in consequence of collapse of the third cervical, and a radiograph showed this condition distinctly.

Subsequent Progress.

On June 6, 1905, he was seen by Sir Victor Horsley, who admitted him to the National Hospital, Queen Square.

On June 25 the laminæ of the second, third, fourth and fifth cervical vertebræ were freely exposed; the third neural arch was found to have been fractured and pushed downwards. There was, however, no evidence of pressure on the spinal cord. The third arch was removed and the probe was passed both upwards and downwards, without the discovery of further fracture or pressure on the cord. But, in order to make certain, the laminæ of the fourth vertebræ were cut through. The cord was seen to be pulsating well and there was no sign of hæmorrhage within the membranes. The wound was then closed. The patient stood the operation unusually well and showed little evidence of shock.

He recovered perfectly from the operation and the wound healed by first intention. For the first fortnight he was completely free from pain or abnormal sensations, but, at the end of that time, the burning in the left side returned worse than before. At the same time he noticed that the right arm seemed stiff and cramped.

In October, 1905, he was again seen by one of us. He complained that "his right leg felt exactly as if it was a cork leg." and that all the muscles on this side "felt tight." He believed that he had lost power both in the right arm and leg since the operation.

Motion.—He still walked with a hemiplegic gait, and there was no obvious increase in the loss of muscular power. But all movements in the right leg and right arm had become more difficult in consequence of definite ataxy. He could no longer touch the tip of his nose with his right forefinger, nor bring the two forefingers together when the eyes were closed. He could not stand on his right foot with any certainty, and on closing his eyes fell at once.

There was no further wasting beyond that noticed in May.

Sensation.—Over the left half of the body and left leg all sensation of pain, of heat, and of cold was abolished as before (Fig. 112). Light touch and pressure were perfectly appreciated and localised with certainty. The sense of passive position and movement was excellent, and the compass test gave normal results; the vibration of the tuning fork could be everywhere recognised.

Over the right leg, the right half of the body and the right arm, cutaneous painful stimuli were normally appreciated. Sensations of heat and cold were perfect. Sensibility to light touch and pressure was equal to that on the opposite side; but a remarkable change had occurred in the pain produced by increasing this stimulus. All down the right side and in the right leg, pressure with the head of a pin produced a painful sensation. There was no tenderness when the point was dragged gently across the skin, or when it was picked up between the fingers. But, as soon as the head of a pin was lightly pressed anywhere over the right half of the body, he complained of pain. Deep tenderness was certainly present.

Moreover, he was no longer conscious of the position into which his thumb, index and middle fingers of his right hand were placed passively. He also had considerable difficulty in recognising the position of his wrist. No passive movement of the toes of the right foot could be recognised, and his answers were frequently inaccurate after movements of the right ankle. None of the other physical signs were in any way altered.

Shortly afterwards he left England, and we have had no further opportunity of examining him.

Case 3.—Grace G.

Sudden loss of power in the right leg on February 18, 1898, *whilst sleeping.*

The condition of motion and sensation has shown no material change since August, 1898, *when she first came under our observation.*

The right leg is spastic and paretic. The right knee-jerk is much exaggerated, ankle clonus is obtained on the right side and the plantar reflex gives an extensor response. On the left side the reflexes are normal, no ankle clonus is present and the plantar reflex gives a flexor response.

Complete loss of sensation to pain and temperature over the left lower extremity (*Fig.* 113).

All forms of tactile sensibility are perfect.

Sense of passive position and movement and tactile discrimination (compass test) are disturbed n the right foot.

No other abnormal signs are present in the nervous system.

Grace G., a married woman, aged 39, lay down to sleep as usual at 2 p.m. on the afternoon of February 18, 1898; she was then in perfect health. On rising an hour later, she was seized with pains round the body at the level of the umbilicus. She cried out for help and was found on her feet, holding the edge of the bed. She did not fall, but, when helped into bed, discovered she had lost all power in the right leg. For the first seven days she suffered with pain down the outer side of the right leg, which remained absolutely paralysed for three weeks. At no time was there any loss of power in the left leg.

From the first, she was able to recognise when the paralysed right leg was pricked, but it was not until four weeks after the onset that she discovered, on taking a bath, she was unable to discriminate heat from cold when applied to the left leg. The paralysed limb has remained throughout sensitive to these stimuli.

The complete paralysis of the right leg passed away gradually within the first two months; the leg became stiff and has remained in the same condition until the present time. For eight years the sensory condition of the left leg has remained unaltered.

The date of the attack coincided with the first day of a normal menstrual period. She is usually regular at intervals of twenty-eight days; the menstrual flow lasts for five days and is not usually profuse. Occasionally, however, since her marriage, she has gone two to three weeks over her normal time, and then the flow has been more profuse than usual. Five months after her marriage, she had an attack of what was thought to be peritonitis; she suffered much pain and was in bed for three weeks. During this time there was a constant discharge of blood from the vagina. This was possibly a miscarriage; but at no time has she ever been certain that she was pregnant.

There is no history of venereal disease and nothing pointing to the probability of infection.

She first came under the observation of one of us in August, 1898, five months after the onset of the paralysis. During the last eight years, she has been repeatedly examined; and although we have amplified the scope of our observations, her condition has remained unchanged. The observations made in 1898 are in complete accord with those of the present time.

Present Condition.

She is a tall, well-built woman, of unusual intelligence, not anæmic nor wasted, and, except for the difficulty in walking, she says she is in perfect health.

Motion.—She walks with a stick, dragging the right leg, which she holds stiffly. She says she dare not let the right knee go slack, or she would fall. This leg is rigid and spastic; but the rigidity can be overcome by the exercise of steady pressure. At night she suffers from involuntary "jumping" of this leg. The right foot is in a position of slight pes cavus, due apparently to the extreme extensor response to all stimulation of the sole.

It is difficult to test the amount of voluntary power in this leg on account of its spasticity. But both dorsiflexion and plantar extension are feebly performed at the ankle-joint and flexion of the knee and hip is weak. Extension of the knee and hip can be more perfectly carried out, though less strongly, than with the left leg.

There is no profound wasting of either leg, but the right calf is one inch (2·5 cm.) smaller than the left at its largest circumference.

The motor power of the left leg is unaltered, and the upper extremities are entirely unaffected.

The electrical reactions, even of the right leg, are everywhere normal.

Reflexes.—The right knee-jerk is greatly exaggerated and ankle clonus is easily obtained. The right great toe gives an extreme extensor response when the sole of the foot is stimulated.

On the left side the knee-jerk is brisk, but there is no ankle clonus. The great toe either does not respond or occasionally gives a faint flexor response.

Sensation.—She complains that the right leg nearly always seems to her to be cold; but the left leg is never hot nor is it cold even in the winter. When she touches the right leg it always appears to be colder than the left. But, apart from these symptoms, she is not troubled by any pain or other abnormal sensation.

(*a*) *Loss of Painful Sensibility.*—The prick of a pin caused no pain over the whole of the left leg and thigh as high as the level of the iliac crest. The boundary between sensitive and insensitive parts was clearly defined, following the line marked upon Fig. 113. So sharp was this border that it made little or no difference whether the observations were made from the direction of normal to abnormal skin or vice versa.

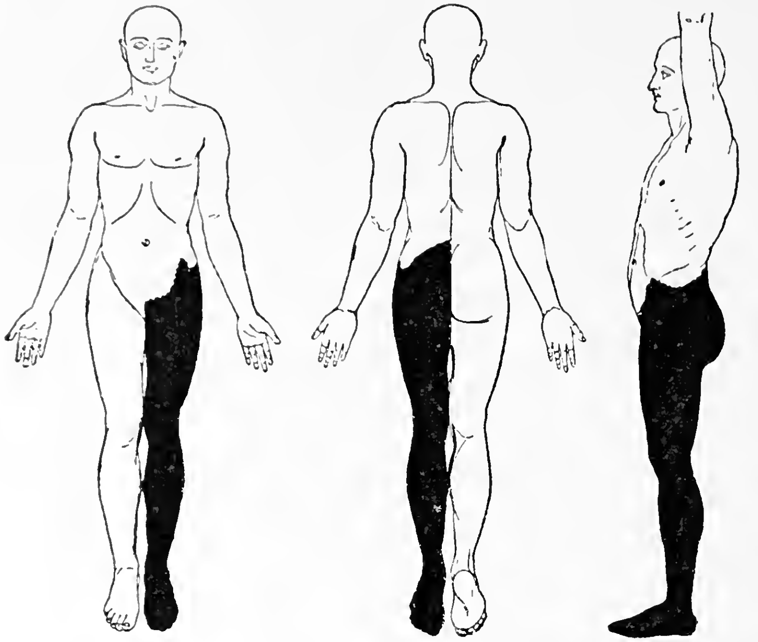

Fig. 113.

To show the loss of sensibility to painful and thermal stimulation in Case 3.
The border between the normal parts and those which were completely insensitive was unusually well defined, corresponding to the caudal border of the eleventh thoracic segment.

The algometer gave the following readings, showing that the parts insensitive to a prick were also insensitive to the pain of pressure.

	Right [*motor loss*].	*Left* [*analgesic and thermo-anæsthetic*].
Sterno-clavicular joint	3 (pain) ..	3 (pain).
Palms	4 (pain) ..	4 (pain).
Lower ribs	2 (pain) ..	2·5 (pain).
Outer aspect of ileum close to ant. sup. spine	3·5 (pain) ..	10 (pain).
Front of thigh	4 (pain) ..	14 (no pain).
Inner aspect of knee	5 (pain) ..	15 (no pain).
Shin	2 (pain) ..	11 (slightly uncomfortable).
Sole of foot	1·6 (pain) ..	12 [1] (uncomfortable).

[1] She complains of an uncomfortable tickling when the algometer is pressed on to the sole of the left foot, which greatly disturbs the readings. Sometimes this condition makes it impossible to test the sole of the left foot.

The loss of sensation to the painful interrupted current corresponded exactly to the area insensitive to prick. But she complains that when the current is applied to the left leg, which is completely analgesic, an exaggerated tickling sensation is produced. This is disagreeable and is associated with rapid withdrawal of the leg.

(*b*) *Heat and cold.*—Over the whole of the area on the left leg, shown in Fig. 113, she was entirely insensitive to all degrees of temperature. Over the right leg all temperature stimuli were correctly appreciated.

(*c*) *Tactile sensibility.*—Stimulation with cotton wool produced a normal sensation, which was in no way different in the two legs. Pressure was everywhere correctly recognised, and even over parts where the algometer produced no pain the increasing pressure was distinctly appreciated. When tested with von Frey's hairs, no difference could be discovered between the two legs, but she was somewhat insensitive to this form of stimulation over both lower extremities. No. 5 [21 grm./mm.^{2}] was as frequently appreciated over the left as over the right leg; but over both legs she not infrequently failed to recognise this stimulus.

(*e*) *Recognition of a point and appreciation of differences in size.*—Over the whole of the analgesic leg she was able to tell the head from the point of a pin; in twenty stimulations to the sole of each foot, ten of which were made with the head and ten with the point, she did not give a single incorrect answer. Her power of recognising the relative size of objects was tested with three metal cylinders, 2 cm., ·75 cm., and ·2 cm. in diameter. In spite of the most varying combinations, her answers were always correct over both legs.

(*f*) *Tactile localisation.*—Light touches and deep pressure were localised with remarkable accuracy, whatever method we adopted. Sometimes she was asked to name the point touched, at others she was allowed to point to the spot with a cardboard rod. At other times, we adopted the method of touching the skin through a hole in a piece of paper, held a short distance above the skin, and she attempted to mark the spot touched with a soft pencil. At no time were we able to find the least difference between the two legs, and, when allowed to point, her accuracy and quickness was remarkable, although her eyes remained closed.

(*g*) *Recognition of passive position.*—At every joint in the *left* lower extremity (analgesic and thermo-anæsthetic) her answers were remarkably quick and accurate. The position into which the *right* knee and ankle had been placed was also well recognised, but she was greatly at fault with regard to the position of the great toe on the right side. A comparison of the records of twenty stimuli in each foot, arranged graphically, shows this difference in a very striking manner, even the answers that were correct in the right foot were more slowly given than on the left side.

Left (analgesic and thermo-anæsthetic).

Great Toe	Flexion	I. III. II. II. II.
	Extension	II. II. I. III. II.

Right (spastic).

Great Toe	Flexion	II. X. IIIX. III.
	Extension	XX. I. XI. XXIXX.

Left.

Ankle	Flexion	I. III. I. III. II.
	Extension	II. III. I. IIII.

Right.

Ankle	Flexion	III. I. I. III. II.
	Extension	I. III. II. III. I.

(*h*) *Compass test.*—No difference between the two legs could be discovered until the foot was reached. Even over the feet the records, as she lay in bed, were almost equally good on the two sides.

	Left (analgesic and thermo-anæsthetic).			Right (spastic).		
Sole of foot . .	2 cm.	1	7 R. 3 W.	2 cm.	1	9 R. 1 W.
		2	10 R.		2	2 R. 8 W.
	2·5 cm.	1	9 R. 1 W.	2·5 cm.	1	8 R. 2 W.
		2	10 R.		2	8 R. 2 W.
	3 cm.	1	10 R.	3 cm.	1	10 R.
		2	10 R.		2	10 R.
Dorsum of foot	2·5 cm.	1	7 R. 3 W.	2·5 cm.	1	7 R. 3 W.
		2	10 R.		2	5 R. 5 W.
	3 cm.	1	7 R. 3 W.	3 cm.	1	7 R. 3 W.
		2	10 R.		2	9 R. 1 W.

Thus after a rest of two hours in bed there was no material difference between the formulæ .3 cm.

She then rose and walked 150 metres up and down a corridor. After returning to bed the difference between the two feet was distinct even at 4 cm.

	Left.			Right.		
	4 cm.	1	10 R.	4 cm.	1	6 R. 4 W.
		2	10 R.		2	6 R. 4 W.

Thus, the only interference with her power of discriminating two points occurred over the right foot, *i. e.* on the side of the motor paralysis and on the side opposed to the analgesia.

(*i*) *Tuning fork.*—The vibrations of a tuning fork were everywhere recognised, and there was no difference between the two legs.

Sphincters.—She has no trouble in holding or passing her urine or fæces.

Cranial nerves.—The pupils react well: disc and fundus are normal. Hearing, smell and taste are perfect.

No other part of the nervous system is in any way affected.

There is no disease of the heart or lungs. The pulse is good, and the vessels show no abnormality.

Case 4.—Albert H.

Fell into the hold of a ship on December 3, 1901.

Is said at first to have been able to move his right leg only, but when first seen by us in February, 1902, the loss of power was confined to the left arm and leg.

He is a characteristic instance of Brown-Séquard paralysis.

Right.	*Left.*
No motor disturbance.	*Paresis and wasting of left hand.*
Knee-jerks normal.	*Paralysis of triceps.*
No ankle clonus.	*Spasticity of left leg.*
Plantar reflex flexor in type.	*Knee-jerks greatly exaggerated.*
Loss of sensation to painful and thermal stimuli over an area shown in Fig. 114.	*Plantar reflex extensor in type.*
Diminution in tactile sensibility over the right foot, with coincident uncertainty in answers to the compass test.	*Sensation perfect.*
All other forms of sensation perfect.	

Albert H., aged 25, a boiler-maker, fell into the hold of a ship on December 3, 1901.

He went below to screw up some frames but did not trouble to take a light. Expecting to step on to the lower deck, he walked into space, and was picked up head downwards unconscious in the hold.

He was taken to Poplar Hospital, where he lay unconscious until the evening.

When he woke he found he could move the right leg only.

In about three weeks he began to recover movement in the right arm. Gradually power came back in the left leg, so that by the end of January, 1902, he could walk; and when seen by us in February, 1902, he said power was returning to his left arm.

It is impossible to make any statement with regard to the condition of sensation after the accident, as he confuses sensory with motor paralysis. The dominant facts in his mind concern the paralysis, first of both arms and the left leg, later of the left arm and left leg, and finally the condition which he calls paralysis of the left arm only.

When he first came under our notice in February, 1902, two months after the accident, his condition was as follows:—

He walked like a hemiplegic, dragging the left foot. He could not grasp with the left hand, and the movements of the left wrist were weak. The intrinsic muscles of the left hand were wasted. Dorsiflexion and plantar extension of the left ankle were feeble, and the left leg was spastic

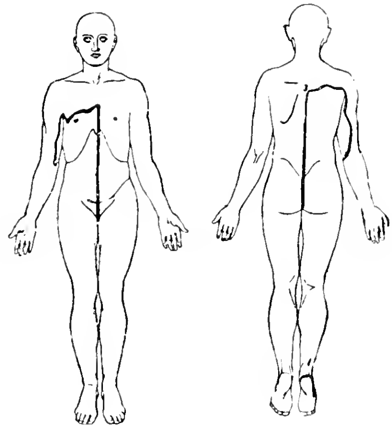

Fig. 114.

To show the border at which sensation to pain, heat and cold ceased in Case 4.

The left knee-jerk was greatly exaggerated; ankle clonus was obtained on the left side, and the left plantar reflex gave an extensor response. The wrist-jerk and elbow-jerk were exaggerated on the left side. All the reflexes in the right arm and leg were normal.

The sphincters were not affected, and there was no alteration in the reaction of the pupils to light or to shade. The left palpebral fissure was smaller and the left ear colder than on the right side.

The whole of the right half of the body below the line on Fig. 114 was insensitive to pain, heat, and cold; as the condition of sensation has changed little in the last five years, we shall give the further details later.

By July, 1902, he had considerably improved, and could walk without a stick.

Motor power steadily increased until the end of 1902. Since that time his condition has remained stationary. He now keeps a small sweet-shop, and feels in perfect health except for the difficulty in walking.

During the last five years he has been examined repeatedly, and the following account, based on his condition during the latter half of 1906, includes some of the observations made throughout the previous period.

Present Condition.

He is a short, somewhat youthful looking man of moderate intelligence. He has never been intemperate, and does not now take any alcohol.

Except for the defects in the nervous system he shows no symptoms or signs of disease.

Motion.—He walks like a man with hemiplegia, sweeping the left leg outwards to enable the left foot to clear the ground. At the same time the left leg is kept rigidly extended. He can stand steadily with the eyes open or shut, but has difficulty in standing on either leg alone.

The left leg is distinctly spastic. He can slightly extend the toes but cannot dorsiflex the ankle; flexion of the toes and plantar extension of the ankle are slowly and feebly performed against resistance. If given time he can flex and extend the knee; but the movement is feeble against resistance. Movements at the hip are better performed, and, though slow, are powerful.

The left leg is not wasted.

The left hand is held with the wrist a little flexed and the fingers doubled into the palm. The fingers cannot be extended unless the wrist is fully flexed, in consequence of the shortening of the flexor muscles. He seems to have lost the power of straightening the fingers voluntarily, but can grasp feebly. He can extend the wrist well until this movement is checked by the shortening of the flexor muscles, and can pronate and supinate the forearm.

The triceps acts extremely badly, if at all; when the arm is flexed and the patient is told to extend it he moves the whole arm until it is jerked into the extended position. The biceps, deltoid and supinator longus contract well, and the muscles of the left shoulder are unaffected.

The interrosseous spaces of the left hand are hollowed and all its small muscles are somewhat wasted. The left forearm is 1 cm. and the left arm 1·5 cm. smaller in circumference than the right.

All the muscles of the left upper extremity, with the exception of the triceps, react normally to electrical stimulation. The triceps reacts badly, if at all, to the strongest interrupted current, and, on closing the constant current, contracts more easily to the anode than to the kathode.

On the right half of the body every motor function has been perfectly normal since he first came under observation, three months after the accident.

Reflexes.—The left knee-jerk is greatly increased; ankle clonus is obtained on the left side, and the plantar reflex gives an extensor response.

On the right side the knee-jerk is normal, no ankle clonus can be obtained and the plantar reflex is of the flexor type.

Wrist and elbow jerks are equal on the two sides.

Sensation.—He complains of no abnormal sensation and says that if he had not been tested he would not have known that sensation was in any way defective.

(*a*) *Sensibility to painful stimuli.*—At the line marked on Fig. 114 a profound change occurs in his sensibility to painful cutaneous stimuli, such as a prick or the painful interrupted current. All sensibility to pain is lost as soon as this line is passed, when travelling from normal to abnormal parts: at the same time, when passing from the analgesic area he becomes sensitive at this line. Throughout the five years he has been under observation this border has always been well defined, and Fig. 114 exactly corresponds with a photograph taken in November, 1902.

He is insensitive to the pain of deep pressure over the right half of the body as high as the lower ribs, and the following readings in kilograms were obtained by means of the pressure algometer.

	Right.	*Left.*
Sole	15 (no pain)	4 (pain).
Internal malleolus	12 (no pain)	3·5 (pain).
Shin	14 (no pain)	3·5 (pain).
Inner aspect of knee	14 (no pain)	5 (pain).
Front of thigh	13 (no pain)	5 (pain).
Outer part of ant. sup. spine of ilium	12 (no pain)	3 (pain).
Lower ribs	4 (pain)	2 (pain).
Palm	7 (pain)	6 (pain).
Shoulder	4 (pain)	4 (pain).
Clavicle	2 (pain)	2 (pain).
Mastoid	2 (pain)	2 (pain).
Temple	1·5 (pain)	1·5 (pain).

He was able to recognise the gradually increasing pressure everywhere over the analgesic area, although it caused no pain.

(*b*) *Sensibility to thermal stimuli.*—Throughout the five years, he has been entirely insensitive to all thermal stimuli over the right leg and right half of the body below the line on Fig. 114.

He has been carefully tested on many occasions with temperatures of 0° C., 20° C., 30° C., 40° C., and 50° C., and found to be insensitive to all degrees. The patch on the inner aspect of the right arm can be perfectly defined with thermal stimuli.

(*c*) *Tactile sensibility.*—Touches with cotton wool can be appreciated everywhere; but over the sole of the right foot his answers are less certain to this stimulus than over the opposite sole. This difference becomes measurable when he is tested with von Frey's hairs. For over the left sole and left shin he recognised No. 8 (23 grm./mm.^{2}) with ease, whilst over similar parts on the right lower extremity this stimulus produced no sensation. This diminished tactile sensibility appears in the defective compass records obtained over the right sole.

Sensibility to deep pressure was nowhere appreciably different on the two sides of the body.

(*d*) *Compass test.*—The records obtained to this test were everywhere perfect and equal on the two sides except those obtained from the right sole. Here his answers were slower and somewhat less perfect, and he recognises that this is due to a diminution of tactile sensibility. He says he cannot "feel the touch so well" over the right foot. We believe that this is an instance where the compass records are disturbed by defective tactile sensibility rather than by a loss of tactile discrimination.

Over the palm his answers are equally quick and accurate at 1·5 cm. But over the soles we obtained the following results.

Compasses applied transversely :—

		Right.		*Left.*
2 cm.	1	10 R.	1	9 R. 1 W.
	2	10 W.	2	9 R. 1 W.
3 cm.	1	8 R. 1 W. 1 no answer.	1	10 R.
	2	9 R. 1 no answer (answers given slowly).	2	10 R. (answers quick).

At 4 cm. his answers were equally good over both soles.

When the right sole is tested the accuracy of his answers can be greatly improved by practice. Thus he may fail on four or five occasions to answer at all during a series of twenty stimuli with one or two points separated at a distance of 3 cm. But after further testing of the sole with the points at different distances he sometimes gives a perfect series of answers at 3 cm.

(*e*) *Passive position and movement* can be perfectly appreciated on both sides of the body, and there is no difference in the records obtained from the great toes, ankles, knees, hips, or any joints of the upper extremities.

(*f*) *Tactile localisation* is equally good on the two halves of the body both to naming and groping.

(*g*) *The vibrations of a tuning fork* were equally well appreciated everywhere over the two halves of the body.

(*h*) *Appreciation of differences in size.*—Cylindrical rods were used with diameters of 2 cm., 0·6 cm., and 0·2 cm. The difference in size could be appreciated equally well over the two halves of the body except the soles, which could not be tested with certainty.

Cranial nerves.—Taste and smell are unaffected. There has been no limitation of the visual field in either eye, and disc and fundus have always been normal.

The pupils are equal and react normally to light and to shade. The left pupil dilates well to cocaine.

The movements of the face and tongue are normal.

Sphincters.—Micturition and defæcation have never been affected in any way.

Spine.—No gross abnormality is visible in the spine, but a radiograph shows that the fourth neural arch has been fractured.

Case 5.—Walter M.

May 18, 1904, he fell fifteen feet on to a heap of bricks. Immediate loss of power in the right arm and leg. Shortly afterwards defective sensation was discovered in the left leg.

Seen by us in 1906.

He was then a characteristic instance of Brown-Séquard paralysis.

Right.	*Left.*
Wasting of muscles of hand.	*No paralysis or muscular wasting.*
Spasticity of wrist and of leg.	*Reflexes normal.*
Knee-jerks increased.	*Loss of sensibility to pain, heat and cold.*
Ankle clonus.	*Tactile sensibility, tactile localisation, tactile discrimination, sense of passive position and movement unaffected.*
Extensor plantar reflex.	
No change in sensation.	

Walter M., aged 46, a carpenter and joiner, fell fifteen feet on May 18, 1904. He was working on a scaffold, and, in attempting to cross an opening, supported himself by a wooden rail; this broke, and he fell on to a rough heap of bricks. He did not lose consciousness, but was carried by his fellow workmen to St. George's Hospital, where he lay three or four weeks.

He was much bruised, especially at the "bottom of the spine." The right arm was weak and, to a less extent, he had also lost power in the right leg; but at no time was he unable to move both the leg and the arm. He was told by the house physician that over the left leg he did not answer correctly to the prick of a pin, and to hot and cold tests. This surprised him, for he was not conscious of any defective sensation in this leg.

On leaving the hospital, he was able to walk unsteadily. Gradually his gait improved, and he could do a little work, but his neck seemed to want support. He suffered no pain, but when he sat up or walked for a time, he felt an uncomfortable sensation in the region of the seventh cervical spine, which occasionally became an ache.

He has had no abnormal sensations in the left leg, but when he takes a hot bath he always tests the water first with his right foot lest he should burn himself. When he dips the left leg into cold water, it produces numbness and not a sensation of cold.

He thinks the strength of the right arm and leg is still improving.

He has never had trouble with micturition or defæcation. Since the accident, he has had no connection with his wife, and, although occasionally he may have an erection, there has been no emission. Sexual desire is evidently slight.

He has been married for nineteen years and his wife has had no miscarriages. No history could be obtained of venereal disease. He is a life-long teetotaler and non-smoker.

Condition in October, 1906.

He was an unusually intelligent man, self-educated to a high degree. Somewhat excitable in manner and speech, he was absolutely trustworthy to control tests.

Motion.—He walked well, holding the right leg a little stiffly with a slight drag of the right foot. He could stand equally well with his eyes open or shut. The right leg was distinctly spastic, and he complained that it "jumped" at night occasionally. Neither leg showed any signs of wasting, and the measurements were equal on the two sides.

The left hand was in every way normal, but the interossei and hypothenar muscles of the right hand were distinctly wasted, and in them could be seen fibrillary twitchings. Not only were these muscles wasted, but the fingers were rigid; the proximal phalanges were hyper-extended and the two distal phalanges slightly flexed. The thenar muscles were in a similar condition, much wasted compared with those of the other hand, and the thumb was adducted and flexed in consequence of the spasticity. Every movement of the right thumb could be carried out, thoug feebly. The grasp of the right hand was 2 kilograms, that of the left 25 kilograms. All the small muscles of the right hand were less excitable to the interrupted current than those of the left; to the constant current they contracted sluggishly, and more easily on closure to the anode than to the kathode.

All movements of the right wrist could be carried out, but were distinctly spastic. Movements of the elbow were normal and there was no spasticity.

The muscles of the post-axial half of the right forearm were somewhat wasted; the difference between the two forearms at a point 20 cm. above the lower end of the radius was 1·5 cm. (right 22 cm., left 23·5 cm.).

All the muscles of the right forearm and arm reacted well to electrical stimulation.

On quiet respiration the right half of the chest moved distinctly less than the left; this difference became more evident when the patient breathed deeply. Similarly, the movement of the left was greater than that of the right half of the abdomen; when told to contract the muscles of his abdomen, the mid-ventral line was drawn over to the left.

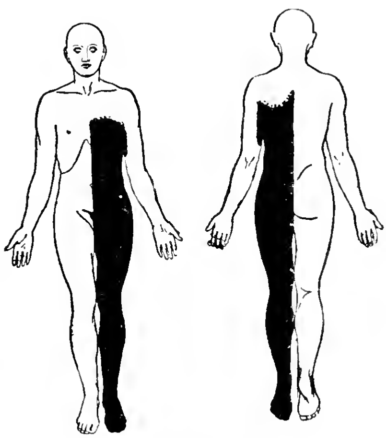

Fig. 115.

To show the loss of sensation to pain, heat and cold in Case 5.

Reflexes.—On the right side, the knee-jerk was greater than that on the left, and ankle clonus was obtained. The right plantar reflex was invariably of the extensor type, whilst flexion was always obtained from the left foot. The right elbow-jerk was definitely brisker than that of the left side.

Sensation.—(*a*) *Sensibility to pain.*—He was entirely insensitive to the prick of a pin over the whole of the left half of the body as high as the level of the third rib, and over a small area on the inner aspect of the left arm (Fig. 115). The limits of this area were well defined in front and on the arm; they varied little according to whether the patient was tested from analgesic parts towards those of normal sensibility or vice versa. Over the scapula the border differed by about 2 to 3 cm. according to the method of testing employed.

When tested with the painful interrupted current, the analgesia was found to agree exactly with that mapped out by means of the prick of a pin.

But, although he was entirely insensitive to the pain produced by the current, it caused violent movements of withdrawal. He complained that the sensation, though in no way painful, was extremely uncomfortable.

Squeezing the right testicle between the fingers caused the usual sickening sensation; when the left testicle was squeezed he appreciated the pressure, but no pain or discomfort was produced.

The pain of pressure was not appreciated as high as the level of the seventh rib on the left side. The algometer gave the following readings :—

	Right (spastic).	*Left (analgesic).*
Sole	Pain at 4	No pain at 15.
External malleolus	Pain at 3	No pain at 10.
Shin	Pain at 4·5	No pain at 13.
Outer aspect of knee	Pain at 5	No pain at 12.
Front of thigh	Pain at 5	No pain at 15.
Outer surface of anterior superior iliac spine	Pain at 3	No pain at 12.
Lower ribs	Pain at 1·5	No pain at 10.
Over seventh rib in axilla	Pain at 1·5	Slight pain at 7.
Inner aspect of arm	Pain at 1·5	Pain at 7.
Clavicle	Pain at 1·5	Pain at 1·5.
Palm	Pain at 6	Pain at 6.
Elbow	Pain at 5	Pain at 5.
Shoulder	Pain at 3	Pain at 3.
Temple	Pain at 2	Pain at 2.

(*b*) *Thermal sensibility.*—Any object brought into contact with the area on Fig. 115 was usually said to be warm, even if it were a tube containing ice. This made the testing of thermal sensibility extremely difficult. But, by varying the stimulus and by employing as a control a test-tube at a temperature which seemed neither hot nor cold to the normal parts, we were able to assure ourselves that neither heat nor cold were appreciated over the affected area. If a tube containing ice was passed slowly down the chest from the left clavicle, it was called "warm" as soon as it entered the area on Fig. 115. Similarly, water at 25° and at 45° and the neutral test-tube seemed to him equally "warm."

(*c*) *Sensibility to light touch.*—Stimulation with cotton wool was quickly and accurately appreciated everywhere; no difference could be discovered between the two sides of the body.

Tested with von Frey's hairs we found that No. 5 (21 grm./mm.^{2}) could be appreciated on both palms and both soles. No. 8 (23 grm. mm.^{2}) produced a sensation everywhere on the abdomen, the front of the thighs and the back of both calves.

(*d*) *Deep touch.*—He recognised deep touches and was conscious of the gradual increase of the pressure caused by the algometer, even when it failed to produce pain.

(*e*) *Recognition of a point.*—The head of a pin could be correctly discriminated from the point everywhere over the analgesic area.

(*f*) *Appreciation of difference in size.*—Tested by cylindrical metal rods with diameters of 2 cm., 0·75 cm. and 0·2 cm., he was equally accurate in his answers on both halves of the body.

(*g*) *The vibrations of a tuning fork* (128) were accurately appreciated everywhere. There was no difference between the two halves of the body.

(*h*) *The sense of passive position* was perfect in both great toes, both ankles, both knees, and at all the joints of both upper limbs.

(*i*) *The compass test.*—This was difficult to apply, owing to the violent reflex movements which were produced when the two points were brought into contact with the skin over any part of the analgesic and thermo-anæsthetic area, particularly over the sole of the left foot. This made it impossible to determine the threshold with any accuracy on the left side. But, when the points were applied carefully to the left sole and those answers only recorded that were unaccompanied by a violent reflex movement, we could not assure ourselves that there was any difference between the response from the right or the left foot.

(*j*) *Tactile localisation* was unusually accurate, and we could find no difference between the two sides of the body.

Cranial Nerves.—The pupils reacted well to light and to shade. The movements of the eyes, face and tongue were perfectly performed.

Spine.—A radiograph of the spine showed disorganisation of the sixth and seventh cervica vertebræ.

CASE 6.—JAMES M.

He injured his spine by diving into shallow water in June, 1886. He did not lose consciousness at once, but was delirious for six weeks.

He gradually recovered power, and in three years reached his present condition. He came to the London Hospital in December, 1906, for lead colic, and was found to be a characteristic instance of Brown-Séquard paralysis.

Right.

No motor disturbance.

Reflexes normal.

Loss of sensation to pain, heat and cold (Figs. 116 *and* 117).

Tactile sensibility perfect.

Left.

Wasting of small muscles of hand.

Slight spasticity of leg.

Knee-jerk exaggerated.

Ankle clonus.

Plantar reflex, extensor.

No change in sensation.

Passive position and movement perfectly appreciated. Compass test gave perfect results.

James M., aged 41, a painter, came to the London Hospital in December, 1906, complaining of an attack of lead colic. He was discovered to have the symptoms of Brown-Séquard paralysis, of which he gave the following history.

In June, 1886, he was in the Army and was stationed at Aden. It was the custom of those men who could swim to bathe in the evening from Steamer Point. So large were the waves that it was possible to dive into them with safety. But one evening in June when attempting this feat, he miscalculated his distance and, diving into shallow water, struck the sand with his head. All power went from his limbs immediately, but he did not lose consciousness even for a moment. He was swept back by the wave, but was brought to land and stretched out upon the sand. He suffered no pain, but seemed as if swollen to four times his usual size. They carried him to hospital and put him to bed; then he went quietly to sleep and did not regain consciousness for six weeks. He was told that he was delirious all the time. When he came to himself he found that he had several bed-sores; he could move his hands a little but no other limb.

Slowly, power returned to the right leg and both arms. It was six months before he could stand and then the left leg dragged.

He was sent to Netley and remained there until June 26, 1887, able to walk but dragging the left leg.

After his discharge from the Army he found work, and in three years had reached exactly the condition in which he first came under our notice.

He is a foreman painter and is in charge of the mixing of the paint. Once or twice a year he has suffered from pains in the stomach, evidently slight attacks of lead colic; he comes to the hospital and rapidly recovers. It was on one of these visits that his condition was discovered by Mr. Sherren, who transferred him to us.

Condition in December, 1906.

He is an intelligent man, temperate in his habits and answers well to sensory tests. He thinks there is nothing amiss with him, but was content to lie still in bed under observation as often as he was wanted, provided arrangements were made for his men to continue their work.

Motion.—He could stand with his eyes open and shut, and was in no way ataxic.

When he walked, the left leg was held a little stiffly, and he said he could not run, "because the left leg would catch." So long as he walked slowly, the toe cleared the ground completely. All the movements of both lower extremities were strong against resistance and there was no paralysis of any group of muscles.

He said that the left leg occasionally "jumped" at night; this never happened to the right leg.

The small muscles of the left hand were definitely wasted; all the interosseous spaces were hollowed and the hypothenar eminence was unnaturally small. The outer group of thenar muscles, formed by the opponens and abductor, was well developed, but the remaining muscles of the thumb were wasted compared with those of the opposite hand. He could strongly abduct and oppose the thumb, and adduction and flexion were possible; extension was perfect.

The grasp of the left hand was 2 kilograms, compared with a dynamometer reading of 25 kilograms from the right hand. This profound difference in the two hands was produced by the difficulty with which he grasped the instrument, in consequence of the want of power to flex the metacarpo-phalangeal joints strongly; and yet, when he made this movement apart from the dynamometer, it was carried out perfectly. The loss of grasp, when he attempted to exert pressure by flexing the fingers into the palm, seemed to be due to weakness of the interossei. The fingers could not be held out straight without falling out of alignment, and the interossei and lumbricales

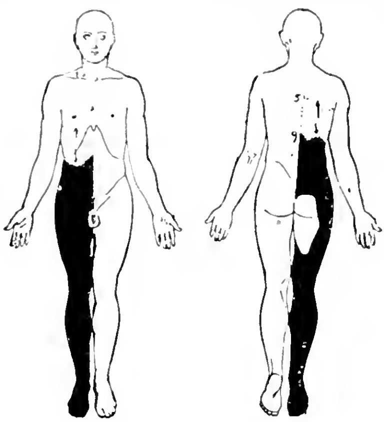

FIG. 116.

To show the loss of sensation to prick in Case 6. The line marked with an arrow pointing upwards corresponds to the border of the cutaneous analgesia discovered by testing from insensitive to sensitive parts. The border marked with an arrow pointing downwards shows the limits of the sensibility to pain when he was tested from normal to insensitive parts.

were acting feebly, if at all. All the long flexors and extensors acted well, and there was no loss of power in the muscles of the elbow and shoulder.

The muscles of the right upper extremity reacted well to both currents. The only changes in electrical irritability were found in the small muscles of the left hand; the interossei and the abductor minimus digiti did not respond to the interrupted or constant currents. The outer thenar muscles reacted briskly and normally, but the inner group contracted poorly to both forms of electrical stimulation.

Reflexes.—Wrist- and elbow-jerks were equal on the two sides. But the left knee-jerk was much exaggerated. Ankle clonus was obtained and the plantar reflex on this side gave an extensor response.

On the right side, the knee-jerk and plantar reflex were normal and no ankle clonus could be obtained.

Sensation.—Except for the slight colic, which rapidly passed away, he complained of no abnormal sensations of any kind. But he found that, when the weather grew cold, he lost the use of his left hand, although in warm weather he could notice little difference between the two hands.

(*a*) *Sensibility to pain.*—To all cutaneous painful stimuli, such as the prick of a pin, sensation was lost over the area on the right half of the body shown in Fig. 116. The frontal boundary of this analgesia varied according to the method of testing. If the stimulus travelled from parts that were insensitive to those of normal sensibility, the analgesia extended up to the higher of the two lines; but, when the testing began over normal parts, he still responded to the painful stimulus, until the second of the two lines was passed. This is a characteristic feature of areas which are partly insensitive only.

Another remarkable feature of this case was the maintenance of sensation to painful cutaneous stimuli over a patch upon the right buttock and over the whole of the penis and scrotum.

The pain of excessive pressure was greatly diminished over the right sole and right leg below the knee. The algometer gave the following readings:—

	Right.	*Left.*
Sole	Pain at 14	Pain at 4.
Inner aspect of leg	Pain at 8	Pain at 2·5.
Outer aspect of leg	Pain at 15	Pain at 7.
Calf	No pain at 12	Pain at 8.
Knee	No pain at 13	Pain at 5.
Front of thigh	Pain at 7	Pain at 6.
Ischial tuberosity	Pain at 8	Pain at 5.
Iliac crest	Pain at 4	Pain at 4.
Sterno-clavicular joint	Pain at 2	Pain at 2.

When a strong current was applied to the right or analgesic leg, he complained that it was "uncomfortable but not painful." Then the same current was applied quickly to the left calf

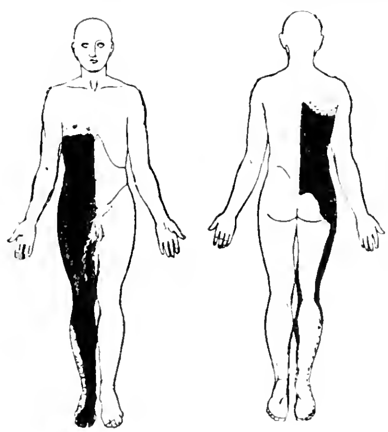

FIG. 117.

To show the extent of the loss of sensibility to thermal stimuli in Case 6.

and immediately withdrawn on account of the pain; but this stimulation had caused "cramp" in the left calf and he sat up in bed, rubbing his leg. Thus it is evident that the deep muscular pain upon which "cramp" depends must have been abolished in the right leg. This agrees with the results obtained with the algometer.

(*b*) *Thermal sensibility.*—He was insensitive to all degrees of cold over the area shown on Fig. 117. The extent of anaesthesia to all degrees of heat almost exactly corresponded with that for cold.

(*c*) *Tactile sensibility* was perfectly preserved; cotton-wool was everywhere recognised, and No. 5 (21 grm. mm.^{2}) of von Frey's hairs produced a sensation of equal intensity over the great toes and over the sole and dorsum of both feet.

(*d*) *The vibrations of a tuning fork* (128) were perfectly appreciated everywhere.

(e) *Recognition of a point.* He could tell the difference between the head and the point of a pin everywhere. In fact he is so clever at telling the head from the point that it is sometimes difficult to work out the loss of painful cutaneous sensibility by means of a pin.

(f) *Sense of passive position and movement* was everywhere perfect. His answers in response to movements of either foot were unusually quick and certain. So trustworthy was he that throughout the testing of the great toes, ankles, knees, elbows, wrists, thumb, index and middle fingers, he did not make a single mistake, although twenty movements were made at each joint (320 stimulations).

(g) *The compass test.* He gave perfect answers over the palms at 2 cm. and over the forearms at 4 cm. distance. When the compasses were applied longitudinally to the sole of the foot, his answers were perfect at 4 cm., but were almost equally faulty at 3 cm.

Right 3 cm.	1	9 R. 1 W.	Left 3 cm.	1	7 R. 3 W.
	2	8 R. 2 W.		2	9 R. 1 W.

Thus, there was certainly no difference in the sensibility of the two soles to this test.

(h) *Tactile localisation* was equally good on the two halves of the body. When asked to name the spot touched, he did so correctly in every case, even when the touch was produced with No. 8 (23 grm. mm.^{2}) of von Frey's hairs.

Tested by Spearman's method, the results were as follows: Six touches were given at each spot and the numbers represent the average deviation of his six attempts to point to the spot stimulated:—

	Right.	*Left.*
Leg	2·6	2·9.
Dorsum of foot	4·2	6·2.

The difference between the two sides was, we believe, within the experimental error.

Cranial Nerves.—The pupils reacted well, and there was no abnormality in the function of any cranial nerve.

Spine.—A radiograph showed no abnormality of any kind.

Sphincters.—He could hold his water for half an hour, but it occasionally dribbled away a little if he attempted to hold it too long. So long as he remained constipated, he could hold his motions, but when they became loose, he lost all control.

Sexual.—He has no desire during the winter months; sometimes during the summer he feels desire, but has never had an erection or emission since his accident. After leaving the Army, he married "for the sake of a home," and has no children.

Case 7.—Cyril Wilfred F.

August 14, 1905, he dived into shallow water and injured his spine. Sensation was affected in the left leg, and, after the effects of shock had passed away, his right arm remained weak.

Seen in November, 1905, there was no definite motor paresis, but the reflexes were brisker on the right side than on the left. Sensibility to pain, to cold and to heat were lost to a different extent over the left leg and left half of the body (Figs. 118, 119, and 120). No other sensory function was disturbed. A radiograph showed changes in the body of the sixth cervical vertebra.

In 1906, observations were made on the behaviour of the area on the trunk insensitive to heat, but sensitive to cold, in order to elucidate the condition known as paradox cold.

Cyril Wilfred F., aged 26, of no occupation.

On August 14, 1905, whilst diving from the top of a bathing-machine, he slipped, pitching head first into shallow water. He believes that the top of his head struck the sand. He floated to the top, and did not lose consciousness, but found he was unable to move his arms or his legs. Power returned in all his limbs within half an hour, but he remained in bed for three weeks, suffering from a good deal of pain in the neck. For nearly three months he could not use the right arm and, from the beginning, noticed that sensation was affected in the left leg, particularly to heat and cold. At first the neck was stiff, and he suffered from pain, especially on movement, at a level of about the seventh cervical vertebra.

Condition in November, 1905.

He came under our notice in November, 1905, exactly three months after the accident. His condition then was as follows. He was a small, well-built, muscular man, and showed no signs of any disease, except in the nervous system.

Motion.—He walked well, and could stand perfectly with his eyes closed. There was no sign of paralysis, or spasticity in the legs. The grasp of the left hand was distinctly more powerful than that of the right, but there was no wasting or paralysis in either upper limb. He could touch his nose perfectly with either hand, even when his eyes were closed.

Reflexes.—The right wrist-jerk was slightly brisker than the left, and the knee-jerk was distinctly more active on the right side than on the left. No ankle clonus was present on either side. When testing for the plantar reflex, the left great toe gave a decided flexor response, but the right remained stationary.

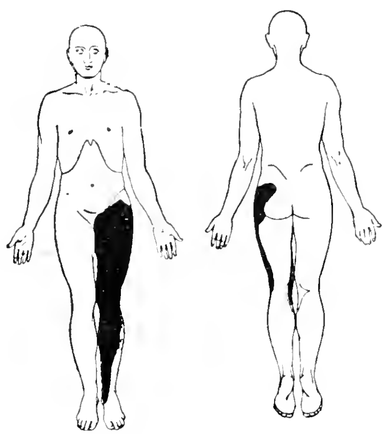

FIG. 118.
To show the loss of sensibility to cutaneous painful stimuli in Case 7.

Sensation. (*a*) *Sensibility to painful stimuli.*—Sensation was profoundly affected over the left lower extremity. Over the area shown in Fig. 118, he was entirely insensitive to the painful aspect of a pin prick; but over the sole of the foot and over the back of the leg he was certainly sensitive to painful cutaneous stimuli. In the direction of the trunk, and also towards the dorsum of the foot, the boundaries of this area of complete cutaneous analgesia shaded gradually into parts of normal sensibility.

(*b*) *Thermal sensibility.*—Over the area in Fig. 119, he was insensitive to a test-tube containing ice water, but the borders of this area were not rigidly defined, excepting over the outer side of the thigh. Within these parts, he was also insensitive to all temperatures which caused a sensation of coolness over the normal leg.

Temperatures of from 30° to 70° C. produced no sensation of heat over the area in Fig. 120. But he complained that with a stimulus of above 50° C. pain was produced over all those parts insensitive to heat, but sensitive to cutaneous painful stimuli. Thus, it was possible to map out the area of cutaneous analgesia with a test-tube containing water at 60° C.

(*c*) *Tactile sensibility* was everywhere perfect, both to light and deep touch.

(*d*) The *vibrations of a tuning fork* were everywhere accurately appreciated.

(*e*) The *sense of passive position and movement* was nowhere disturbed.

(*f*) To the *compass test* his answers were equally good over both halves of his body.

(*g*) *Cutaneous localisation* was equally good over synonymous parts of the body and limbs.

Spine.—A radiograph showed changes in the body of the sixth cervical vertebra.

Condition in October, 1906.

Except that his general health improved, his condition remained unchanged. But, as some additional observations of interest were made in the autumn of 1906, especially those relating to paradox cold, we shall recapitulate shortly his condition at that time.

Motion.—He walked with such ease that he asserted he was as well as ever. The grasps of the two hands were of equal strength.

Reflexes.—The right wrist-jerk was perhaps slightly more active than the left, and the knee-jerk was certainly brisker on the right side than the left. No ankle clonus could be obtained, and whilst the left plantar reflex was certainly flexor in type, the right was indeterminable.

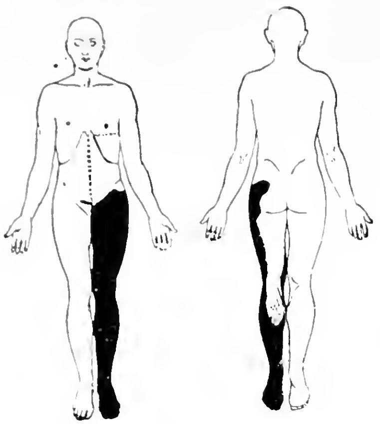

Fig. 119.

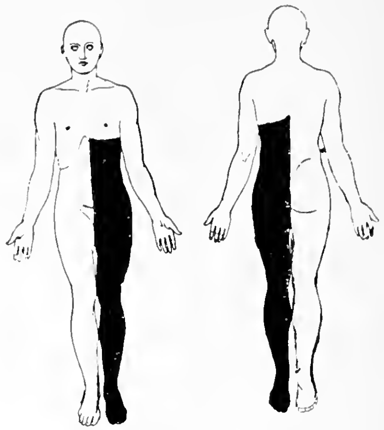

Fig. 120.

To show the loss of sensation to cold (Fig. 119) and to heat (Fig. 120) in Case 7.

The area on Fig. 119 enclosed by a dotted line was sensitive to cold, but not to heat. It was here that the observations were made on the production of paradox cold by temperatures of 45° C. and above.

Sensation. (*a*) *Sensibility to painful stimuli.*—The loss of sensation to the prick of a pin and to the painful interrupted current corresponded exactly to that on Fig. 118.

The algometer gave the following readings, showing how closely the decrease in sensibility to the painful aspect of excessive pressure corresponded with the cutaneous analgesia (compare Fig. 118 with the algometer readings).

	Right (normal).	*Left (sensory loss.)*
Sole	Pain at 2·5	Pain at 2·5.
Shin (inner aspect)	Pain at 1·5	Pain at 10.
Calf	Pain at 4	Pain at 5.
Front of knee	Pain at 1·5	Pain at 10.
Popliteal space	Pain at 2·5	Pain at 5.
Front of thigh	Pain at 4·5	Pain at 11.
Ischial tuberosity	Pain at 3	Pain at 4·5.
External to the anterior superior spine of the ileum :—		
(*a*) Above the line of cutaneous analgesia	Pain at 2·5	Pain at 2·5.
(*b*) Below the line of cutaneous analgesia	Pain at 2	Pain at 5.
Palm of the hand	Pain at 2·5	Pain at 2·5.

(*b*) *Thermal sensibility.*—Some striking experiments were made to elucidate the phenomenon known as "paradox cold." The area insensitive to all cold stimuli was of considerably less extent than that insensitive to heat (Fig. 119 and Fig. 120). Thus, the whole of the abdomen and lower part of the thorax on the left side enclosed by a dotted line on Fig. 119 was sensitive to cold, but not to heat. So long as the stimulus was 40° C. or below, it produced no sensation over this area insensitive to heat; it was called in every instance "a touch." But, as soon as temperatures of over 45° C. were employed, the patient invariably said the stimulus was "cold." If the temperature was raised to 55° C., he complained of "cold pain."

These observations show that, in this instance, the paradox cold obtained by the application of heat to an area insensitive to heat was due to stimulation of cold spots. Such spots react normally to temperatures above about 40° with the production of a sensation of coldness.

(*c* to *g*).—Every other sensory quality was perfect, as was the case in 1905.

Case 8.—G. G. A.

In August, 1904, whilst in India, he began to suffer from fever: this continued till November.

January 31, 1905, *he was suddenly seized with violent pain in the neck, lost power in the left arm and left leg, and became insensitive to pain, heat and cold over the right leg and right half of the body.*

When first seen in April, 1905, *he was a characteristic instance of Brown-Séquard paralysis.*

Right.	*Left.*
No motor disturbance.	*Slight spasticity of left leg.*
	Slight wasting of left hand.
Knee-jerk normal.	*Knee-jerk greatly exaggerated.*
No ankle clonus.	*Ankle clonus.*
Plantar reflex flexor in type.	*Plantar reflex extensor in type.*
Loss of sensibility to cutaneous painful stimuli (Fig. 121) *and to cold (Fig.* 122).	*Sensation perfect.*
No loss to heat.	
All other forms of sensation perfect.	

G. G. A., aged 45, a medical man, was in perfect health until August, 1904. He then began to suffer from pyrexia; his temperature never rose above 100° F. (37° C.), but never remained normal for long. He was in India at the time, and the condition was supposed to be malarial, but quinine was entirely without effect. The pyrexia continued until the middle of November, when he thought he was well and resumed his usual duties.

On January 31, 1905, he was suddenly seized with violent pain slightly to the left of the spine of the seventh cervical vertebra: it radiated down the back of the shoulder and up the neck and was worse at night than in the day. This pain increased rapidly for two weeks and his temperature rose again, rising and falling each day as before.

Then the pain became easier, and he was able to sit up and play the banjo. Within two days, his left arm became paralysed, but the pain continued to decrease in severity. The paralysis spread to the left leg, and at the same time the whole right half of the body as high as the nipple became insensitive to pain, heat and cold.

At no time was the motor power of his right leg diminished, and he had no difficulty in passing or in holding his water.

The right half of the face did not sweat.

About the middle of March, 1905, the paralysis began to pass away from the left arm. By the middle of April, 1905, his temperature ceased to rise above 99° F. (37·2° C.), and since that date he has steadily improved.

At the age of 18 he had an attack of venereal disease under a long foreskin; this produced phimosis, for which he was circumcised. Otherwise he was not treated and suffered no consequences.

Condition in April, 1905.

When he was first seen by one of us in April, 1905, he was a well-built active man, in appearance younger than his age.

There were no abnormal signs in the heart, lungs or abdomen; the spleen was not enlarged and his urine was normal.

Motion.—He walked a little stiffly, in consequence of slight spasticity of the left leg, but could stand firmly on either leg and did not fall when his eyes were closed.

The grasp of the left hand was greater than that of the right. All the interossei of the left hand were a little wasted, especially the first, and the fingers were a little over-extended at the metacarpo-phalangeal, and flexed at the interphalangeal joints. The thenar muscles showed slight signs only of wasting. All the muscles reacted perfectly to the interrupted and constant currents.

Reflexes.—The left knee-jerk was greatly increased compared with the right, and ankle clonus was definitely present on the left side; no clonus could be obtained from the right ankle. On

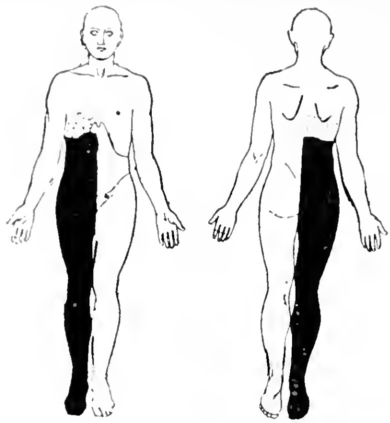

FIG. 121.

To show the loss of sensibility to cutaneous painful stimuli in Case 8. The dotted area represents a band of diminished sensibility.

the left side, the plantar reflex was of the extensor type, whilst that from the right foot gave a flexor response.

Sensation.—He complained of no abnormal sensation, unless the right leg was touched with a cold object; for instance, when standing on a cold floor, he noticed a luke-warm sensation in the right foot instead of the normal coldness.

(*a*) *Sensibility to pain.*—He was completely insensitive to all cutaneous painful stimuli over the area in Fig. 121. The frontal border was ill-defined, merging into parts of normal sensibility, and the boundary of the analgesia differed according to whether testing was carried out from normal to abnormal parts or vice versa.

The right testicle and right half of the penis and scrotum were insensitive to painful stimuli.

(*b*) *Thermal sensibility.*—He showed a remarkable dissociation between sensibility to heat and to cold. All temperatures between 35° C. and 55° C. could be appreciated everywhere over the right leg, and 35° C., 45° C., and 50° C. could be discriminated.

But, over the area marked on Fig. 122 he was entirely insensitive to all temperatures which normally produced a sensation of coldness.

(*c*) *Tactile sensibility* in all its forms was perfect, whether the stimulus was cotton wool or a deep touch.

(*d*) *Recognition of a point.*—He could tell the head from the point of a pin everywhere over the body and limbs.

(*e*) The *sense of passive position and movement* was everywhere perfectly preserved.

(*f*) *Tactile localisation* was equally good over both lower extremities.

Spine.—He had great difficulty in turning his head to the left until a few weeks before he was first seen. Even then he could not turn it rapidly. The radiograph gave results that were uncertain, all that could be said was, that the shadow was somewhat more blurred on the left side than on the right in the region of the transverse processes of the fifth and sixth cervical vertebræ.

Sphincters.—He has had no trouble with micturition and defaecation.

Condition in October, 1906

He greatly improved, and was last seen in October, 1906.

Motion.—The left leg no longer gave him trouble, and was not stiff or spastic; he could run upstairs "two at a time."

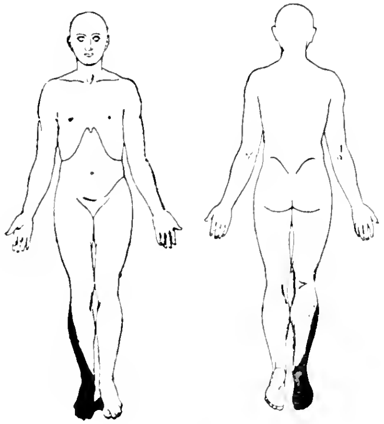

FIG. 122.

To show the loss of sensibility to cold in Case 8.

Reflexes.—The reflexes were exactly in the same condition as in April 1905.

Sensation. (*a*) *Sensibility to pain.*—The area insensitive to prick had greatly decreased, and, although over the back and front of the right thigh and over the sole of the foot the sensation was diminished, the only absolute loss of cutaneous painful sensibility lay over the leg between the knee and the ankle.

This was associated with a diminution in sensibility to the pain of pressure compared with the left leg, as shown by the following algometer readings :—

	Right (sensory loss).	*Left (motor).*
Sole	Pain at 7–6·5	Pain at 2–2·5.
Shin (inner aspect)	Pain at 4	Pain at 1·5–2.
Calf	Pain at 5–6	Pain at 3–3·5.
Knee	Pain at 10–7	Pain at 4–3.
Popliteal space	Pain at 3–4	Pain at 2·5–2·5.
Iliac crest	Pain at 7–6	Pain at 3–3.
Buttocks	Pain at 3–3	Pain at 2·5–2.
Lower ribs	Pain at 1·5	Pain at 1·5.
Palm	Pain at 3–3	Pain at 3–3.

These readings show no absolute loss of sensibility to the pain of pressure, but all those from the right leg are uniformly somewhat higher than those from similar parts of the left leg. Two readings are given to show the manner in which the algometer results vary when sensation is not abolished.

(*b*) *Thermal sensibility.*—Anaesthesia to cold was still present over the external aspect of the right leg and dorsum of the foot, but no longer occupied the sole. Over this area of loss of sensation, water at 20° C. and below was uniformly called "warm."

(*c* to *f*). Every other sensory function was perfect.

Case 9.—Joseph F.

A glio-sarcoma of the central grey matter of the spinal cord extended from the medulla to the seventh thoracic segment. Situated for the greater part in the centre of the cord, it had invaded and destroyed the left half in the region from the third to the seventh cervical segments.

It was found on his admission to the hospital that motion was lost in the left arm, but it was not until shortly before his death that the right arm became paralysed.

Both knee-jerks were increased; ankle clonus was obtained on both sides, and both plantar reflexes gave an extensor response.

For some time after admission, the local disturbance of sensation consisted of analgesia and thermo-anaesthesia of the left upper extremity, with abolition of the sense of passive position and movement and of tactile discrimination. Tactile sensibility was preserved. Shortly before death, tactile sensibility was also lost in this arm.

The remote disturbance of sensation consisted throughout of loss of sensibility to pain, heat and cold over the right leg, right half of the body and right arm and hand.

The sense of passive position was greatly diminished in the left foot, but perfect on the right side.

Joseph F., aged 44, an actor and vocalist, was admitted to the London Hospital under the care of Dr. Dawson on July 6, 1905, and died on August 10.

In November, 1904, he first noticed slight weakness and stiffness in the left arm with a tingling sensation in the fingers of the left hand. Shortly afterwards his neck began to grow stiff.

Until February, 1905, he was able to play the piano with both hands, but the left arm grew steadily weaker; slight weakness appeared in the right arm just before admission.

On two occasions within the fortnight before admission he passed urine involuntarily.

He had suffered from no previous illness, except an attack of venereal disease, accompanied by warts, but followed by no secondary consequences. He had never taken alcohol to excess.

Condition shortly after Admission

He was an intelligent man, interested, until shortly before his death, in his condition and the testing of his sensation. His speech was unaffected, and he never suffered from fits or headache.

Motion.—The left arm lay flaccid and motionless on the bed beside him. The small muscles of the left hand were wasted, and the left arm was nearly 1·5 cm. smaller in diameter than the right. No fibrillary twitchings were visible, and the muscles of the left arm and hand reacted perfectly both to the interrupted and to the constant current.

The small muscles of the right hand were wasted and the grasp was weak; but all movements of the thumb and fingers and of the rest of the upper extremity could be made without difficulty.

Both legs were distinctly spastic but were not paralysed; the muscles were flabby but not wasted.

Reflexes.—Both knee-jerks were increased, ankle clonus was obtained on both sides, and both plantar reflexes gave an extensor response.

Sensation. (*a*) *Sensibility to pain.*—He was insensitive to all cutaneous painful stimuli, such as the prick of a pin or the interrupted current, over the whole of the right leg, right half of the body and right arm (Fig. 123). On the opposite side, the analgesia occupied the left arm and left half of the neck.

Excessive pressure produced no pain over either palm, but the amount of the pressure applied was not measured with the algometer.

(*b*) *Thermal sensibility.*—Sensibility to heat and cold was abolished over the area shown in black on Fig. 124. Over the right side of the neck it was greatly diminished, more so to heat than to cold.

(*c*) *Tactile sensibility* was unimpaired at this time; even cotton wool was appreciated over the left arm and hand.

(*d*) *Sense of passive position and movement.*—He was unable to recognise the position of any part of the left upper extremity, and was ignorant of even the grossest movements; but in the right hand and arm the sense of passive movement and position was perfect.

His power of recognising movements of the left great toe was defective, but from the ankle and knee his answers were correct. On the right side he was uniformly accurate in his appreciation of movements of the great toe, ankle and knee.

Fig. 123.

To show the loss of sensation to cutaneous painful stimuli in Case 9.

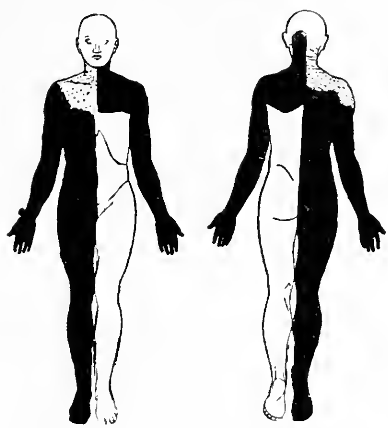

Fig. 124.

To show the loss of sensation to heat and cold in Case 9.

(*e*) *Compass test.*—Tactile discrimination was perfect in the right hand, and he made two mistakes only when the compass-points were separated to a distance of 1 cm. But over the left hand the two points were called one even when 5 cm. apart.

	Left.			*Right.*		
Palm (applied transversely)	5 cm.	1	10 R.	2 cm.	1	10 R.
		2	10 W.		2	10 R.
				1 cm.	1	9 R. 1 W.
					2	9 R. 1 W.

Cranial nerves.—The pupils reacted to light and accommodation, and the ocular movements were good. There was no paralysis of the face, and the tongue was protruded well. He could move both halves of the palate and at this time swallowed well.

Subsequent progress.—He gradually lost power in the right arm and hand, and although every movement could be carried out feebly, was at last unable to feed himself. Tactile sensibility became so greatly diminished in the left arm that the compass test could not be applied; he gave no answer when touched with the two points. Over the whole of the left upper extremity, he now gave no response to the pressure with a pin, whereas previously every prick was said to be a touch.

The extent of the insensibility to pain, heat and cold remained as before.

Gradually complete incontinence of urine and fæces came on and swallowing became difficult.

By August 9 the right arm was completely paralysed, and on the 10th he died suddenly.

Post-mortem Examination.

An autopsy was made on August 11. Rigor mortis was present. No abnormalities were found in the lungs, heart, liver, kidneys, or spleen.

The brain and spinal cord were removed together by sawing through the occipital bone. The spine was found to be entirely unaffected. But it was at once obvious that the spinal cord was greatly enlarged in the cervical region, and this increase in size extended up to the bulb. During the manipulations a considerable quantity of clear fluid escaped.

No changes were found in the cerebrum or cerebellum.

On microscopical examination a growth was found extending from the region of the olive to the eighth thoracic segment, situated in the grey matter around the central canal. But, even at levels as low as the third lumbar, the tissue around the central canal was abnormally extensive. Throughout the cord, the growth lay in the grey matter forming at the first and second cervical level a well-defined round tumour in the centre of the spinal cord. But, at the third cervical level, it had invaded and destroyed the whole of the left half of the spinal cord; the right half was much compressed. This destruction, more particularly of the left half of the cord, extended to the level of the seventh cervical. Below this, the tumour again assumed a more central position and could be clearly seen to the seventh thoracic level. Below this, some increase in the tissue around the central canal alone marked the position occupied by the tumour in higher segments. When stained by the Weigert-Pal method the whole of the crescentric portion representing the displaced right half of the spinal cord took the stain well, and showed large numbers of apparently normal fibres. In the dorsal region this stain showed profound degeneration of the pyramidal tract in the left half of the cord; in the right half this tract took the blue stain well.

The growth consisted of cells with a large deeply-staining nucleus and a small amount of protoplasm. Heidenhain's iron-hæmatoxylin method showed that many of these cells possessed processes which interlaced. It was probably a glio-sarcoma starting in the tissue around the central canal. Hæmorrhage had taken place at several points within the growth.

Case 10.—James Y.

July, 1906, he began to lose power in his legs, first in the left and then in his right; at the same time he ceased to be able to pass his water, and developed retention of urine with overflow.

Admitted to hospital with a high temperature and signs of bronchitis in both lungs.

He improved, and between August 10 and 15 complete examination was possible.

Absolute paralysis of motion was present below the umbilicus.

There was much loss of sensation to painful and thermal stimuli over both lower extremities (Fig. 125).

Sensibility to light touch was perfect except over the left foot.

He had lost all appreciation of passive position and movement in the lower limbs, and was unable to discriminate two points separated to more than twice the normal distance.

Yet he could name the spot touched accurately, although ignorant of the position of his legs.

On post-mortem examination, a metastatic growth secondary to a hypernephroma of the right kidney was found in the left half of the spinal cord. This had caused hæmorrhage, which extended widely in the left half of the cord from the seventh thoracic to the second lumbar segment.

Profound acute degeneration was found in both posterior columns, in both lateral bundles of Gowers and in both direct cerebellar tracts.

James Y., aged 61, was admitted to the London Hospital on July 23, 1906 (Dr. Schorstein).

For about a month he had complained of pains in the back, chiefly in the lower dorsal and upper lumbar region. Three weeks before admission he began to lose power, first in the left and then in the right leg. At the same time he noticed that he was unable to pass water, and yet as he stood it would run from him. Occasionally, during the three weeks before admission, he had lost control over his motions.

He was a file-cutter, but had never suffered from any form of lead poisoning. No history of venereal disease could be obtained; he had been married for thirty-four years and had five healthy children. He denied all excess of alcohol, and had the appearance of a man of temperate habits.

Condition on Admission.

When first admitted in July, 1906, his temperature ranged between 100·2° F. and 102·4 F. (37·8° C. and 39° C.). He lay propped up in bed with flushed cheeks, breathing rapidly; the pulse was 120 in the minute and regular. Both lungs were emphysematous and rales were widely heard, but at first no signs of consolidation were discovered. The heart sounds were in no way abnormal. The bladder was distended almost to the umbilicus, and the urine drawn off by catheter was faintly acid and contained some mucus and urates. Over the sacrum was a large bed-sore.

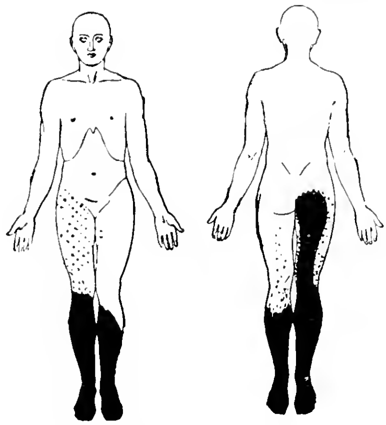

Fig. 125.

To show the loss of sensation to cutaneous painful stimuli in Case 10.

Progress.—During the first fortnight his urine was drawn off regularly, and he rapidly improved under treatment. The temperature gradually fell, so that from August 10 to August 15 it did not rise above 99° F. (37·2° C.). During this period he was so much better that careful observations could be made upon the condition of sensation; he became cheerful, interested in the testing of sensation, and remarkably trustworthy in his answers, if precautions were taken that he should not become exhausted.

But on August 15, the temperature began to rise and on the 16th he had a rigor. Further rigors followed on the 18th; definite signs of pneumonia appeared in the right lung, and he died on August 20.

Observations on the Condition of the Nervous System made between August 10 and August 15.

The patient was intelligent and answered well to the control tests applied. At the time, the following observations were made, his temperature was normal. He was bright and cheerful with the hope that he was on the way to recovery.

Sensation.—He complained of no pain or abnormal sensations in the lower extremities, which were alone the seat of gross sensory defects.

(*a*) *Pain.*—The prick of a pin was not appreciated over the area shown in Fig. 125. Below the knees, the loss of sensation was absolute, merging gradually above into parts of normal sensibility. Over the front of both thighs he could appreciate the pain produced by a prick, but sensation appeared to be diminished; above the level of the groin it was entirely unaffected.

This distribution exactly agreed with the analgesia to the painful interrupted current. Over both lower extremities below the level of the groin, sensation was somewhat diminished, but the only complete loss of sensation to this stimulus corresponded to the parts marked on Fig. 125.

The algometer showed that pain was produced when pressure reached the following amount, measured in kilograms.

	Right.	*Left.*
Sole of foot	10 (dull pain)	10 (dull pain).
External malleolus	7	7
Inner aspect of tibia	5	5
Inner aspect of knee	6	6
External to the anterior superior spine of the ileum	6	6
Head of metacarpal bone of thumb	5 (sharp pain)	5 (sharp pain).

(*b*) *Heat and cold.*—The parts insensitive to a temperature of 50° to 55° C. corresponded to the blackened portions of Fig. 125; but the whole of the right thigh was also insensitive to water at 40° C.

The loss of sensation to temperatures between 0° and 25° C. corresponded on the left lower extremity with the anæsthesia to heat. On the right leg, the loss of sensation extended up to the groin; over the right thigh, stimulation with ice-cold water was invariably said to be "hot." Thus a series of tests with silver tubes, containing water at different temperatures, gave the following results: ice was called "hot," a temperature neutral to the normal skin was called "a touch," 55° C. appeared to be hot, 40° C. was said to be "a touch." At the time these tests were made, the temperature of the room was 24° C.

Here we find an instance of the rule that, when one of the two qualities of thermal sensibility is abolished, extreme degrees will be called by the name of the range of temperature which can be appreciated. Sensibility to cold (0° to 25° C.) was abolished over the right thigh, although 50° C. could be appreciated; the application of ice-cold water to this thigh invariably evoked the statement that the stimulus was hot.

(*c*) *Light touch.*—When first examined there seemed to be no part of either lower limb where he could not appreciate a light touch with cotton wool. But, on August 13, he was somewhat insensitive to this stimulus over the left foot below the level of the ankle; elsewhere, however, even on this date he showed no trace of diminished sensibility to cotton wool.

(*d*) *Deep touch and pressure* were everywhere appreciated, and he never failed to answer correctly throughout the whole period he was under examination.

(*e*) *Passive position and movement.*—He was entirely unable to recognise the position into which his lower limbs had been placed passively, and was unconscious that they had been moved. Extensive movements could be made at the ankles, knees and hips without his knowledge. If his eyes were closed, the legs could be moved from the extended position in any direction and the knees flexed through 40°, and he still imagined they lay stretched out before him on the bed. When he was allowed to open his eyes, his expression of surprise amply testified to the greatness of his error.

He was equally unable to recognise movements of the feet or legs produced by electrical stimulation of the muscles of the lower limb.

The appreciation of passive position and movement was not disturbed in any part of the body, except from the hips downwards.

(*f*) *Compass test.*—Over the palm of the left hand, which we used as a control, he gave perfect answers when the compass points were separated by 1·5 cm. and applied longitudinally. But, over the outer aspect of the left leg, he failed entirely at 15 cm., and over the front of the left thigh when they were 20 cm. apart.

Outer aspect of left leg. 15 cm. 1 | XX. ID. DXD. IXO.
2 | I. XI. IIX. IID. I.

or 1 | 2 Right. 3 Doubtful. 4 Wrong, and once no answer.
2 | 7 Right. 1 Doubtful. 2 Wrong.

Front of left thigh. 20 cm. 1 | XO. XXX. D. IID.
2 | I. II. I. XD. DXXD.

or 1 | 2 Right. 2 Doubtful. 4 Wrong, and once no answer.
2 | 4 Right. 3 Doubtful. 3 Wrong.

(*g*) *Cutaneous localisation.*—On several occasions we satisfied ourselves that he was able to name the spot touched with accuracy; but one sitting was devoted to the following experiments.

(1) He was allowed to see the position of his limbs before they were touched. Then his eyes were closed and he was touched at similar spots on the two lower limbs, on the sole, the instep, the dorsum of the foot and just below the knee. In every case he named correctly the part touched.

(2) His eyes remained closed and his legs were moved so that he was unable to say in what position they lay. Then he was touched on the sole, the dorsum of the foot, the calf and just below the knee, first on the one limb and then on the other. In every instance his answers were correct. In fact, no difference could be discovered in the ease with which he named the spot touched when he knew how his legs were lying, and when he was totally ignorant of the position into which they had been placed.

He was never mistaken in naming the side to which the limb belonged that had been touched.

(3) His eyes were closed and the limbs were moved so that the left leg was flexed at the knee and hip, the right leg extended and abducted. Various points on the legs were touched and he was asked to indicate the spot with a light cardboard rod. The rod struck the bed idly; for so great was the error he was unable even to touch the legs, and yet he continued throughout to name correctly the spot touched.

(*h*) *Recognition of the point.*—He was able to distinguish the head from the point of a pin all over both lower limbs, even over parts which were entirely insensitive to all painful stimuli.

Motion.—Below the level of the umbilicus he was completely paralysed, and could make no movements of the hips, knees, ankles or toes. The legs lay flaccid, neither wasted nor spastic, all the muscles reacting normally to the interrupted and constant current.

Every other movement was perfectly performed and there was no wasting of the hands or arms.

Reflexes.—The knee-jerks were abolished, but ankle clonus was obtained on both sides. Wrist and elbow-jerks were in every way normal.

The plantar reflexes gave an uncertain response.

Cranial nerves.—The pupils were equal and reacted to light and accommodation. Ocular movements were perfect. There was no affection of the face and tongue.

No changes were found on ophthalmoscopic examination.

Sphincters.—On admission to the hospital, his bladder was greatly distended and he never regained the power of passing his water. It was drawn off twice daily by catheter.

The bowels were obstinately confined, but when opened by enemata he was unable to retain his motions.

Post-mortem Examination (*August* 21).

The body had been preserved in the cool chamber at a temperature just above freezing point. Rigor mortis was present. Over the sacrum and buttocks was a large bed-sore which was present on the patient's admission to the hospital.

The right lung was almost solid from septic broncho-pneumonia, and within it, at the extreme base, was found a small abscess-cavity of about the size of a walnut. This lung was adherent to the chest-wall except at the base; here there was a small collection of pus.

The left lung was widely adherent and contained patches of septic broncho-pneumonia.

The larynx and trachea were healthy.

No abnormality was found in the pericardium or heart, but the aorta was somewhat atheromatous.

No fluid was found in the abdominal cavity. The spleen was much enlarged and weighed 14½ ozs. (411 grms.); its substance was softened. No abnormal changes were found in the liver, which was not enlarged.

On removing the right kidney a large encapsuled growth was seen adherent to and distorting its upper surface. This growth was about the size of a walnut, soft and of a light yellow colour. On its inner aspect was seen the suprarenal capsule. In the lower part of the same kidney was a secondary growth, enclosed in a capsule, and of the same yellow colour.

On microscopical examination, the tumour was found to be a hypernephroma formed of columnar cells arranged in columns. Extensive hæmorrhage separated these columns of cells. Many of the cells contained brown granular material, apparently altered blood pigment.

The left kidney showed no gross abnormality.

No changes in the brain could be seen with the naked eye; it contained no secondary growths.

Condition of the spinal cord.—The cord was removed and hardened in 5 per cent. formalin. No growth or other abnormal changes were present in the membranes and no gross disease could be discovered before the cord was incised. But, as soon as it was cut across at the level of entry of each pair of roots, profound changes were at once visible, consisting firstly of hæmorrhage around a growth, and secondly of obvious degeneration in the posterior columns, which were whiter than the rest of the cord.

Distribution of the focal lesion.—The first sign of a focal lesion was found at the level of the seventh thoracic; here the base of the left posterior horn was occupied by an extravasation of blood. On both sides, the vessels of the posterior and lateral columns in the neighbourhood of this hæmorrhage were dilated and unduly visible.

At the level of the eighth thoracic, this hæmorrhage had spread so that it occupied the apex of the triangle formed by the left posterior column, but did not encroach on the lateral column.

At the ninth thoracic level, the hæmorrhage was rather more extensive, and for the first time dark granules could be seen amongst the extravasated blood.

At the level of the tenth thoracic, the lesion had reached such proportions that the whole of the left posterior horn and the greater part of the lateral column was destroyed. The external portions of the lateral column stained well by the Weigert-Pal method, but the whole of the blunt angle between the anterior and posterior horns was filled up with extravasated blood, which had also completely destroyed the central portion of the posterior horn. The posterior column was pressed upon and displaced, but took the Weigert stain well. Within the hæmorrhagic area were two foci, which consisted of small cells containing pigment. In sections stained by Van Gieson's method, the disease was seen to have invaded the whole of the grey matter on the posterior and left lateral aspects of the central canal.

At the level of the twelfth thoracic, the hæmorrhage had assumed the form of an oval ring, which entirely separated the base of the posterior horn and a portion of the left posterior column from the remainder of the spinal cord. Within this ring of extravasated blood lay fibres which stained blue with the Weigert-Pal stain.

At the level of the first lumbar, the hæmorrhage occupied about the same extent, but within its limits the tissue was more profoundly disintegrated.

At the level of the second lumbar, the hæmorrhage had destroyed the whole of the left posterior horn and a portion of the left posterior column. No definite signs of growth could be seen at this level.

From this point downwards, the cord showed no signs of a focal lesion.

Distribution of the systemic degeneration.—At the level of the seventh thoracic staining by Busch's modification of Marchi's osmic acid method showed degeneration in the whole extent of the posterior columns on both sides. At this level, the extreme upper end of the focal lesion could be seen as a hæmorrhage in the left posterior horn. But in spite of the apparently unilateral position of the focal lesion, both posterior columns were profoundly and equally degenerated.

At the level of the fourth thoracic, the root-zones and greater part of the postero-external columns were seen to be free from degeneration, which occupied mainly the postero-internal columns on both sides; but the cornu-commissural tracts were degenerated.

At the level of the first thoracic, the degeneration did not extend into the postero-external columns, but, with this exception, occupied the whole of the posterior columns. The cornu commissural tracts were slightly degenerated only.

At the level of the fourth cervical, the degeneration occupied the postero-internal columns only, and mainly their dorsal portions; the degeneration in the more ventral portions was much less than in the lower segments. The cornu-commissural tract was not degenerated.

Above the level of the seventh thoracic, both lateral bundles of Gowers and the direct cerebellar tract of both sides showed profound degeneration, slightly greater in the left than in the right half of the cord. This degeneration extended throughout the cervical region.

There was definite degeneration in the region of the spino-thalamicus of both sides, greater on the side (right) opposed to the main focal lesion.

Some degenerated fibres were also seen on the ventral surface of the cord, especially in that part traversed by the anterior roots.

Summary of Post-mortem Appearances.

The right lung was solid with septic broncho-pneumonia and a small abscess was found at its extreme base.

The right kidney was the seat of a malignant growth (hypernephroma), characterised by columnar cells and the presence of pigment due to extravasated blood.

Secondary growths were found in the kidney and in the spinal cord.

That in the spinal cord had caused hæmorrhage which had extended beyond the limits of the metastatic growth. This focal lesion extended from the seventh thoracic to the second lumbar segment, occupying mainly the left posterior horn and the adjacent parts of the posterior and lateral columns. At the level of the tenth thoracic, it reached its maximum extent, destroying the whole of the left posterior horn and a greater portion of the left lateral column.

Acute ascending degeneration was found in both posterior columns.

Both lateral bundles of Gowers, the direct cerebellar tract and apparently the spino-thalamicus, also showed signs of acute degeneration.

Case 11.—Charles H.

A case of unilateral syringomyelia, which has been under observation from December, 1903.

Motion remains unaffected and he shows no wasting of any group of muscles.

The reflexes are still normal. He suffers from arthropathy of the right shoulder, which at one time gave rise to intense deep tenderness over a part of the analgesic limb.

Sensation to pain, heat and cold was at first lost over the whole of the right upper extremity and the upper part of the chest on the right side. This loss of sensation gradually spread on to the face and scalp. It has always been more extensive to heat and cold than to pain.

Tactile sensibility, the sense of passive position, tactile discrimination and tactile localisation have never been in any way affected.

Charles H., aged 30, first came under the care of Dr. Head at the London Hospital on December 7, 1903.

Eight years previously he was driving an omnibus; wishing to descend from the box, he missed the strap and fell, striking his right shoulder violently. He experienced "a feeling of numbness" and came to the London Hospital, but no serious injury was discovered. At the end of a week he returned to work.

Some considerable time afterwards, he noticed that his shoulder joint "clicked" when he moved his arm, although it was entirely painless.

But, about six months before his admission in 1903, he began to suffer pain whenever his shoulder "clicked." The pain was situated not only in the shoulder, but also around the right ear.

Shortly before admission, the right arm and shoulder began to swell and "became set"; when he placed his hand into his pocket, he could not remove it again.

He had had no other illness, and denied all venereal disease. He had been married nine years and had two healthy children.

He has been under observation from December, 1903, until the present time, and we have repeatedly examined him together, and separately. We shall, therefore, give a summary of his condition, noting under each separate heading any change that may have occurred in the condition of the part, or function, of which we are treating.

Physical Condition.

He is a splendidly built man with well-developed muscles. His heart and lungs are sound and he has shown no signs of visceral disease.

Throughout, he has been intelligent and unusually trustworthy to control tests. His answers over normal parts have always been quick and accurate.

Motion.—Throughout the last three years, motor power has never been affected, except from the pain produced by moving the right arm. The grasps have remained equal and powerful, and no muscles have shown signs of wasting.

He walks well and can stand perfectly with his eyes closed. The legs are neither spastic, paretic, nor wasted.

Reflexes.—The knee-jerks and wrist-jerks have remained normal, and both plantar reflexes have given a flexor response throughout. No ankle clonus was ever obtained.

Condition of the right shoulder joint.—When he was admitted to the hospital in 1903, the right shoulder joint was much swollen and evidently contained fluid. A radiograph showed that the head of the humerus had been eroded, so that its surface was concave instead of convex; there was also some excessive formation of bone around the trochanters and articular surface of the scapula. The fluid threw a dark hazy shadow round the joint. On February 8, 1904, a small quantity of fluid was removed from the joint; it was of a pinkish yellow colour and sterile on cultivation.

A considerable part of the swelling seemed to be due to muscular contraction, which varied from time to time.

At first, the joint was excessively painful, especially when the arm was moved. But gradually the pain subsided, and in September, 1906, movements produced no pain, although the joint was still swollen and measured 7 cm. more in circumference than the left shoulder.

Sensation. (*a*) *Symptomatic changes in sensation.*—He has complained throughout of no abnormal sensation, except of pain in connection with the right shoulder joint. This was aggravated by movement and relieved by keeping the arm at rest; although particularly severe during the hot summer of 1906, it had entirely disappeared by September of the same year.

(*b*) *Sensibility to pain.*—(1) *Analgesia.*—When first seen, he was insensitive to the pain of a prick over the whole of the right upper limb, almost as high as the acromion. The cutaneous analgesia extended over the scapula behind, and over the third rib and third interspace in front.

This area has gradually increased under observation, and the extent of the cutaneous analgesia at the end of 1906 is represented on Fig. 126.

Throughout, the extent of the insensibility to the painful interrupted current has corresponded exactly with that to the pain of a prick.

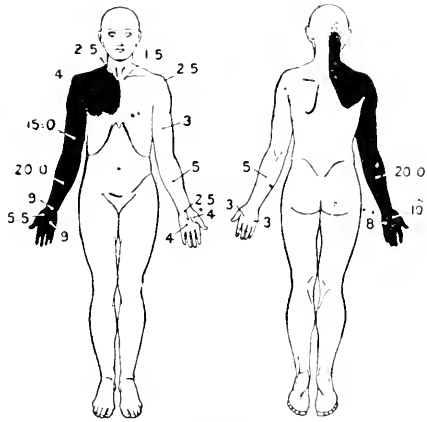

FIG. 126.

To show the loss of sensibility to pain in Case 11.

The area marked in black corresponds to the cutaneous analgesia. At various points are placed numbers corresponding to the pressure which caused pain. Thus 5·5 means that pain was caused by an algometer pressure of 5·5 kilograms. But such a number as 20 = 0 means that no pain could be caused even by a pressure of 20 kilograms.

In 1906, his sensibility to the pain of pressure was measured with the algometer, and the following readings were obtained :—

	Right.	*Left.*
Thenar eminence	Pain at 5·5	Pain at 4.
Centre of palm	Pain at 9	Pain at 4.
Ulnar palm over fifth metacarpal	Pain at 5	Pain at 4·5.
Dorsum of hand :—		
Over second metacarpal	Slight pain at 10	Pain at 3.
Over third metacarpal	Just painful at 11	Pain at 2.
Over fifth metacarpal	Pain at 8	Pain at 3.
Anterior aspect of wrist	Pain at 9	Pain at 2·5.
Forearm :—		
Flexor aspect	No pain at 20	Pain at 5.
Extensor aspect	No pain at 20	Pain at 5.
Arm :—		
Outer aspect	No pain at 15	Pain at 3.
Inner aspect	No pain at 15	Pain at 3·5.
Shoulder joint	Deep hyperalgesia (*vide* p. 442)	Pain at 2.
Acromion	Pain at 4	Pain at 2·5.
Sterno-clavicular joint	Pain at 2·5	Pain at 1·5.
Mastoid	Pain at 1·5	Pain at 1·5.
Temple	Pain at 1·5	Pain at 1·5.
Iliac crest	Pain at 2	Pain at 2.
Sole	Pain at 2	Pain at 2.

The results of these observations have been transferred to Fig. 126. The area marked in black is that which was insensitive to all cutaneous painful stimuli, and the numbers represent the pressure in kilograms which caused pain. It will be seen that over both the extensor and flexor aspect of the forearms and over the arm, pressure even up to 15 kilograms produced no pain. But no part of the hand was insensitive to this stimulus, although greater pressure was required to cause pain than over the normal hand.

(2) *Deep hyperalgesia.*—When first admitted in 1903, he suffered intensely from pain in and around the right shoulder joint. But, in addition to this pain, he was found to be tender to deep touch over an area which occupied, on the outer aspect of the arm, the whole of the region of the deltoid to a point somewhat distal to the insertion of that muscle. When touched with the head of a pin, or when the skin was pinched between the finger and thumb, this area was exquisitely tender, and by means of either of these manipulations, its limits could be mapped out with considerable accuracy.

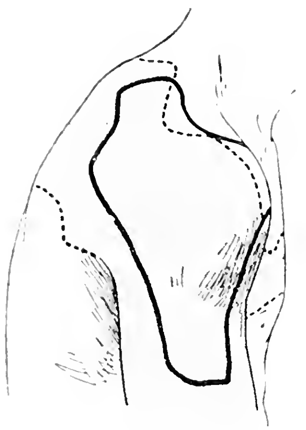

Fig. 127.

To show the relation of the deep hyperalgesia to the cutaneous analgesia in Case 11. The area of cutaneous analgesia is coloured grey and enclosed by a broken line; the area hyperalgesic even to the lightest pressure is enclosed by a heavy black line.

There was no tenderness to light touches, but pain was produced if the skin was tapped with cotton wool rolled into a hard wisp.

Yet the whole of this area, as far as it lay over the arm, was absolutely insensitive to the pain of a prick and to the painful interrupted current.

These observations were made and repeatedly confirmed during the first four months of 1904. Throughout the whole of this period the shoulder joint was unusually painful.

A year later, in March, 1905, the joint was less painful and the area of tenderness less extensive. It then lay entirely within the limits of the cutaneous analgesia. If he was pricked within the limits of this tenderness, he complained of an "acute sharp pain" which persisted for about a minute after the stimulus had ceased. But, when the skin over the same parts was gently lifted between the finger and thumb, the prick of a pin over the lifted skin was said to be a touch only; as soon as it was released, the prick was again said to cause pain. Any pressure over this area caused an "aching feeling."

In September, 1906, the joint was still swollen but no longer painful. All widespread hyperalgesia had disappeared. But, when tested with the algometer, he complained that any pressure produced pain. "Something seemed to shift in the joint which immediately caused pain"; yet the pressure was below 1 kilogram, and could not be registered on the instrument.

Here we were face to face with a true deep hyperalgesia, co-existing beneath an area of complete cutaneous analgesia. The lightest pressure stimuli caused pain and the extent of the hyperalgesia could be marked out on the skin. Yet the superficial layers of the skin were analgesic to the prick of a pin when raised from the subcutaneous structures.

As the cutaneous analgesia gradually advanced up the neck, the joint became less painful and the area of excessive tenderness disappeared.

(c) *Thermal sensibility.*—When he was first seen, the loss of sensibility to cold had not invaded the scalp, but occupied the right half of the neck only. Gradually, it assumed the form shown on Fig. 128.

The extent of the loss to heat usually corresponded closely to that of the loss to cold. But at times the two forms of sensibility were dissociated, as seen on Fig. 129, where the anæsthesia to heat exceeded that to cold. Over this dissociated area, he was carefully tested with temperatures of 25° C., 27° C., 35° C., and 40° C.; all were said to produce a sensation of touch only. None of these borders were at this time absolutely fixed, and the figures are given to illustrate the complete dissociation between the sensibility to heat and to cold, occurring over a part so sensitive to these stimuli as the forehead.

(*d*) *Tactile sensibility.*—Light touches were everywhere appreciated and there was no difference between the two upper limbs on careful testing with von Frey's hairs.

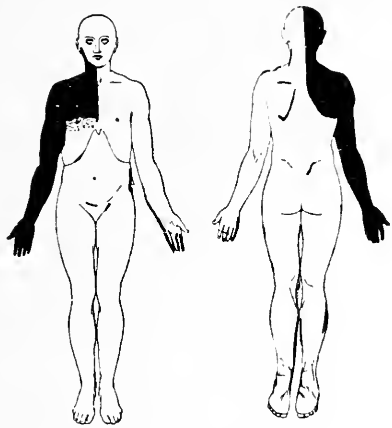

Fig. 128.

To show the loss of sensation to heat and cold in Case 11. The extent of the loss to heat on the face was occasionally somewhat greater than that of the loss to cold (*vide* Fig. 129).

(*e*) *Recognition of a point.*—He could distinguish the head from the point of the pin everywhere over the analgesic area of the right upper limb.

(*f*) *Appreciation of the difference in size* was tested by means of metal rods with diameters of 2 cm., 0·5 cm., and 0·2 cm. His answers were equally accurate over both upper limbs.

(*g*) *The vibrations of a tuning fork* (128) were appreciated everywhere equally on the two upper

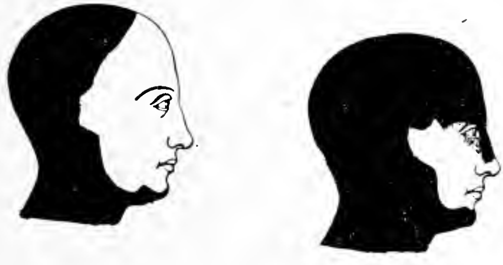

Fig. 129.

The extent of the loss to heat in Case 11 usually corresponded closely to that of the loss to cold. But at times the area insensible to heat exceeded in extent that insensitive to cold, as shown in this Fig.

limbs. He was extremely quick in answering to a careful series of control experiments, which consisted of suddenly and unexpectedly damping the vibrations.

The legs were in every way normal.

(*h*) *The sense of passive position and movement* was everywhere preserved, even for movements of the grossly disorganised shoulder joint.

(*i*) *The compass test.*—Throughout, we have been unable to discover any difference in the compass records obtained from the two upper limbs. His threshold (transverse) for the palms lies between 1 cm. and 2 cm.; at 2 cm. he has always answered correctly, and occasionally he has given a perfect series of answers at 1·5 cm. over both palms; but at 1 cm. he has uniformly failed to a varying degree.

(j) *Tactile localisation* was equally good over both arms and both legs.

Cranial nerves.—The pupils were equal, and reacted well to light and accommodation. The movements of the face, tongue, palate and vocal cords were perfectly performed.

Sphincters.—He had no trouble with the sphincters at any time.

Spine.—When first seen, his spine was straight; but by April, 1905, a slight degree of scoliosis had appeared, the concavity of the curve lying to the right, in the middle of the thoracic region.

Case 12.—Walter John H.

First examined in March, 1904. For eight years before this date he had been unable to appreciate heat and cold applied to the right hand, or to feel the pain of a suppurating finger. For one year the right half of the face had sweated excessively when he ate or drank.

At this time there were no changes of any kind pointing to disease of the nervous system, except the loss of sensation to painful or thermal stimulation shown on Figs. 130 and 131. His condition remained unchanged until September, 1905.

By August, 1906, the muscles of the right hand had become wasted and the hand had lost power. The loss of sensation had greatly increased, and had invaded the left hand (Figs. 132 and 133). Sensibility to light touch and pressure, and the sense of passive position and movement, were unaffected.

Walter John H. was first examined in March, 1904. He was then 30 years of age and a fishmonger by trade.

He complained that for the last eight years or more he had noticed that the right arm was different from the left; it seemed colder and there was a sensation of tightness in his fingers. When he took a hot thing into his right hand, he did not at once recognise it was hot. In 1903, he poisoned the thumb of the right hand; it "gathered" and suppurated, but he experienced no throbbing or pain, as with other fingers under similar circumstances.

For the last twelve months, it happened that whenever he ate or even at times when he drank, the whole right half of his face, forehead and head sweated profusely. He has been compelled to use a handkerchief to prevent the sweat running off his face.

Otherwise, he complained of no abnormal symptoms and said he was in the best of health.

He had suffered twice from gonorrhœa ten years before, but neither attack was followed by any symptoms pointing to syphilis. He was married, and had two healthy children.

His father died at the age of 47 of dementia paralytica, and his mother is highly neurotic; she has had several attacks of hysteria in which she has lost her speech. He has nine living brothers and sisters, all of whom are healthy. No collateral history of neuroses could be obtained.

From 1904 until April, 1905, the signs and symptoms of his disease remained unchanged, and we shall therefore give first the results of our examination in April, 1905.

Condition in April, 1905.

He was a largely built man, unduly corpulent for his age, but otherwise of healthy appearance. His pulse was regular, of good tension, and the arterial wall was not thickened. Heart and lungs were unaffected, and the urine was normal.

From the point of view of the nervous system, the only change was in sensation; there was no paralysis or wasting of muscles, no trophic changes in the skin or nails. His knee-jerks were equal and normal, ankle clonus was not obtained, and both plantar reflexes gave a flexor response. The pupils reacted to light and accommodation. Vision was good; hearing, taste and smell were unaffected. No abnormality was found in the movements of the face, the tongue, the palate or the larynx. Both sphincters acted normally.

Sensation.—About 1896 he began to notice that whenever he had a cough a stabbing pain struck him in the right shoulder blade over a point at the vertebral border of the spine of the scapula. The centre of incidence of this pain gradually shifted upwards. At first it was situated close to the spine of the scapula; then it moved to the back of the neck, thence to the parietal region. From this point it moved forwards to the vertex, then to the temple, and in April, 1905, was situated in the right eyeball. Each time he coughed he had a feeling as if he had been struck a violent blow in the eye.

He complained of no abnormal sensations in the right arm and hand, except that in the winter they did not suffer from the cold weather in the same way as the left.

Cutaneous painful stimuli were not appreciated when applied anywhere within the heavily shaded area of Fig. 130. Over the parts dotted in this figure, a prick sometimes caused pain, but was frequently said to be a touch only.

He was entirely insensitive to all degrees of heat and cold over the darkened parts of Fig. 131. The border on the face and behind the ear was unusually definite.

The stimuli of light touch, deep touch and pressure were everywhere appreciated and accurately localised. He could tell the head from the point of a pin, even over parts that were

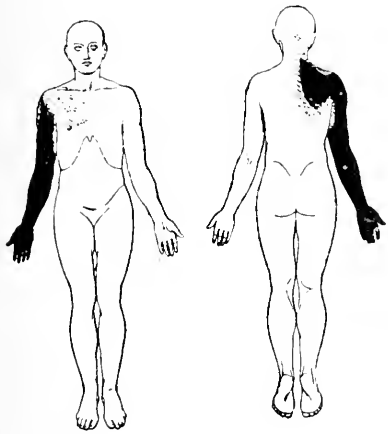

Fig. 130.

To show the loss of sensibility to cutaneous painful stimuli in 1905.

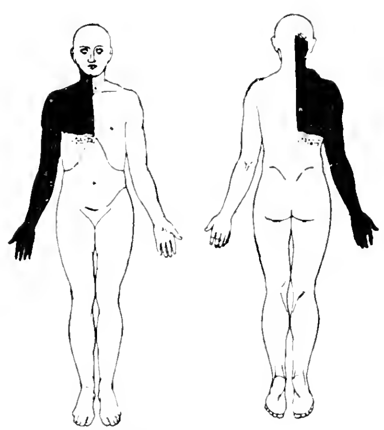

Fig. 131.

To show the loss of sensation to heat and cold in 1905.

completely analgesic. In the same way, he was able to discriminate everywhere between contact with a circular metal surface 1 cm. in diameter and a similar surface with a diameter of 2·5 cm. There was no loss of the sense of passive position or movement. The vibrations of a tuning fork (128) were everywhere recognised. The two points of the compasses gave the same result on both the normal and abnormal hand: his answers were good, when the two points were separated for a distance of 1 cm., and applied transversely.

Condition in 1906.

In August, 1906, his condition had undergone a remarkable change. During the previous winter, he had noticed a gradual loss of power in the right arm, and the grip of the right hand had become less powerful. The little finger became gradually abducted from its fellows, when the hand was at rest. He also noticed involuntary twitchings in the muscles of the thumb and of the forearm.

He stated that in September, 1905, he experienced a sudden acute pain in the left arm, and since then had suffered from cramp in the left hand. These symptoms were, he believed, the same as those which preceded the loss of power in the right hand.

Motion.—The thenar and hypothenar eminences and the muscles in the first interosseous space of the right hand were definitely wasted. Fibrillary twitchings could be seen in the muscles of the right thumb, and in those which arise from the external condyle of the humerus.

The grip of the right hand was weaker than that of the left, and he had difficulty in opposing the thumb. All the interosseous movements were well performed.

The small thumb-muscles reacted slowly to the interrupted current, and, when the right abductor minimi digiti was stimulated, a certain number of fibrils only contracted, in contrast to the normal reaction of the synonymous muscles in the other hand. All the muscles reacted well to the constant current, except the thenar group of the right hand, which reacted as easily with the anode as with the kathode.

The muscles of the left hand and arm were entirely unaffected.

Sensation.—A remarkable increase had occurred in the extent of the loss of sensation to painful and thermal stimulation (as shown on Figs. 132 and 133). The limits of the loss of sensation to the painful interrupted current corresponded exactly with those of the analgesia to prick.

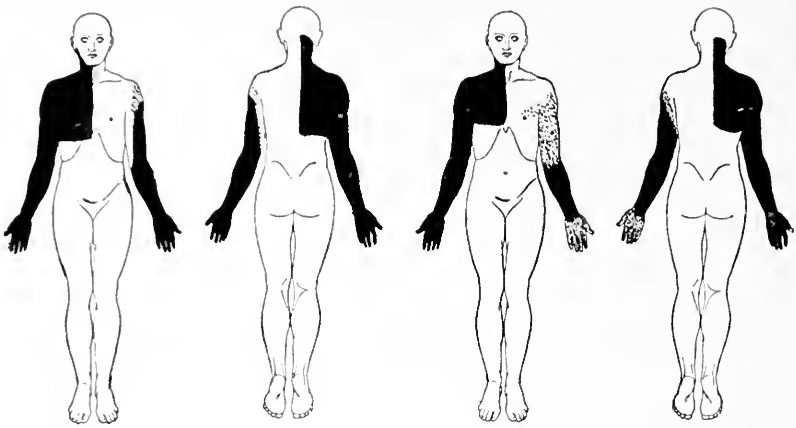

FIG. 132. FIG. 133.

To show the loss of sensation to cutaneous painful stimuli (Fig. 132) and to heat and cold (Fig. 133) in 1906. Evidently the loss of sensation was extending in the left upper extremity.

Over the whole of the thermo-anæsthetic area on the right arm, he failed to recognise heat and cold with any degree of temperature between melting ice and 60° C. Over the left arm the results were less definite, and he sometimes seemed to appreciate stimulation by the more extreme degrees of heat and cold, where water at 40° or 20° C. produced no sensation. Evidently, the loss of sensibility to heat and cold was here less complete than in the right arm.

The border on the face between parts that were sensitive and those that were insensitive to thermal stimuli was remarkably constant and varied little, according to the direction in which the tests were made. In 1905 the analgesia did not extend on to the face, as will be seen from Fig. 130. But in 1906 the loss of sensation to painful stimuli spread until the residual sensibility was identical to prick, to heat, and to cold. Moreover, the border so marked out corresponded exactly with that determined by means of thermal stimuli nearly a year and a half before. This border is shown on Fig. 102, p. 382.

The algometer gave the following readings, which showed that deep pressure caused no pain over the whole of the right upper extremity. Over the left palm and flexor surface of the forearm, pain was not produced at first until the pressure was raised considerably above the normal threshold. But on repeating the experiment pain was produced by pressures no greater than those which are painful on a normal hand.

	Right.	Left.
Palm of hand	No pain at 10	Pain at 10-7-4.
Over first metacarpo-phalangeal joint	No pain at 10	Pain at 6.
Lower end of radius	No pain at 10	Pain at 6.
Flexor aspect of forearm	No pain at 15	Pain at 10-7-5.
Elbow	No pain at 10	Pain at 5.
Outer aspect of shoulder	No pain at 15	Pain at 5-3·5.
Sterno-clavicular joint	No pain at 10	Pain at 1·5-1.
Occiput	Pain at 1·5	Pain at 1·5.
Temple	Pain at 2	Pain at 2.
Over inner aspect of shin	Pain at 3	Pain at 3.

The vibrations of the tuning fork (128) were less clearly recognised over the whole of the right arm from the elbow to the shoulder joint than over similar parts of the left side.

Stimulation with cotton wool and with pressure was everywhere appreciated, and the point of contact accurately localised.

No. 5 of von Frey's hairs (21 grm./mm.^{2}) produced a sensation of touch over both palms and the flexor aspect of both forearms.

The sense of passive movement and position was entirely unaffected, and there was no difference in the sensibility to the compass test between the two upper limbs. Everywhere, over both arms and both hands, he could tell the point from the head of a pin, even over parts that were insensitive to a prick, and he could appreciate the difference in size between metal discs of 2 cm., 1·4 cm., ·75 cm., ·2 cm.; but he was somewhat less accurate on the right side than the left.

Case 13.—Thomas B.

For three years, and probably longer, he had suffered from chronic disease of the spinal cord (syringomyelia).

Analgesia and thermo-anæsthesia existed over the areas in Fig. 134.

No other forms of sensation were affected.

The muscles of both hands, especially the right, were wasted.

The left elbow joint was disorganised.

The reflexes were unaffected.

Thomas B., aged 48, a labourer in a jam factory, came to the London Hospital on November 18, 1905, complaining of a painful swelling of the left elbow.

He dated his illness from a fall on to his head three years before. But, for more than three years, his hands had always "felt cold," even when he was sitting before a fire; and when he went to bed, it was more than an hour before they became warm.

During the last two years before he came to the hospital, he had noticed wasting of the muscles of his hands, first in the right and later in the left.

He had been in the Army, serving five years in India; there he had contracted syphilis, for which he was treated for a month only. Otherwise, his health had been excellent. He had been married for twenty-four years and his wife had had thirteen children.

Present Condition.

He has been under observation for over twelve months and his condition has changed little, if at all. He is a short but sturdily built man of fair intelligence. He was firm to control tests, and, provided the experiments were not too complex, gave consistently accurate answers.

He was in every way normal, except for the following changes in the nervous system.

Motion.—The small muscles of the right hand were much wasted, the thenar and hypothenar eminences were flattened, and the thumb was extended, lying in the plane of the palm. All the interossei showed signs of atrophy. The proximal phalanges of the fingers were hyper-extended at the metacarpo-phalangeal joints, and the two terminal phalanges were flexed. No contraction could be seen or felt when he attempted to abduct or oppose the thumb; interosseous movements were impossible, and he could not abduct the index or little finger.

All movements of the wrist could be performed with ease, and the forearm muscles showed no signs of wasting.

The left hand was wasted, but to a less degree than the right, and the thenar eminence was flattened.

He could carry out all movements with his left hand and could even oppose and abduct his thumb.

None of the muscles of the left forearm were wasted, and all acted perfectly.

All the muscles of both upper extremities reacted well to the interrupted and to the constant current, excepting only the outer thenar group and the interossei of the right hand; these muscles could not be made to react, even to a strong interrupted current. On stimulation with the constant current, they reacted slightly, more easily to the cathode than to the anode.

His gait was normal and he could stand steadily even with his eyes closed.

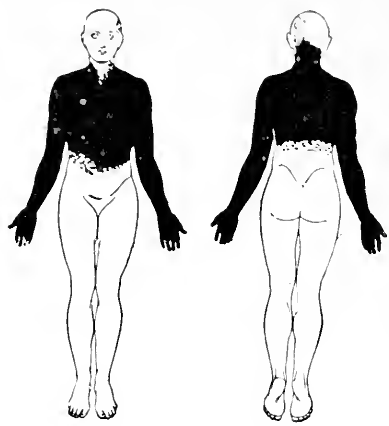

Fig. 134.

To show the loss of sensation to cutaneous painful stimuli and to heat in Case 13. The loss of sensation to cold is described in the text.

The muscles of the legs showed no signs of wasting or spasticity.

Reflexes.—The knee-jerks were in every way normal: no ankle clonus could be obtained and the plantar reflex gave a flexor response on both sides.

Articular changes.—The left elbow was much swollen and disorganised; creaking could be obtained on manipulation, and there was excess of fluid with much bony outgrowth around the joint. A radiograph showed much destruction of the opposing surfaces of the elbow joint, with the formation of many osteophytic masses.

He complained of no other joint in his body, but a radiograph of the right elbow also showed slight bony changes.

Spinal column.—The spine showed a distinct lateral curve in the thoracic region with a convexity to the right, and a second curve towards the left in the region of the lower thoracic and lumbar spines.

Sensation.—He occasionally complained of pain in the left elbow, probably induced by the nature of his work; for, owing to the loss of power in the right hand, he was compelled to use the left arm to raise heavy bags of sugar by means of a hand-winch. At no time could we elicit pain by manipulation of this joint.

The curious sensations of coldness in the hands, so marked a feature during the winter, greatly improved with the coming of summer. On an extremely hot day in September, 1906, these sensations had entirely disappeared.

(*a*) *Sensibility to painful stimuli.*—He was entirely analgesic to the prick of a pin and to the painful interrupted current over the area shown in Fig. 134; this was of somewhat greater extent in the winter than in the summer. But the borders of the loss of sensation always merged gradually into parts of normal sensibility.

The pain of deep pressure, as tested by the algometer, was completely lost over both upper extremities and over the upper part of the trunk. Elsewhere, pain was produced as usual, as will be seen from the following records. At each application he was able to recognise the gradually increasing pressure; but over the analgesic areas it caused no pain.

	Right.	*Left.*
Palm of hand	No pain at 15	No pain at 15.
Thenar eminence	No pain at 15	No pain at 15.
Elbow	No pain at 15	No pain at 15.
Shoulder	No pain at 15	No pain at 15.
Sterno-clavicular joint	No pain at 10	No pain at 10.
Mastoid process	Pain at 3	Pain at 3.
Temple	Pain at 2	Pain at 2.
Sole of foot	Pain at 3	Pain at 4.
Inner aspect of tibia	Pain at 3·5	Pain at 3·5.
Outer aspect of anterior superior iliac spine	Pain at 5	Pain at 5.

(*b*) *Sensibility to thermal stimuli.*—During the winter, the thermo-anæsthesia corresponded almost completely with the extent of the cutaneous insensibility to pain; but during the summer of 1906, it was found that, although the insensibility to heat still corresponded with the loss of sensation to prick, the anæsthesia to ice was of somewhat smaller extent. A long series of experiments were made at this time over the outer aspect of the arms, where he seemed to be sensitive to ice, though insensitive to heat, and it was found that he was able to appreciate temperatures from 0° to 27° C., calling them all cold; but above this temperature, he seemed to be unable to appreciate certainly any thermal stimulus, calling 70° C. " a shade warm."

(*c*) *Tactile sensibility.*—The palms of both hands were horny and insensitive; but, except over the hairless parts of the hands, he was normally sensitive everywhere to stimulations with cotton wool. Sensibility to pressure was nowhere disturbed.

(*d*) *Recognition of a point and discrimination of difference in size.*—He could distinguish accurately the head from the point of a pin all over the analgesic area. Neither caused pain, but he described a prick as "like the point of a needle"; the head of the pin was said to be "blunter."

To test his power of recognising differences in size, steel rods were used with diameters of 2 cm., 0·4 cm. and 0·2 cm. His answers were invariably correct even over both palms.

(*e*) *Passive position and movement.*—To this test his answers were remarkably quick and accurate; even movements of the disorganised elbow were correctly appreciated.

When any muscle of one hand was thrown into action by stimulation with the interrupted current, he recognised the movement, imitating it perfectly with the opposite hand. Similarly, he could reproduce with the one upper extremity every movement produced in the other by electrical stimulation.

(*f*) *The compass test.*—Over both palms the threshold to the compasses applied transversely lay between 2 and 3 cm. When applied longitudinally, he gave a perfect series of answers at 2·5 cm.

(*g*) Tactile localisation was nowhere affected, and we could find no difference between the two sides of the body.

Sphincters.—Micturition and defæcation were unaffected.

Case 14.—Florence R.

A case of syringomyelia, watched from 1899 to the present time [1906]. The first signs consisted of wasting of the small muscles of the left hand with disturbed sensibility, which was transitory only.

Gradually, the muscular wasting increased, and in 1902 sensibility was again found to be disturbed in the left hand. This change progressed until, at the end of 1906, the cutaneous insensibility to pain was complete everywhere and the thermo-anæsthesia was widespread.

No other form of sensibility has been disturbed at any time.

The reflexes and sphincters have remained unaffected.

Florence R. has been under observation since October, 1899, when she first came to the London Hospital complaining of neuralgic pains in the occipital region and numbness in the left arm. For several months she had noticed a tendency to drop things from her left hand but, until the muscular atrophy was pointed out to her at the hospital, she was not aware that the hand was wasted.

A stout, healthy looking woman of 24, she showed no abnormal signs except those pointing to disease of the nervous system.

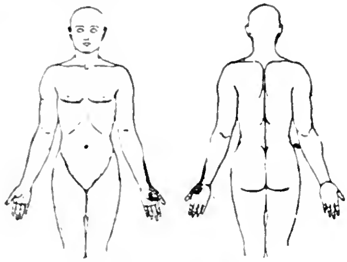

Fig. 135.

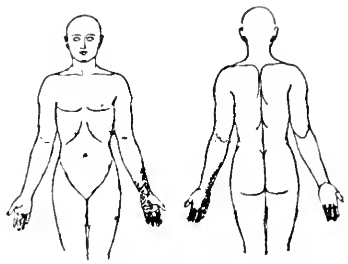

Fig. 136.

Fig. 135 shows the disturbance of thermal sensibility discovered in October, 1899. Sensation to prick was unaffected.

Fig. 136 shows the disturbance of sensibility to heat, to cold, and to prick, which appeared in March, 1902. For the intervening two and a half years no definite loss of sensation could be discovered in spite of the progressive muscular atrophy.

The small muscles of the left hand were wasted, especially the interossei. The hand had begun to assume the " clawed " position, but the thumb lay in the normal position, and the thenar muscles, though flabby, were not definitely wasted.

At this time the only other abnormal sign consisted of a diminished sensibility to heat and cold over a small area on the forearm and hand (Fig. 135).

By January, 1900, the muscular atrophy in the left hand had greatly increased, and the muscles of the left forearm showed signs of wasting, but no sensory disturbance could be discovered.

In March, 1900, the interossei, thenar and hypothenar muscles of the left hand were much wasted, and she could not oppose, abduct or adduct the thumb. The hand was " clawed," with the fingers over-extended at the metacarpo-phalangeal and flexed at the phalangeal joints. At this time the muscles of the right hand had begun to waste, more particularly the first dorsal interosseous and the muscles of the thenar eminence. The only muscles of either extremity which did not react normally to electrical stimulation were the interossei and the abductor and opponens pollicis of the left hand; none of these muscles responded to the interrupted current, but they contracted slowly to making the constant current more readily with the anode than with the cathode.

Throughout the first two and a half years, no definite change could be discovered in sensation except during October, 1899, when she first came to the hospital. But in March, 1902, after another severe attack of neuralgic pains, distinct loss of sensation to heat and cold and to prick was found over the area shown on Fig. 136. The muscular wasting had steadily progressed, not only in the left hand, but also in the small muscles of the right hand; the left forearm had already become affected.

In November, 1902, she suffered greatly from pain up the back of her neck and in both shoulder blades, and was so unwell she was compelled to give up her employment. The loss of sensation advanced greatly in extent. Over the areas shown on Fig. 137, she was insensitive to stimulation with all degrees of cold; the loss of sensation to heat was somewhat more extensive on the left upper extremity, somewhat less extensive on the right. Sensibility to prick was nowhere lost,

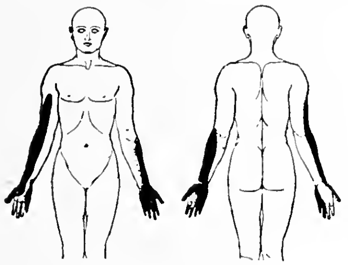

Fig. 137.

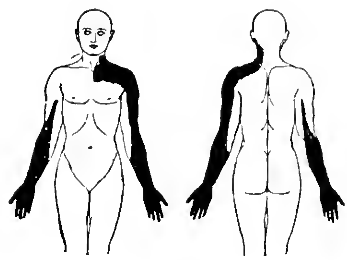

Fig. 138.

Fig. 137 shows the areas insensitive to cold in November, 1902.
Fig. 138 shows the areas insensitive to cold in June, 1903. The extent of the loss to heat and to prick is given in the text.

but was undoubtedly diminished over the left hand. Every other form of sensation was perfectly preserved.

The muscular wasting had made little or no progress, and the electrical reactions were identical with those obtained in March, 1900.

By June, 1903, the loss of sensation had progressed greatly. The greater part of the left arm and the whole of the right forearm and hand were insensitive to all degrees of cold (Fig. 138).

The extent of the loss of sensation to heat corresponded on the left arm with that to cold,

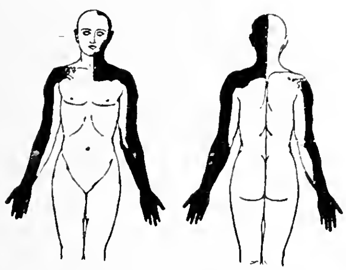

Fig. 139.

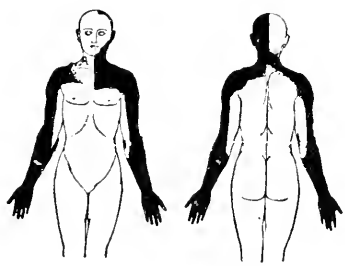

Fig. 140.

Fig. 139 shows the loss to sensation to cold and to heat in November, 1903.
Fig. 140 shows how little the loss of sensation had advanced by February, 1904.

but was less extensive over the right upper extremity. Analgesia to prick was almost confined to the left half of the neck and left upper extremity, where it corresponded exactly with the area on Fig. 138. Every other form of sensibility was perfectly preserved.

The muscular wasting had progressed very little, if at all, and the reflexes were unaffected.

The loss of sensation spread rapidly, and by November, 1903, had invaded the face and greater part of the scalp on the left side. Over the whole left half of the body, the loss of sensation was coterminous to prick, to heat and to cold (Fig. 139). But on the right side, although the thermo-anæsthesia occupied a considerable portion of the right upper extremity, analgesia to prick was found over the hand and part of the forearm only.

The muscles originally affected had continued to waste, but no further ones had been attacked since March, 1902. The thenar muscles and abductor minimi digiti of the left hand did not react to the interrupted current, but a response could be obtained from all the interossei in spite of their profound wasting. Every muscle of the left hand reacted to the constant current, even the wasted strips which represented the muscles of the thumb. In the right hand, normal reactions were everywhere obtained.

From November, 1903, to February, 1904, the loss of sensation did not extend on the left half of the body and head, but slight advance took place over the right shoulder and neck.

During this period, advantage was taken of the stationary condition of the symptoms to work out the extent of residual sensibility on the left half of the face (Fig. 104, p. 382). The border between normal and abnormal parts was found to differ little, whether the stimulus was a prick, or test tube containing water at different temperatures.

By February, 1905, the loss of sensation to all three stimuli had extended considerably on the trunk, and the thermo-anæsthesia exceeded somewhat the loss to prick, and was no longer bounded by definite borders (Fig. 141).

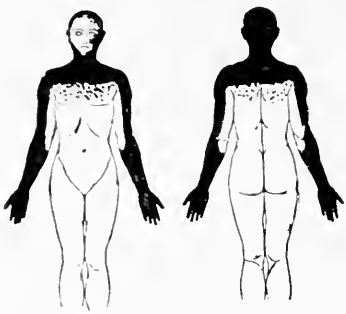

Fig. 141.

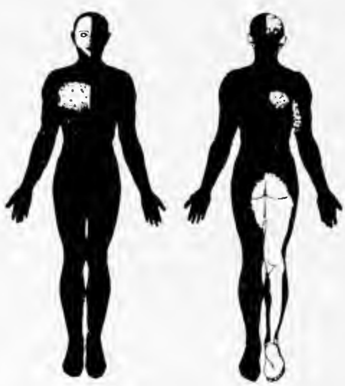

Fig. 142.

Fig. 141 shows the thermo-anæsthesia in March, 1905.
Fig. 142 shows the loss of sensation to cold in September, 1906.

The muscular wasting was at this time profound in all the small muscles of both hands, but greater in the left than the right. She could not make any movement with the small muscles of the left thumb, and adduction and abduction of the fingers was impossible. All movements of the right hand could be performed, but those requiring contraction of the intrinsic muscles were feeble. The only muscles which did not react to the interrupted current were those of the left thumb.

Condition from May to September, 1906.

She was a short, red-cheeked woman, of healthy appearance, except for her wasted hands.

Her speech is unaffected and she has never suffered from fits or sudden attacks of weakness in any limb.

Sensation.—She has suffered from much pain in the head, beginning in the left temple and passing over the forehead and bridge of the nose. The pain then passed into the spine, extending as low as the lumbar region.

Not uncommonly she experienced a curious sensation in the left half of the face, exactly as if it had been rubbed with menthol. Occasionally she has felt as if she had no left ear, and is compelled to touch it to assure herself of its presence.

During the extremely hot weather she was comfortably cool.

(*a*) *Sensibility to pain.*—The cutaneous analgesia had advanced to such an extent, that there was no part of the body or face where she could appreciate the prick of a pin, or the painful aspect of an interrupted current.

Over both upper extremities and over both thighs no pain could be produced by excessive pressure, and the following records were obtained on the algometer:—

	Right.	*Left.*
Palm	No pain at 20	No pain at 20.
Forearm	No pain at 15	No pain at 15.
Arm	No pain at 15	No pain at 15.
Shoulder	No pain at 15	No pain at 15.
Sterno-clavicular joint	Slight pain at 5	Slight pain at 5.
Temple	Slight pain at 5	Slight pain at 5.
Sole	No pain at 20	Pain at 5.
Outer malleolus	Pain at 10	Pain at 4.
Inner aspect of shin	Pain at 9	Pain at 3.
Knee	No pain at 15	No pain at 15.
Thigh	No pain at 15	No pain at 15.
Outer aspect of ant. sup. spine of ileum	No pain at 15	No pain at 15.

(*b*) *Thermal sensibility.*—She was insensitive to all degrees of cold stimulation over the areas shown on Fig. 142. But, over the parts which remain undarkened on this figure, she did not always respond, even to stimulation with ice. It was evident that the sensibility of these parts varied with her general condition.

To heat, especially the more extreme degrees, she was more widely sensitive; but it is extremely difficult to be certain how far this is based on a true appreciation of the nature of the stimulus, on account of her tendency to call even neutral touches "warm."

(*c*) *Tactile sensibility.*—Stimulation with cotton wool was everywhere appreciated, and she recognised No. 5 of von Frey's hairs over both palms.

(*d*) *Recognition of a point.*—She could tell the head from the point of a pin everywhere, in spite of the total cutaneous analgesia.

(*e*) *The vibrations of a tuning fork* were quickly recognised everywhere.

(*f*) *Sense of passive position and movement* was everywhere perfectly preserved.

(*g*) *Tactile discrimination.*—Over both palms the compass records were perfect at 2 cm., when the points were applied longitudinally.

(*h*) *Tactile localisation* was good everywhere; a series of tests were made over the hands, using No. 5 of von Frey's hairs as the stimulus, and she named the spot touched with remarkable accuracy.

Motion.—The wasting and loss of power had not changed materially from the condition in 1905.

Reflexes.—The knee-jerks were normal. No ankle clonus could be obtained and both plantar reflexes gave a flexor response.

Sphincters.—She had no trouble with micturition or defæcation.

Cranial Nerves.—The pupils were equal and reacted normally. Movements of the face and tongue were well performed.

On ophthalmoscopic examination, disc and fundus were found to be normal.

Case 15.—George B.

A case of chronic intramedullary growth or syringomyelia.

When first seen by us in October, 1906, he complained that sensation had been altered in his right hand for seven years, and that he had gradually lost the power of writing.

Profound loss of sensation was present over the right upper extremity. The loss of tactile sensibility was unilateral (Figs. 146 and 147), but to painful and thermal stimuli the left upper extremity was also affected (Figs. 143, 144, and 145).

The sense of passive position was absent in the fingers and thumb of the right hand. Tactile localisation and tactile discrimination were unaffected over parts which were sensitive to touch.

Early signs of wasting and some weakness were present in the right hand. The right leg tended to be spastic.

The right knee-jerk was greatly increased, and the right plantar reflex gave an extensor response.

Rotatory nystagmus was present in both eyes when he looked to the right.

No other abnormal signs were found in the territory of the cranial nerves.

For some time he had had difficulty in passing water and in holding his motions when they were loose.

George B., aged 35, a painter, came to the London Hospital in October, 1906, for numbness and loss of power in the right hand.

Seven years before, he began to notice that the hand seemed always cold. On many occasions he burnt himself and knew nothing of it until he saw the burns on his right hand. He could retain an object so long as he saw what he was holding, but often dropped it from his right hand, ignorant that it was no longer in his grasp. The power of writing had gradually left him.

Two years before he came to the hospital his right hand was poisoned by the bite of a mosquito, but the inflammation and even the incisions which became necessary on account of the swelling were entirely painless.

For eighteen months he had noticed stiffness of the right hip with some "numbness" of the sole of the right foot, and this leg had "jumped" at night.

He had noticed some difficulty in passing water for a considerable time before coming to the hospital, and for ten months had lost all sexual desire.

A bony projection had been slowly growing at the distal end of the proximal phalanx of the right thumb.

He was temperate and denied infection with syphilis or gonorrhœa. He had been married for ten years; his wife had never been pregnant.

Condition from October, 1906, to February, 1907.

He was a stout, heavily built man, somewhat slow of speech, but intelligent, and able to concentrate his attention during the testing of sensation.

Except for the symptoms and signs produced by the disease of the nervous system, he was in every way normal.

Motion.—He walked on a somewhat broad base, but did not drag either foot, and could stand well with the eyes closed. He could not stand on either foot alone. When he attempted to stand on the left foot with the right raised, a few swaying movements preceded his fall, but when he raised the left foot he fell instantly.

The right leg was held stiffly and, if he was examined after he had been walking about, all the joints could be moved passively without undue effort. But the right leg was distinctly spastic after he had been for some time in bed, especially at the end of a morning spent in sensory stimulation whereby the leg had been frequently thrown into spasmodic contraction. The right leg was not paralysed or wasted.

The condition of the left leg was in every way normal.

There was no wasting of either hand, but fibrillary twitching was noticed in the third and fourth interosseous spaces. The grasp of the right hand was somewhat more feeble than that of the left (right 16 kgm., left 23 kgm.), and the fingers were out of alignment, coming together unsteadily. This was especially noticeable in the little and ring fingers; but every movement of the right hand was possible. The extensors of the right wrist acted less powerfully than those of the left forearm; every other movement of both upper extremities was well and equally performed. All muscles, including those of the right hand, reacted normally to both forms of electrical stimulation.

Reflexes.—The right knee-jerk was greatly increased compared with the left. No ankle clonus could be obtained, but the right plantar reflex gave an extensor response. That on the left side was of the normal flexor type.

Sensation. (*a*) *Sensibility to painful stimuli.*—The whole of the parts marked on Fig. 143 were insensitive to cutaneous painful stimuli. Over the inner aspect of the right arm, sensation was still present to prick and to the painful interrupted current, and the borders of this area in the long axis of the arm were sharply defined.

The condition of the left hand and forearm varied from day to day, but at the best sensibility to cutaneous painful stimuli was gravely diminished, and on several occasions the greater part of the hand was entirely analgesic.

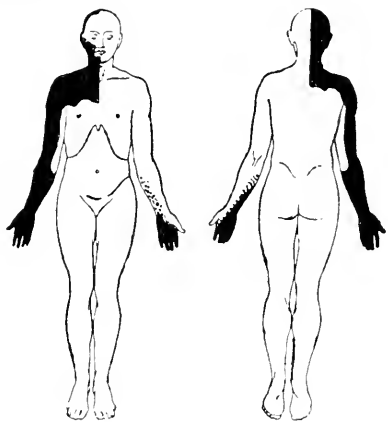

FIG. 143.

To show the loss of sensation to cutaneous painful stimuli in Case 15. The patch of remaining sensibility on the inner aspect of the right arm was worked out by testing from sensitive towards insensitive parts.

The algometer gave the following remarkable results, which are the average records in kilograms of many examinations.

	Right.	*Left.*
Palm of the hand	Pain from 10 to 13	No pain with 15.
Dorsum of the hand	Pain at 7	Pain at from 4 to 7.
Flexor and extensor aspects of forearm	Pain usually absent at pressures below 13	Pain usually absent at pressures below 13.
Olecranon	No pain at 14	Pain at 6.
Shoulder joint	No pain at 13	Pain at 6.
Clavicle	Pain at 8	Pain at 3.
Angle of jaw	Pain at 3	Pain at 2.
Temple	Pain at 1·5	Pain at 1·5.

Over the remainder of the body there was no loss of sensibility to painful pressure, and the algometer gave equal readings on the two lower extremities.

	Right.	*Left.*
Sole	Pain at 2	Pain at 2.
External malleolus	Pain at 2·5	Pain at 2.
Shin	Pain at 2	Pain at 2·5.
Inner aspect of knee	Pain at 4	Pain at 4.
Front of thigh	Pain at 5	Pain at 5·5.

It is evident from these records that the loss of sensibility to the painful aspect of the pressure was less extensive than that of the cutaneous analgesia. Moreover, the right hand still remained sensitive to painful pressure though to a diminished degree, in spite of the complete insensibility of the whole forearm and hand to cutaneous painful stimulation.

(*b*) *Thermal sensibility.*—He was insensitive to all degrees of heat over the whole of the right upper extremity (Fig. 144). On the left side, the extent of the loss of sensation varied somewhat from day to day, and merged gradually into parts of normal sensibility.

To cold the loss was less extensive and a small area remained sensitive on the inner aspect of the right arm (Fig. 145). Over the left hand and forearm, the distribution of the anæsthesia varied somewhat, corresponding to the evident advance of the lesion on this side of the nervous system.

(*c*) *Tactile sensibility* was abolished over the whole of the area shown on Fig. 146. The absolute loss of sensation to pressure touch merged gradually on the neck into parts that were sensitive

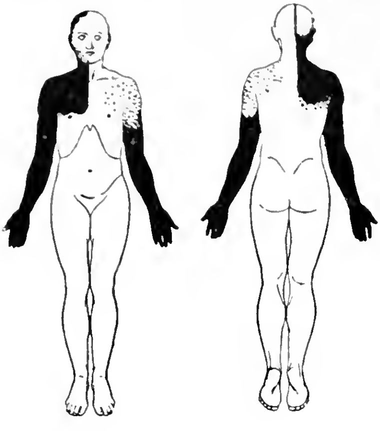

FIG. 144.

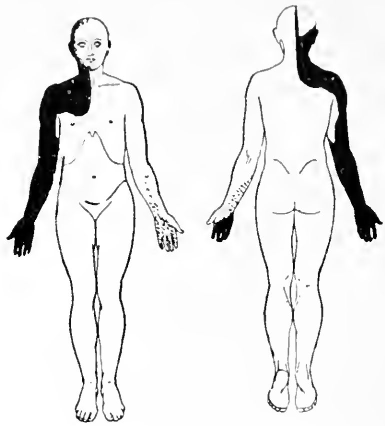

FIG. 145.

Fig. 144 shows the loss of sensation to heat in Case 15.
Fig. 145 shows the loss of sensation to cold in the same case. Here the patch of remaining sensibility on the inner aspect of the right arm was worked out by testing from sensitive towards insensitive parts.

to this stimulus. But on the inner aspect of the forearm was a well-defined area of residual tactile sensibility.

When cotton wool was used, the whole of the parts on Fig. 146 were found to be insensitive, including the right half of the neck to the line marked on Fig. 148.

The condition of the right half of the neck between these two lines was instructive; when tested with von Frey's hairs, it was found that even No. 8 (23 grm. / mm.^{2}) could not be recognised, as soon as the border in the neighbourhood of the jaw was passed; and yet over the left half of the neck he uniformly responded to No. 2 (12 grm./mm.^{2}). Tactile sensibility was sufficiently diminished at the line marked on the face to prevent a response to such stimuli as cotton wool and von Frey's hairs. But No. 8 of these hairs is a pressure stimulus, and with peripheral lesions can be appreciated over parts of cutaneous insensibility. We concluded, therefore, that all forms of tactile sensibility were diminished at the line marked on Fig. 148. At this border, cotton wool and von Frey's hairs ceased to cause a sensation. The anæsthesia gradually deepened until within the dotted area even a pressure-touch frequently failed to evoke a response. Finally, within the area marked black no tactile stimulus was appreciated.

(*d*) *Recognition of a point.*—He could tell the head from the point of a pin everywhere except over those parts of the right upper extremity insensitive to light touch. Over the area sensitive to pressure but not to light touch, he was unable to distinguish the head from the point. But, wherever he was sensitive to light touch within the analgesic area, his power of distinguishing the head from the point was perfectly preserved.

(*e*) *Appreciation of differences in size* could not be tested over the right upper extremity. But over the left hand and arm his answers were correct to rods of a diameter of 2 cm., 0·75 cm. and 0·2 cm.

(*f*) *The vibrations of a tuning fork* could not be appreciated anywhere over the right upper extremity, but over the left arm and hand he everywhere answered correctly.

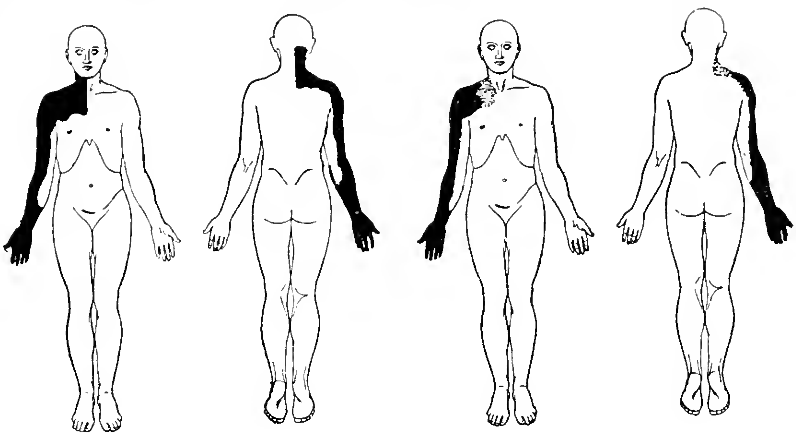

Fig. 146. Fig. 147.

Fig. 146 shows the extent of the anæsthesia to cotton wool in Case 15.
Fig. 147 shows the parts insensitive to deep touch in the same case.

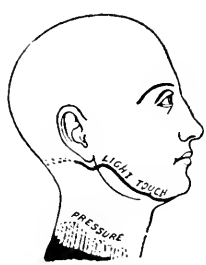

Fig. 148.

Fig. 148 shows the relation of the borders at which different tactile stimuli no longer caused sensation. At the line marked "light touch" the patient ceased to appreciate cotton wool and No. 8 of von Frey's hairs (23 grm./mm.²). At the border of the dotted area pressure frequently failed to evoke a response. Finally, over the black area no tactile stimulus, even the firmest pressure, was appreciated as a touch.

(*g*) *Sense of passive position and movement.*—He could not recognise any movement of the fingers or thumb of the right hand, and was liable to drop anything he was holding unless his eyes were fixed upon it. He entirely failed to appreciate any movement of the fingers produced by electrical stimulation. Movements at the wrist were not recognised until they had exceeded 20°; at the right elbow, until they had exceeded 10°; but movements of the right shoulder joint were readily recognised.

All movements of the left upper extremity and of the legs were readily appreciated.

(*h*) *Compass test.*—This test could not be applied to the right upper extremity, on account of the loss of tactile sensibility. Elsewhere the records were normal.

The records obtained by testing the area on the right half of the neck insensitive to light touch but sensitive to pressure, show well the effect produced upon the compass test by a genera diminution of tactile sensibility, produced by an intra-medullary lesion.

		Right.	*Left.*
3 cm.	1	10 R.	10 R.
	2	4 R. 6 W.	10 R.
10 cm.	1	10 R.	
	2	5 R. 1 Doubtful. 4 W.	

(*i*) *Tactile localisation.*—Wherever he was able to recognise a touch, whether it were caused by pressure, cotton wool, or von Frey's hairs, he invariably named the spot accurately. When allowed to grope for the spot touched he was never more than 3 cm. away, and was remarkably quick and accurate, provided it lay over parts where tactile sensibility was preserved.

Cranial nerves.—The pupils were equal and reacted normally to light, to shade, and to accommodation. The eyes moved well in all directions, except that, when he looked to the right, a bilateral rotatory nystagmus appeared; the rotation occurred in a direction opposite to movement of the hands of a clock. No similar nystagmus was present when he looked to the left. No abnormal condition was found on ophthalmoscopic examination. All movements of the face and tongue were normally performed and the palate moved well.

Spine.—There was no lateral curve or other abnormality.

Sphincters.—For some time he had noticed that he could not retain his motions when they were loose and that he had some difficulty in starting micturition.

Case 16.—Robert Arthur H.

In June, 1902, *he woke to find the left hand and arm numb; he noticed that over the numb parts heat and cold produced a sensation different from that over the normal parts.*

Nine months later his throat became affected.

Painless swelling of the left shoulder joint was present.

First seen March, 1904. *His condition has advanced little since that date.*

The motor affection consists of paralysis of the left vocal cord and the left half of palate.

Reflexes.—Left knee-jerk exaggerated, left ankle clonus, left extensor plantar reflex.

Sensation.—Profound loss of sensibility to prick (*Figs.* 149 *and* 150), *to thermal stimuli* (*Figs.* 151 *and* 152), *of all forms of tactile stimulation* (*Fig* 153).

Appreciation of passive position and movement lost in the left arm and left leg below the knee.

Tactile discrimination lost in the left leg; cannot be tested in the left arm on account of the loss of tactile sensibility.

Tactile localisation, (1) *by naming, equally good in both legs,* (2) *by groping, profoundly changed in the left leg; normal in the right leg.*

Robert Arthur H., aged 33, a general provision dealer, was first seen by us in March, 1904, and since then has been under observation from time to time.

He was apparently in perfect health until one morning in June, 1902, when he found on rising that his left hand and arm were numb. At the same time he noticed that heat and cold produced a different effect upon the sensation of this arm.

Nine months later, he began to suffer from choking sensations and his voice became affected. About the same time he found that the left leg troubled him in walking; it seemed stiff and awkward, although it "could feel perfectly." He then began to suffer from sensations of giddiness, and his eyesight became confused.

It was not until October 14, 1903, that the right hand was affected; it became red and swollen, and he suffered from a violent shivering attack in which he vomited. This was said to be due to a small poisoned wound for which the doctor bound up the hand with the fingers flexed into the palm. So he remained for a month, and, when the bandages were taken off, his fingers had stiffened permanently.

About nine months later, the left shoulder joint enlarged, but the swelling was accompanied by no pain.

As a boy, he had had an attack of typhoid fever, and on several occasions had suffered from "influenza," most severely in 1890.

He has been a life-long teetotaler.

No history could be obtained of venereal disease, nor according to his account is it likely that he could ever have been infected. He was married in 1899 and has one healthy child, born in 1905. His wife has never miscarried.

Condition on Examination (November and December, 1906).

In the following account we shall give the results of a series of examinations, extending over the last two months of 1906, alluding briefly when necessary to his condition on previous occasions.

He is a medium-sized, strongly built man, of unusual intelligence. He answered well and did not fail with the control tests used.

Cranial nerves.—A remarkable nystagmus was present, not only with movement in all directions, but also when he looked in front with his eyes directed towards a distant point. When looking to the right or to the left, the nystagmus was purely horizontal and at no time was it truly rotatory. Otherwise, the eyes moved well, and there was no ocular paralysis. He had perfect muscular control of both eyelids. The face moved well both on emotional and voluntary excitation. The tongue was protruded in a straight line, but the right half seemed to be smaller than the left; this appeared to be due to a greater contraction of the muscles of the right half of the tongue, whilst the left half was flattened and flabby. The left half of the palate was paralysed, and on laryngoscopic examination, the left cord was seen to lie in the cadaveric position, completely motionless. The right vocal cord moved well, passing across the middle line to meet the left cord during phonation.

Motion.—There was no wasting of any muscle in the upper extremities, but the right hand was held in a half clenched position, and he was unable fully to extend the fingers in consequence of changes in the joints. The subcutaneous tissues were somewhat swollen, and the fixation of the fingers, combined with this swelling, accounted for the difference in the grasp of the two hands (right 8 kgm., left 17 kgm.).

But the grasp of the left hand was also defective, as shown by the low reading of the dynamometer; this was probably due, not to muscular weakness, but to the profound sensory changes in this hand.

For the left upper extremity was profoundly ataxic; he could touch his nose clumsily when his eyes were open, but as soon as they were closed, the difficulty became greatly increased. Even when allowed to look, he could scarcely bring the tips of the two forefingers together, and when his eyes were closed, this movement became impossible.

There was no ataxy of the right arm or hand.

His gait was slightly unsteady, and on examination this was found to be due to the condition of the left leg. He could stand with his feet together, but when his eyes were closed, swayed and ultimately fell. In attempting to maintain his balance, the movements of the right foot were more extensive than those of the left; ultimately, he either fell towards the left, or thrust out his left leg laterally to act as a prop. Asked to stand on the right leg only, he finally succeeded; but at first he had difficulty in maintaining his balance, owing to the absence of compensatory movements in the left leg, which was lifted. When he attempted to stand on the left leg only, he at once fell. Under such conditions, there was a striking difference between the violent balancing movements of the right foot and the complete quiescence of the left foot.

The left leg was slightly spastic, but was not paretic; nor were the muscles wasted.

All the muscles of the upper and lower extremities reacted perfectly to the interrupted and to the constant current.

Reflexes.—The left knee-jerk was greatly exaggerated, and ankle clonus was obtained; the left plantar reflex gave an extensor response. On the right side the knee-jerk was obtained, but there was no ankle clonus, and the plantar reflex was of the flexor type.

Sensation.—The loss of sensation was slightly less extensive in March, 1904, than in 1906. But since the changes which have occurred during the last two and a half years consist solely of a slight increase in the area affected, and not in the disturbance of any further sensory quality, we shall confine ourselves mainly to the present condition.

(*a*) *Sensibility to painful stimuli.* He was insensitive to the prick of a pin over the whole of the left upper extremity, and over the left half of the neck and scalp (Fig. 149). The frontal

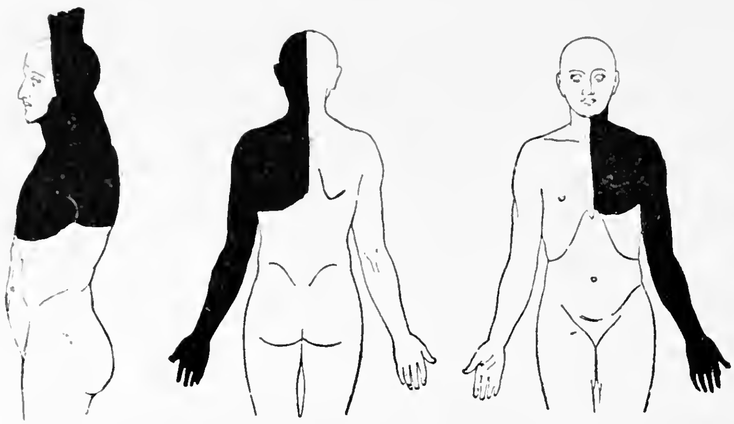

FIG. 149.

FIG. 150.

Figs. 149 and 150 show the loss of sensation to cutaneous painful stimuli in Case 16. The frontal border on the face (Fig. 150) was worked out by testing from sensitive towards insensitive parts. The caudal border shown on Fig. 149 was also worked out by determining the extent of residual sensibility to prick.

border of the analgesia extended on to the face, including the left ear and part of the left cheek; the scalp was insensitive to a point a little in front of the vertical line joining the two ears (Fig. 150).

The lower border of the analgesic area on the trunk was remarkably well defined; it extended round the trunk, crossing the sixth, seventh, and eighth ribs in the axilla to end at the level of the sixth vertebral spine. When he was tested from parts of normal sensibility towards those that were analgesic, sensation to the prick of a pin or to a painful interrupted current ceased at the border on Fig. 149; from this, the border of returning sensibility scarcely differed by one centimetre, when we tested from insensitive towards sensitive parts.

Sensibility to a pin prick and to the painful interrupted current was perfect elsewhere over the body, except that it was somewhat diminished over the right forearm.

With the algometer, it was found that sensibility to the pain of excessive pressure was lost over the area insensitive to cutaneous painful stimuli. Over the right arm, the algometer gave somewhat higher readings where cutaneous sensibility to pain was diminished.

	Right.	*Left.*
Temple	Pain at 2 ..	Pain at 7.
Mastoid	Pain at 2 ..	No pain at 10.
Sterno-clavicular joint	Pain at 3 ..	No pain at 10.
Shoulder joint	Pain at 6 ..	No pain at 15.
Inner aspect of elbow	Pain at 6 ..	No pain at 15.
Outer aspect of elbow	Pain at 7 ..	No pain at 15.
Front of forearm	Pain at 6 ..	No pain at 15.
Back of forearm	Pain at 10 ..	No pain at 15.
Palm	Pain at 9 ..	Slight pain at 1.
Back of hand	Pain at 5 ..	Slight pain at 14.
Outer aspect of anterior superior spine of ileum	Pain at 3 ..	Pain at 3.
Front of thigh	Pain at 4 ..	Pain at 4.
Inner aspect of knee	Pain at 4 ..	Pain at 4.
Shin	Pain at 2·5 ..	Pain at 2.
Sole of foot	Pain at 3 ..	Pain at 3·5.

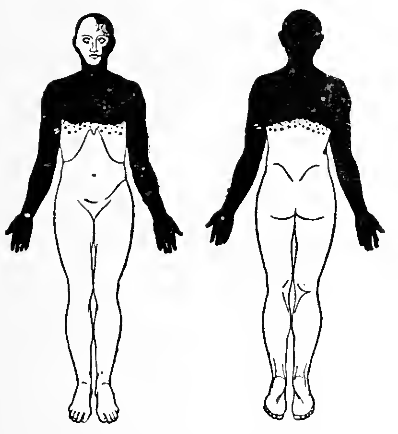

Fig. 151.

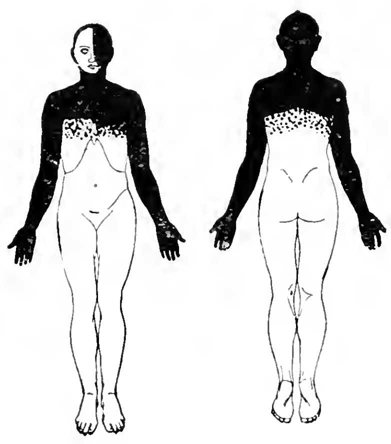

Fig. 152.

Fig. 151 to show the extent of the loss of sensation to cold, and Fig. 152 to show the loss to heat in Case 16.

(*b*) *Thermal sensibility.*—The area insensitive to all degrees of cold between 0° and 25° C., is shown on Fig. 151. The parts insensitive to all degrees of heat are marked on Fig. 152. These two figures almost correspond with one another except on the face. But, in 1904, the loss to cold considerably exceeded the loss to heat; the area insensitive to cold nearly corresponded with that on Fig. 151, but the extent of the anæsthesia to heat more nearly agreed with the area that is now insensitive to painful stimuli (Fig. 149). Thus, at this time the whole of the right arm was sensitive to heat, but insensitive to cold.

(*c*) *Tactile sensibility.*—Stimulation with cotton wool was not appreciated over the whole of the left upper extremity, and the left half of the chest above the level of the nipple (Fig. 153). Elsewhere over the body and limbs, this stimulus was perfectly appreciated.

Firm pressure was not appreciated over the same area (Fig. 153) as that insensitive to light touch. This complete abolition of tactile sensibility over the left upper extremity was present when he was first examined in March, 1904.

(*d*) *Passive position and movement.*—He stated that he was able to appreciate the movements of the fingers of his left hand; but when they were moved passively he never recognised the movement, until the finger had travelled through an angle of over 60°. He was entirely unable to say into what position the fingers of the left hand had been placed. When the left thumb was tested, he answered as follows:—

Flexion	1 R. 9 W.
Extension	2 R. 8 W.

When allowed to look at the true position of his thumb, he volunteered that he thought it was pointing in a different direction.

At the left wrist joint, he appreciated flexion and extension when movement had been made through an angle of 40°. He was, however, always correct in his appreciation of the position into

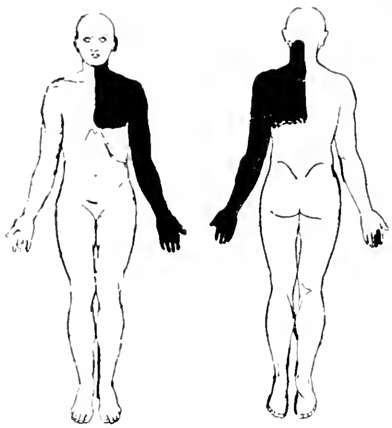

Fig. 153.

To show the loss of sensibility to stimulation with cotton wool, with von Frey's hairs and with pressure touch in Case 16.

which the hand had been placed by passive movements at the wrist, although his answers were somewhat slow.

Passive position and movement at the left elbow and shoulder were quickly and accurately appreciated; he recognised passive movement through 5° only.

In the whole of the right upper extremity, passive position and movement were accurately appreciated, and the difference between the condition of the right (normal) and left (affected) hands was most evident.

But it was in the lower extremities, where all other forms of sensibility were perfect, that the disturbed appreciation of passive position and movement was most striking. When his left great toe was moved, his answers were hesitating and very uncertain, but he quickly and accurately recognised all movements of the right great toe.

	Right.		*Left.*	
Great Toe	Extension	10 R.	Extension	4 R. 6 W.
	Flexion	10 R.	Flexion	9 R. 1 W.

He could not recognise movements of the left ankle, until it had been moved through more than 20°, whilst on the right side he answered correctly with movements of less than 5°.

		Right.		*Left.*	
Ankle	Dorsiflexion	10 R.	Dorsiflexion	3 R. 7 W.
	Plantar extension	10 R.	Plantar extension	6 R. 4 W.

At the knees and hips his answers were equally accurate on the two sides.
At a later date the following similar results were obtained :—

		Right.		*Left.*
Great Toe	Extension	10 R.	Extension	10 W.
	Flexion	10 R.	Flexion	3 R. 7 W.

		Right.		*Left.*
Ankle	Dorsiflexion	10 R.	Dorsiflexion	1 R. 9 W.
	Plantar extension	10 R.	Plantar extension	6 R. 4 W.

The same facts were illustrated when the movements of the foot were produced by electrical stimulation of the muscles. If the right foot was dorsiflexed by the application of an interrupted current to the anterior tibial group of muscles, or plantar extended by stimulating the calf, he answered quickly, repeating the movement correctly in the same leg. The same result followed the outward movement produced by stimulation of the peronei.

But, when similar stimulation was applied to the muscles of the left leg, he was completely puzzled, and answered "the leg jumps," whatever movement resulted.

(*e*) *The compass test.*—Owing to the loss of tactile sensibility in the left upper extremity it was impossible to compare the behaviour of the two hands towards the compass test.

But over the lower extremities, where tactile, painful and thermal sensibility were perfect even to the finest tests, a remarkable difference was discovered in the behaviour of the two limbs. For over the right sole he made one mistake only when the points were separated for a distance of 2·5 cm., and applied transversely; over the left sole he gave eight false answers when the points were 6 cm. apart. Over the outer aspect of the left leg he gave perfect answers at 8 cm., but over the right leg 15 cm. was well below the threshold.

Sole :	*Right.*			*Left.*		
Compasses applied transversely	2·5 cm.	1	10 R.	6 cm.	1	10 R.
		2	9 R. 1 W.		2	2 R. 8 W.
Compasses applied longitudinally	4 cm.	1	10 R.	4 cm.	1	10 R.
		2	10 R.		2	10 W.
				8 cm.	1	10 R.
					2	4 R. 6 W.
Outer aspect of leg	8 cm.	1	10 R.	15 cm.	1	6 R. 4 W.
		2	10 R.		2	5 R. 5 W.

(*f*) *Tactile localisation.*—(1) Tested by the power of naming the part touched.

A number of points were chosen, such as the ball of the great toe, the centre of the sole of the foot, the heel, the "outer ankle" (external malleolus), "the inner part of the leg over the calf," "outer side, and just below the knee," the knee-cap, the "centre of the calf," the "middle of the front of the thigh." All these points when touched were named quickly and accurately; no difference could be discovered between the two lower extremities. Nor did he seem to be slower in naming a point touched on the lower extremities than when he was touched on the right hand or arm.

Then his eyes were closed and the legs were moved passively into a fresh position. This movement in the right leg was fully appreciated, but he was unable to tell into what position his left foot and leg had been placed; yet, in spite of this difference, he named the spots touched on the two legs in their new position with equal accuracy.

(2) Tested by Spearman's modification of the groping method.

A hole was cut in the centre of a piece of thin cardboard, on to which was fastened a sheet of white paper. The patient sat propped up in bed, with his legs stretched out in front of him. He was given a long soft-pointed pencil, and his eyes were closed. The cardboard was then held over his foot about 1 cm. from the skin, so that the hole lay over the centre of the dorsal surface. Through this hole he was touched, and he then attempted to touch the spot with the pencil used as a pointer. Now, since the cardboard intervened between his foot and the pointer, except at the small hole, his groping efforts were marked on the white paper, and the distance of the final mark from the centre of the hole gave the measure of his accuracy. A series of experiments were made with the centre hole over similar points on the dorsum of the right and left foot, on the outer aspect of the legs, and on the front of the thighs. Six tactile stimuli were given at each spot, and the numbers given below represent the average deviation at each point.

	Right (normal).	*Left (affected).*
Dorsum of the foot	5·7 cm.	7 cm.
Outer aspect of leg	4·3 cm.	6·8 cm.
Front of thigh	2·5 cm.	4·3 cm.

The deviation was uniformly a little greater on the left than on the right leg, but the difference was within the limits of error of observation.

Another set of experiments was made as follows: The legs were allowed to lie stretched out in front of him and his eyes were closed. A series of observations were made exactly in the same way as those quoted above. Then his legs were moved passively, his eyes remaining constantly closed, and another set of observations made by touching the same spot on the dorsum of his foot. The results can be tabulated as follows:—

	Right (normal).	*Left (affected).*
Before movement	9·7 cm.	9 cm.
After movement	9·7 cm.	13 cm.

It will be seen that the deviation on the sound side remained the same, although the leg had been displaced passively; but on the affected foot the deviation increased 4 cm. after the foot had been moved.

(*g*) *Recognition of a point.*—Under normal circumstances he never made a mistake between stimulation with the head and the point of a pin over the right arm and hand, right half of the trunk, and both lower extremities. The left upper extremity was insensitive to touch and pain.

But the following observation will serve as an instance of the erroneous answers which may be given, if the patient is in any way uncomfortable. On one occasion at the end of a morning's examinaton this test was applied to the right arm. He gave curiously false answers as follows:

Right palm	Head	2 R. 8 W.
	Point	10 R.
Right forearm	Head	4 R. 6 W.
	Point	10 R.

He then said he wished to pass urine, which he did copiously. From that time he gave perfect answers everywhere over the right arm, just as on previous occasions.

(*h*) *Appreciation of differcnce in size.*—This was tested with three metal cylinders, 2 cm., 0·75 cm., and 0·4 cm. in diameter. Except over the left upper extremity his answers were correct in every instance.

CASE 17.—FRANK L.

On August 3, 1904, he was injured by the fall of a skip which struck him in the back.

On August 9, the spine was opened in the region of the first, second and third lumbar vertebræ. No abnormality was discovered, showing that the condition was not due to injury of the cauda equina.

He gradually recovered and, when seen by us in May, 1906, showed some spasticity of the left leg, associated with analgesia and thermo-anæsthesia of the right leg (Fig. 154).

Over this area, he was sensitive to the tactile aspect of pressure, but excessive pressure produced no pain.

All other forms of sensibility were perfectly preserved.

Frank L., aged 25, was admitted to the London Hospital on August 3, 1904, in consequence of an accident when working on the Rotherhithe tunnel. A skip of concrete fell, striking him in the lower thoracic and upper lumbar regions. He did not lose consciousness, but when pulled from under the skip, his legs dropped as if they were broken.

When admitted to the London Hospital, a hæmatoma was present over the second, third and fourth lumbar spines, and he was much bruised about the body. The knee-jerks and plantar reflexes were absent, and both legs were completely paralysed.

He did not seem to be improving, and on August 9, 1904, Mr. Rigby operated upon the spine. He removed the laminæ of the first, second and third lumbar vertebræ. The dura mater was opened, and the cauda equina was exposed. No signs of rupture or bruising could be discovered anywhere. The wound was sewn up again and healed by first intention.

Power considerably improved in both legs, and he gained control to a great extent over micturition. When first examined by us, he had reached the following condition.

Condition in May, 1906.

He was a largely-built, intelligent man.

Motion.—When walking, he dragged the left leg like a man with hemiplegia, raising his pelvis with each step so that the left foot should clear the ground. He could stand on either leg, but could not support himself on the left leg only for more than a few seconds.

This leg was stiff, especially below the knee, and he complained that he could not move it as quickly and easily as the right. All movements at the left hip and knee were strongly performed, but at the left ankle he moved slowly, although with considerable force. He could dorsiflex the foot, and plantar extension was good.

All movements of the right leg were well performed and it was not stiff or spastic.

Reflexes.—Both knee-jerks were exaggerated, the left more so than the right. Ankle clonus was obtained on both sides and both plantar reflexes gave an extensor response.

Spine.—The scar of a well-healed wound extended from the eleventh thoracic to the fourth lumbar spine.

A radiograph of the dorsal region of the spinal column showed no obvious signs of fracture or other bony change.

Sphincters.—He could pass his water normally; but if he desired to micturate he was forced to do so at once, or the urine ran from him.

Defæcation was not affected in May, 1906.

Sensation. (*a*) *Tactile sensibility.*—He was sensitive everywhere to cotton wool, and no difference in this respect could be discovered between the two legs. He recognised increasing pressure equally over both lower limbs.

(*b*) *Sensibility to pain.*—He was insensitive to all forms of cutaneous painful stimulation over the area shown in Fig. 154.

Deep pressure caused no pain over the sole of the foot, nor over both aspects of the right leg. But, over the front of the thigh, above the limits of the analgesia, pain was produced by a pressure of 5 kilograms on both sides.

	Right.	*Left.*
Outer aspect of leg	No pain at 16 ..	Pain at 5.
Inner aspect of leg over tibia	No pain at 10 ..	Pain at 4.
Front of thigh above the limits of the analgesia	Pain at 5. ..	Pain at 5.

(c) *Thermal sensibility* was lost for all degrees of heat and cold over the area marked in Fig. 154. The borders of this loss of sensation were ill-defined.

(d) *The vibrations of a tuning-fork* (128) were appreciated with equal ease over both legs.

(e) The *sense of passive position and movement* was preserved everywhere.

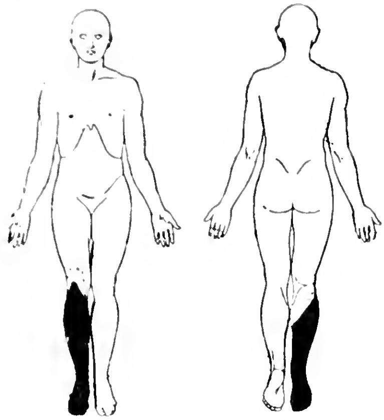

FIG. 154.

To show the loss of sensation in Case 17.

The dark area represents the parts insensitive to cutaneous painful stimuli and also to the pain of excessive pressure. It also corresponds to the extent of the thermo-anæsthesia.

(f) *The compass test.*—The threshold over the outer aspect of the shins lay between 4 and 6 cm. when the compasses were applied longitudinally. We were unable to discover any difference between the two legs in their sensibility to this test.

(g) *Tactile localisation* was everywhere good.

THE AUTOMATIC BLADDER, EXCESSIVE SWEATING AND SOME OTHER REFLEX CONDITIONS IN GROSS INJURIES OF THE SPINAL CORD

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THE War has afforded innumerable opportunities for investigating the phenomena due to gross injuries of the spinal cord, and much has already been written on the clinical aspects of this subject. It was obviously impossible for any one observer to cover so vast a ground, or to add anything to the general stock of knowledge, without concentrated study of a limited portion of the field. Each one of us became interested in a special group of problems working at first independently, and, as it seemed, at manifestations which had no bearing on one another. For nearly two years, Captain Riddoch had paid special attention to the phenomena which follow total transverse division of the spinal cord, more especially to the condition of the reflexes, whilst Dr. Head had set himself to discover some explanation for the excessive sweating, a well-known sequel to spinal cord injuries, of which two extreme cases had come under his notice. But as soon as we both became interested in measuring the functional capacity of the automatic bladder, we realised that we were looking at different phases of the same general problem.

The following paper is an attempt to establish certain physiological principles which have emerged from our several lines of research. We make no attempt to give a complete clinical account of the condition of the bladder, or of the various reflexes in cases of gross injury to the spinal cord, nor can we deal with the signs or symptoms of its total transverse division from the diagnostic point of view. These are treated in Riddoch's systematic study [96]. Our object in this paper is to state consecutively the physiological principles which underlie the phenomena he describes and, if possible, to give a general explanation for the remarkable behaviour of the distal end of the severed spinal cord.

We were anxious not to hamper our exposition of these principles by frequent digressions into the literature of the subject; and yet it was impossible to neglect the work of the Cambridge school of physiologists on the nature of the involuntary nervous system, which forms the basis of all our conceptions. Moreover, all the experimental work of serious importance on the innervation of the bladder has been carried out by Langley, Anderson, Elliott and other workers of this school. A combined retrospect of their results has therefore been put together by Fearnsides [29]. On the other hand, the literature of importance, connected with total transverse division of the spinal cord, is dealt with by Riddoch in his monograph on this subject [96].

Our sincere thanks are due to Dr. Batten, Dr. Buzzard, Dr. Collier and Dr. Guthrie for the extreme generosity with which they have permitted us, not only to see the patients under their care, but also to publish our observations upon them.

CHAPTER I

THE AUTOMATIC BLADDER

When the spinal cord has been so gravely injured that all power of voluntary micturition is abolished, urine may be voided in several different ways, depending largely on the general condition of the patient and on the treatment he has undergone.

At first there is complete retention, and if no catheter is passed for several days the bladder may become over-distended and the urine pass away frequently and in small quantities; cystitis may occur in a severe form and the patient probably dies before any signs of the complete act of automatic micturition can appear. Fortunately, however, this is an uncommon event in the present day, now that the wounded are gathered in more quickly, and a catheter is passed at the first casualty clearing station as a matter of routine.

If cystitis has been set up and has been long continued, the bladder may shrink and its musculature be so damaged that it responds imperfectly to the tension stimuli of injected fluid: urine is passed at irregular intervals and in small quantities corresponding to the diminished vesical capacity. These, however, are not the cases with which we deal in this chapter; the patients on whom our observations were made were the fortunate ones in whom cystitis played comparatively little part and the wall of the bladder retained both its sensibility to pressure and tonic activity.

The complete act of automatic micturition, accompanied by the phenomena of spreading reflexes, may never become established, owing not only to local conditions, but to general septic poisoning. A foul bladder, pyelitis and sloughing bed-sores may produce so grave a septicæmia that the spinal cord never recovers from the primary condition of shock. It passes from the first stage into a terminal toxic degeneration without reaching a state in which it is capable of that form of widespread reflex activity that is the subject of this paper. The muscular wall may be capable of responding to fluid pressure, when a catheter is passed into the bladder, and some power of evacuation may be present under these conditions; but involuntary automatic micturition may never occur spontaneously and the patient is then dependent to the end of his life on catheterisation for the passage of his urine.

If a catheter has been passed within about twenty-four hours of the injury and the urine has not been allowed subsequently to accumulate in excessive quantities, retention usually passes off, giving place first of all to occasional and fitful evacuation. The larger quantity of urine voided in the twenty-four hours has to be withdrawn by catheter, but a small amount is passed unconsciously at irregular intervals into the bottle. After a few days in a favourable case this gives place to true automatic micturition. Some urine remains behind after each act of involuntary evacuation and this has to be removed by catheter once or twice daily. Moreover it is necessary, in most cases, that some form of wash should be used, if the mucous membrane is to regain its normal condition and complete automatic activity is to be established. Finally, catheterisation can be discontinued; urine accumulates in the bladder up to a volume different in each case, and of this a certain proportion is voided unconsciously at each act of micturition. In many cases some fluid remains behind, but occasionally the bladder appears to be emptied entirely.

Such is the condition that we shall investigate in this chapter. We hope to show that if the spinal cord recovers its functions after the first period of shock produced by the injury, it may pass into a condition in which peripheral extra-vesical stimuli not only produce an abnormally wide effect, but may even influence automatic evacuation of the bladder.

In three of the cases reported by Riddoch (96), where the spinal cord was proved to have been completely divided, this automatic condition of the bladder became established within the following periods from the date of the wound. In No. 1 it dribbled on the twenty-second day and a considerable quantity of the daily amount of urine was voided automatically by the twenty-fifth day; No. 3 was passing urine automatically by the twenty-ninth day, and No. 5 by the sixteenth day after the wound. If the spinal cord is less severely injured, automatic micturition may be established within the first fortnight after the patient has been wounded, provided the local and general conditions are favourable. In gross sacral injuries, however, especially in lesions of the cauda equina, the appearance of involuntary micturition may be delayed for several months, and yet finally become fully established.

§ 1.—The Activity of the Bladder-wall

In all attempts to measure the activity of an automatic bladder it is most important to avoid any considerable pressure. No results of any value can be obtained by raising the vessel containing the fluid to a height of several feet above the bed. The contractile power of the musculature is easily overcome and, if evacuation cannot occur at the moment when tension becomes an effective stimulus, tonic contraction yields and the bladder accepts a further addition to its contents. Thus many a bladder, washed out by the customary method under considerable pressure, is thought to be passive and the urine passed into the bottle during the day is attributed to dribbling, although in reality the musculature is capable of expelling a considerable volume of fluid by automatic contraction.

Our observations on the functional capacity of the bladder in any particular case were made as follows. If possible we determined how long a time has elapsed since any urine has been voided automatically; a catheter was then passed and the amount found in the bladder measured. This varies greatly, but, as a rule, does not materially exceed the volume of fluid to which the evacuating mechanism was found to respond experimentally. A burette with a diameter of 4 cm. tapering to a narrow neck commanded by a glass stopcock, was attached directly to the opening of the catheter. Into this burette, which was graduated in cubic centimetres, was passed 100 c.c. of sterile slightly warm fluid, and the tap was turned so that the fluid could run through the catheter into the bladder. As soon as a back flow occurred, the burette was rapidly detached from the catheter and the fluid expelled allowed to pass into a flat dish held at a level just above the horizontal. During these manipulations the penis remained horizontal and the only pressure of fluid was due to that in the short burette held vertically.

The following observations made on No. 1, 158 days after total division of the spinal cord, will give some idea of the results we have obtained and the procedure adopted. Before passing the catheter the glans penis was carefully swabbed in the usual manner: this led to the immediate passage of 110 c.c. of urine, for in some cases this is a most effective method of stimulating reflex evacuation. On passing the catheter 340 c.c. were then drawn off. The bladder having been emptied completely, fluid was poured into the burette and when 600 c.c., had entered, automatic contraction began; he passed in all 595 c.c., and no more could be recovered by pressure on the abdomen. Fluid was again allowed to run into the bladder and at 600 c.c. was again evacuated to the amount of 590 c.c. Throughout these observations his bladder was astonishingly active; from the beginning the column of fluid in his tube showed oscillations which, on asking him to stop breathing, proved to be of respiratory origin. But after about 400 to 500 c.c. had entered the bladder, bigger oscillations began, which culminated at 600 c.c. in a back flow; about 300 c.c. were passed at once, followed, after a pause, by 200 c.c. Then came another pause followed by the expulsion of a smaller amount, and finally, when all activity had ceased, he had passed in all 590 c.c. He was throughout unconscious of any of our manipulations or of the passage of fluid to or from his bladder. Moreover, he was quite unable to influence the evacuation in any way voluntarily, even through the abdominal muscles. At this time the urine was acid, slightly cloudy and contained no albumen; there was no deposit of pus or mucus.

Another series of observations made on the same patient 266 days after the injury, illustrates some of the reflex functions of the automatic spinal cord, in as far as they influence the activity of the bladder. It will be noticed that the capacity of the bladder was no longer so great as in the earlier stages, probably owing to the natural tendency of these automatic bladders to shrink, or to a febrile attack due to pyelitis from which he had suffered between the two sets of observations.

In consequence of the preliminary swabbing of the glans penis he passed 85 c.c. of urine and 200 c.c. were subsequently drawn off by catheter, giving a total amount of about 285 c.c. or 10 fluid oz. Sterile fluid was then allowed to run in through the catheter and at 180 c.c. he voided the total amount; nothing could be recovered by pressure. On a second observation, evacuation occurred at 210 c.c. and again he passed the whole amount. A third observation gave 240 c.c. as the effective stimulus and the bladder once more emptied itself completely.

Thus it was obvious that from 180 to 240 c.c. of fluid were required to evoke automatic evacuation through a catheter. We then allowed 100 c.c. of fluid to run into the bladder and stimulated the sole of the foot. This produced a characteristic flexor spasm, but the fluid was not ejected from the bladder. But on adding another 10 c.c. (110 c.c. in all) scratching the sole made the stimulus effective and 105 c.c. were evacuated by the contraction of the vesical musculature. A second experiment was carried out by running in 115 c.c. of fluid: scratching the sole produced no effect on the bladder, but on adding another 10 c.c. (125 c.c. in all) evacuation occurred immediately the flexor spasm was evoked. He passed 130 c.c. of fluid, an amount slightly in excess of that run into the bladder.

These observations show that an automatic bladder, which did not usually respond to less than 180 c.c. of fluid, could be made to eject its contents at a lower amount by evoking a flexor spasm. A stimulus to the sole of the foot, which should normally cause withdrawal of that limb only, increased the automatic irritability of the bladder to such an extent that it responded to a considerably smaller volume of fluid.

Close association between reflex evacuation and the other activities of the spinal cord in this condition was well illustrated in the case of No. 2, in whom the spinal cord had been completely divided at the level of the fourth thoracic segment 218 days before the following observations were made. A catheter was passed and 175 c.c. drawn off. When 250 c.c. of fluid had run into the bladder, evacuation occurred and 135 c.c. were voided; on pressure over the lower part of the abdomen a further 130 c.c. were recovered. But we noticed that this pressure did not act purely mechanically; for as soon as the hand was pressed upon the abdomen a flexor spasm was produced. A second observation was therefore made as follows: Fluid was allowed to run into the bladder and at 290 c.c. it ejected 175 c.c. of its contents. The glans penis was gently pinched and a further 57 c.c. were passed; finally 70 c.c. were recovered by pressure. In a third experiment we stopped at 250 c.c. just short of the point at which we knew the bladder would expel its contents; stimulation of the glans at once started the flow and 140 c.c. were ejected. Then a flexor spasm was evoked by scratching the sole and an additional 50 c.c. were passed; pressure produced the expulsion of another 90 c.c. The next observations were carried out somewhat differently: we inserted a certain volume of fluid, evoked reflexes and determined to what extent we could facilitate evacuation.

Thus 100 c.c. were allowed to run in and the penis was stimulated without producing any return of fluid: but when 150 c.c. had entered the bladder, stroking the glans caused evacuation of 30 c.c. We also found that when the bladder contained 150 c.c. of fluid stimulating the sole of the foot at once caused detrusor contraction.

This shows that after complete division of the spinal cord, an automatic bladder which normally reacts to about 250 c.c. ("a 9-oz. bladder") could be made to expel its contents at a little over half that amount by evoking a reflex from the glans penis or from the sole of the foot. But in this case the expulsion was not complete: some fluid always remained behind in the bladder after the reflex had expended itself.

A similar condition was found in another case (No. 3) thirty-one days after total transverse division of the spinal cord. He began to return the fluid from his bladder at 350 c.c., voiding 350 c.c.; 5 c.c. were recovered by pressure over the abdomen. On the next observation the bladder expelled its contents at 375 c.c., and on this occasion the complete amount of fluid was discharged, but 15 c.c. in addition were expelled by pressure, showing he must have passed some urine into his bladder. This proved that evacuation now occurred at from 350 to 375 c.c. provided the stimulus lay entirely within the bladder itself.

But if some additional reflex activity was evoked in the lower end of the severed cord, this amount could be greatly reduced. Fluid was allowed to run in through the catheter and the sole of the foot was stimulated. At 100 c.c. no change occurred; at 150 c.c. the fluid rose slightly in the tube but no evacuation took place, and another 50 c.c. were permitted to pass into the bladder. At 200 c.c., however, scratching the sole of the foot produced a brisk expulsion of 150 c.c. of fluid.

One of the most potent of these facilitating stimuli is deep breathing. The influence of respiration on ejection of the bladder contents has been thought to be purely passive; but we shall show that a single deep breath may start an automatic discharge which leads to steady and complete evacuation. This was particularly well illustrated by a series of observations made on the above-mentioned patient sixty days after division of the spinal cord.

He had not made water for four hours before our observations began, and on passing the catheter 250 c.c. were drawn off. When fluid was allowed to run in through the catheter three observations gave the following results. At 300 c.c. he passed 305 c.c., and a further 15 c.c. were recovered by pressure; at 395 c.c. he passed 390 c.c., and at 380 c.c. he passed 380 c.c. During the first observation it was obvious that the quantity voided distinctly exceeded that injected, and a few cubic centimetres of urine must have been secreted during the experimental period. We have usually found that when this occurs the third observation, as in this instance, shows a more perfect accord between the amount entering and that ejected from the bladder. Thus we can say that in this case the bladder emptied itself automatically through a catheter when its contents reached about 380 c.c.

When the sole was scratched and a flexor spasm induced rhythmically, the bladder emptied itself completely on one occasion at 185 c.c. and on another at 180 c.c. But when he was asked to take one deep breath as each 10 c.c. passed out of the burette, the column of fluid rose a little at 60 c.c. and the bladder emptied itself completely at 80 c.c. A second observation gave 60 c.c. as the point of hesitation and 70 c.c. as the amount at which evacuation occurred. This remarkable series of observations shows that a bladder, which did not respond until its contents amounted to about 380 c.c., could be made to evacuate itself completely at from 70 to 80 c.c. if the patient drew a deep breath.

This effect of respiration was also seen in a series of observations made on another patient, 277 days after injury to the spinal cord in the region of the sixth dorsal segment. When the stimulus was solely due to pressure within the bladder he responded at 220 c.c., voiding 180 c.c., at 180 c.c. voiding 140 c.c., and at 200 c.c. voiding 130 c.c. If, however, a flexor spasm was evoked the response was facilitated and evacuation occurred at 100 c.c. A deep breath was, however, so potent an adjuvant, that the bladder contracted when 10 c.c. only had been allowed to enter, and the whole amount was ejected. This cannot be purely passive, for, before we awoke to the full significance of this method of aiding automatic evacuation, we had tested him in this same series at 70 c.c., when one deep breath caused him to void 50 c.c., at 50 c.c. and at 40 c.c., when the whole amount was passed, and then finally at 10 c.c., with the result detailed above.

In the cases we have described so far the lesion lay sufficiently high to abolish all consciousness of anything that happened within the bladder and urinary tract. In No. 6, however, the spinal cord was injured at the level of the fourth and fifth lumbar segments and the majority of the afferent fibres of the thoracico-lumbar system were still in connection with the nervous system above the lesion. His bladder began to act automatically about four months after the injury and, when he came under our care, he was passing the whole of his urine unconsciously without the help of a catheter. This man was astonishingly accurate in his account of the sensation produced by fluid in his bladder, although he had no control over its ejection, or appreciation of its passage down the urethra. He knew with certainty when evacuation was going to occur and said: "I have a pleasant desire to make water, just as I had when my bladder was full before I was hurt." Thus it is obvious that the existence of perfect consciousness of tension within the bladder does not of necessity influence automatic involuntary micturition.

The amount of the spinal cord which lay below the lesion must, in this case, have been extremely small; and yet we were able to show that contraction of the bladder could be facilitated by suitable reflexes. No response could be obtained to scratching the sole of either foot, but we noticed that when he was pricked around the anal opening a definite reflex was evoked, although these parts, supplied from the lower sacral segments, were entirely insensitive. If fluid was allowed to run into his bladder through a catheter evacuation occurred at a volume which varied considerably on different occasions, but was never less than 75 c.c. But if the anal reflex was produced, evacuation invariably occurred when 10 c.c. only had entered the bladder. Reflexes from above the level of the lesion, such as those evoked by scratching the thighs or abdomen, had no effect on the activity of the vesical musculature.

It must not, however, be supposed that this condition occurs only in cases of total transverse division of the spinal cord. If the disturbance of function is sufficiently severe and long-standing, and particularly if the general condition of the patient is favourable to recovery, the original retention may pass into a period of automatic action indistinguishable from that found in cases where the cord is completely divided anatomically.

No. 8 was particularly instructive from this point of view, because the two halves of the body were in a different condition and stimulation of the two soles had a profoundly different effect upon the action of the automatic bladder. He was hit in the left side of the neck on August 24, 1916. This produced complete paralysis below the level of the fourth rib on both sides with some weakness of the left hand and forearm. All sensation to prick, heat and cold was absent over the right lower extremity and right half of the body as high as the level of the nipple, but was not materially affected to the left of the middle line. Spacial recognition and appreciation of the vibration of a large tuning-fork were abolished on the right side up to the iliac crest and on the left side almost up to the fourth rib. Tactile sensibility was not materially affected. Knee-jerks and ankle-jerks were greatly increased, and ankle clonus was present on both sides.

This patient always knew when his bladder was about to empty itself and was conscious that it was being filled as soon as the contents reached about two-thirds of that necessary to evoke automatic action. He had no desire to micturate, but experienced pleasure when the urine was passed or when the bladder wash was automatically ejected. He could not, however, control the action of the bladder in any way. Eight months after the injury a series of measurements showed that the bladder ejected its contents at between 70 c.c. and 115 c.c. (115, 70, 90, 100) and that in each case evacuation was complete.

We then proceeded to test the effect on the activity of this automatic bladder of evoking flexor spasms; but this case differed fundamentally from those we have previously described, in that the two lower extremities were in a different condition of sensibility. He could not recognise painful or thermal stimuli over the right leg, whilst in the left these aspects of sensation were not materially affected. On both sides knee- and ankle-jerks were exaggerated, ankle clonus was present and the plantar reflexes gave an upward response and flexor jerk. If, then, the right (analgesic) sole was stimulated vesical contraction occurred at 30 c.c. and the whole of this amount was expelled. Thus the production of a flexor spasm so facilitated the activity of this bladder that it was enabled to evacuate its contents at 30 c.c. instead of at 70 c.c.

When, however, the left or sensitive sole was stimulated during the steady inflow of fluid, nothing happened, in spite of the flexor spasms, until, at 70 c.c., he said: " It will fire off of itself in a minute," and back came the fluid into the tube. Flexor spasms evoked on the side where sensation was intact could not influence or facilitate the action of the automatic bladder. Local signature was present and the bladder was not affected by reflexes due to extra-vesical stimuli.

The difference in reflex local signature of the two lower extremities was also evident in the flexor spasms themselves. For when the analgesic (right) foot was scratched not only did the great toe move upwards, but ankle, knee and hip became flexed, the thigh was adducted and a strong contraction occurred in the muscles of the right half of the abdomen. Moreover, a distinct extensor reaction appeared in the opposite (left) leg; the great toe moved downwards, the ankle became extended and a distinct contraction could be seen and felt in the left quadriceps extensor.

Contrast this reaction with that which occurred when the sole of the foot on the sensitive (left) side was scratched in the same way. A violent flexor withdrawal occurred: the great toe moved upwards and the inner hamstrings contracted, but there was little or no movement of the abdomen and no crossed extension could be seen or felt. The reflex movement was violent and completely abnormal in form, but it was almost entirely confined to the affected limb. Such a flexor spasm had maintained its local signature and the energy evoked could not materially affect the activity of the bladder or other functions of the spinal cord. On the other hand the reflex elicited from the analgesic limb was unchecked, and not only spread widely, but also facilitated the automatic evacuation of the bladder; the energy set free in this " massive response " rendered effective a previously insufficient stimulus.

We have given instances of the mode of action of an automatic bladder arising after total and partial division of the spinal cord. But this condition may also appear when there is reason to believe that the cauda equina has been destroyed. This we should have expected from the experimental observations of Goltz on a dog, in whom the whole lower end of the spinal cord had been destroyed. There is, however, one fundamental difference between the behaviour of an automatic bladder arising after a complete lesion of the cauda equina and the condition which appears in favourable cases after total transverse division of the spinal cord; reflexes cannot influence its activity in any way and even those evoked by stimulating the fully sensitive abdomen or thighs produce no effect.

For example, in No. 7, where the spinal roots from the second lumbar downwards were gravely injured, automatic micturition had begun within thirty-four days after the injury and we were able to make the following observations. When 225 c.c. of fluid had run in through the catheter, he evacuated 230 c.c.; evidently a small quantity of urine had been passed into the bladder during our manipulations. A second observation gave 220 c.c. as the effective stimulus and he ejected this exact amount. Owing to the injury to nerve roots, no cutaneous or deep reflexes could be evoked from any part below the lesion. On scratching the abdominal wall evacuation occurred at 220 c.c., as before, and with deep breathing he rejected the fluid when 230 c.c. had passed into the bladder. The production of abdominal reflexes from above the level of the lesion produced, as might have been expected, no effect on vesical activity. In this case automatic involuntary micturition had been established under conditions which precluded the exercise of any reflex influence upon the expulsive activity of the bladder.

§ 2.—Behaviour of the Sphincter Mechanism

So far we have considered the behaviour of the bladder-wall only and have eliminated the sphincter by making our observations with a catheter in situ. But many of these patients pass all their urine automatically and, in such a case, the act of micturition demands not only contraction of the bladder-wall, but also relaxation of the internal sphincter. Both the sensibility of the mucous membrane and the muscular contractions are sufficient to generate the act of expulsion and, in addition, this reflex response of the bladder is associated with the requisite inhibition of the tonic sphincter.

We have described the remarkable way in which any stimulus, capable of evoking a reflex from the spinal cord below the lesion, may facilitate the reaction of the bladder-wall. These extra-vesical stimuli can also influence the moment at which the sphincter relaxes and so hurry automatic micturition.

But such observations are much more difficult technically to carry out than those we have discussed in the earlier part of this chapter. The volume at which the bladder-wall evacuates its contents must first be determined through the catheter in the usual way. Then a smaller amount of fluid is allowed to run into the bladder and the catheter removed; various stimuli are applied to the parts below the level of the lesion in the attempt to evoke the complete act of automatic micturition: and in some cases this is found to occur although the bladder contains a volume of fluid smaller than that to which it would otherwise respond.

Thus forty-four weeks after complete division of the spinal cord in the region of the sixth thoracic segment No. 1 was automatically emptying his bladder through a catheter when its contents reached 490 c.c. But when the sole of the foot was scratched evacuation occurred at 160 c.c., and with deep breathing it began as soon as 25 c.c. only had passed into the bladder.

Now we knew, from the clinical records, that this patient was passing a full quantity of urine daily into the bottle. It was obvious, therefore, not only that his bladder-wall could expel the fluid when it reached a certain volume, but that the detrusor stimulus must have been associated with inhibition of the sphincter. We had then to determine whether extra-vesical stimuli could facilitate this complete act of evacuation, when the catheter was removed and the sphincter allowed to have free play. We allowed 400 c.c. of fluid to run in and the catheter was removed; deep breathing produced no obvious result, but on scratching the thigh he passed 80 c.c. in a fine strong stream. When, however, the bladder contained 200 c.c. no stimulus of any kind led to micturition owing to the obstruction of the tonic sphincter.

In this instance the bladder expelled its contents with a catheter in situ at 490 c.c. But even when the catheter was removed and the sphincter came into action some fluid was voided at 400 c.c., if flexor spasms of the legs were evoked by scratching the thigh. This shows that extra-vesical stimuli can not only bring about premature contraction of the bladder-wall, but also coincident relaxation of the sphincter. It is, however, obvious that, even in this most favourable case, facilitation occurred much less readily when the sphincter was in action than when we had to deal with the activity of the bladder-wall only, and in many patients it is impossible, owing to technical difficulties, to show that such facilitation occurs at all.

For instance, in No. 3, the bladder-wall evacuated its contents completely at 290 c.c. with the catheter in situ. We succeeded in spite of the technical difficulty in passing just short of 290 c.c. into the bladder and removing the catheter without evoking expulsive efforts; then deep breathing, stimulating the soles, and rubbing the belly all failed to evoke evacuation, although if the catheter had been in place and the sphincter thrown out of action, any one of these stimuli would have caused him to empty his bladder at 150 c.c. Thus in some cases it is impossible to prove whether or no such extra-vesical stimuli facilitate relaxation of the sphincter, because of purely technical difficulties in carrying out the experiment; the bladder-wall ejects its contents through the catheter before they have reached an amount capable of evoking the complete act of automatic micturition, even under the facilitating influence of mass-reflexes. And yet in many of these patients we know clinically that grasping the lower extremities, lifting them from a bed to a chair and other similar excitants of spasm will cause the bladder to be emptied, in some cases completely.

If the sphincter has been injured or unduly irritated by the passage of a catheter it may not relax at all in spite of powerful contractions of the bladder-wall. This condition is a fruitful source of abnormal reflex activity in the lower end of the spinal cord, which may be manifested in spasmodic movements of the lower extremity, contracture of the abdominal wall and, in some cases, an outburst of excessive sweating (No. 5).

But apart altogether from such irritation the early return of tone to the sphincter mechanism compared with the later recovery of detrusor activity gives the sphincter a dominance that is overcome only under the most favourable conditions. We have given an example of complete automatic micturition, consisting not only of contraction of the bladder-wall, but of relaxation of the sphincter, in a case where the sacral roots were destroyed. It is therefore certain that even under such conditions the urine may be passed automatically; but it is no longer amenable to those reflex effects, due to activity of the distal portion of the spinal cord, which form the main theme of this paper.

§ 3.—Conditions which influence the Functions of an Automatic Bladder

(*a*) *Influence of the nervous system.*—When once automatic micturition has been established after injury to the spinal cord, evacuation of urine is governed by three factors: the response to tension of the bladder-wall, the relaxation of the tonic sphincter and the effect of extra-vesical reflexes.

Now there can be no doubt, from the experimental evidence, that the act of micturition can occur when the bladder is entirely separated from the central nervous system, or when the whole of the lower portion of the spinal cord has been destroyed. We have given an instance where a patient with destruction of the sacral nerve roots passed urine involuntarily and ejected fluid run into the bladder through a catheter as soon as it reached a volume of from 220 c.c. to 230 c.c. Under these conditions the spinal cord can exert no influence on micturition; involuntary expulsion takes place in consequence of the activity of structures outside the central nervous system. Our observations tend to support the views of those experimental physiologists who have shown in animals that the condition known as an automatic bladder may arise independently of the spinal cord.

But we have been able to show that, even when the spinal cord is completely divided, afferent impulses reaching the parts below the lesion may have a profound effect on automatic evacuation of fluid by the bladder-wall, and even, in some cases, on the complete act of involuntary micturition. Scratching the sole of the foot, the groin, or the abdomen, swabbing the glans penis and almost any manipulation capable of evoking reflex spasms, tend to facilitate the automatic activity of the bladder. Under such conditions the activity of the lower end of the spinal cord has obviously changed its character; the reflexes have lost their local signature and the energy excited by an afferent impulse from any one receptive field produces a profound general modification of all its functions. A stimulus that would normally evoke withdrawal of the foot tends also to facilitate automatic evacuation, and conversely injection of fluid into the bladder may be associated with a flexor spasm of the legs.

It has sometimes been taught that the form assumed by automatic micturition depends on the situation of the injury to the spinal cord. This is not borne out by our observations. Given that the lesion is sufficiently severe and the conditions both local and general are favourable, the reaction of the bladder-wall to endo-vesical tension will be the same in principle whatever the situation of the lesion. Of this we can be certain because our experience is based on measured observations. When, however, we are dealing with the complete act of involuntary micturition, we are forced to rely to a greater extent on clinical observation, and cannot state so definitely that the situation of the lesion in the spinal cord is entirely without effect. But we have brought forward instances where the spinal cord was injured in the most various situations between the seventh cervical and the twelfth thoracic segment, and yet the phenomena of automatic evacuation were identical in character.

In some cases when the lesion is situated below the tenth thoracic or is not sufficiently severe to destroy all sensibility, the patient may be conscious of tension within his bladder and yet be unable to influence voluntarily automatic evacuation. No. 6 was conscious that fluid was entering his bladder, he knew the moment at which the wall contracted, and experienced both the discomfort of distension and the pleasurable relief following the expulsion of the fluid: and yet these sensations did not in any way modify the act of involuntary evacuation.

(*b*) *Influence of shock, fever, and other general states.*—Long-continued cystitis tends greatly to diminish the size of the bladder, and at any rate in the earlier stages, to decrease the completeness with which it is evacuated. But, apart from such local inflammatory conditions, the fact that it is acting automatically seems to lead to a smaller capacity. This is not to be wondered at, and it is in agreement with Elliott's experience in animals, where cystitis is a rare event. For under normal conditions in man desire to micturate may be resisted; the bladder then resumes a new tonic position, and it is not until the quantity of urine has reached a very large amount that pain of necessity compels its expulsion. In the case, however, of the automatic bladder, all voluntary control is lost, and, as soon as the endo-vesical tension becomes a sufficient stimulus, expulsion occurs. But it must be remembered that even in our experiments, made with the least possible pressure, there appeared moments when the bladder hesitated on the brink of evacuation, but finally accepted a further addition to its contents. If this happens when the sphincter mechanism is thrown out of play, it is still more likely to occur during the complete act of involuntary micturition, which demands not only contraction of the bladder-wall, but coincident relaxation of the sphincter. It must often happen that urine collects in the bladder to an amount sufficient to excite muscular contractions, but inadequate to inhibit the sphincter; the stimulus then dies away and the vesical tone yields to allow the assumption of a larger volume. Here, however, comes in the value of that remarkable facilitation, due to extra-vesical stimuli, of which we have so frequently spoken. The patient has only to turn on his side or to have an access of reflex spasms, for the contents of the bladder to become an effective stimulus to micturition;

and it is probably for this reason that, in favourable cases, the volume of fluid to which the bladder-wall responds in our experiments corresponds approximately to the amount at which involuntary micturition occurs. This can never be ascertained with certainty. For although it may be measured by removing the bottle as soon as the patient has passed urine, there is no means by which we can be certain that these measurements are typical. We shall, therefore, confine ourselves to describing the effect of general conditions such as shock, fever and toxic states on the volume of fluid to which the bladder-wall reacts with the catheter in situ; for this is a measurable quantity and can be determined with considerable accuracy.

Any severe febrile disturbance, whether it be due to a septic bed-sore or to pyelitis, tends to diminish the volume to which the bladder-wall responds. Provided, however, that cystitis is absent, or present to a small extent only, evacuation may still be complete. The more severe the cystitis the greater will be the difference between the amount of fluid run into the bladder and that which is expelled in any one observation.

No. 1 is a good example of the effect of a febrile disturbance uncomplicated by cystitis; 158 days after he was wounded his bladder responded to 600 c.c., expelling from 590 to 595 c.c. spontaneously. At this time his urine was acid and contained no pus or albumin. He then passed through a febrile attack with rigors, apparently due to pyelitis. This passed away entirely and did not recur. But on the 266th day after he was shot, measurements showed that the capacity of his bladder had diminished; he now responded to from 180 to 240 c.c., but still emptied his bladder completely. Fifty days later (306th day) the capacity had increased to 490 c.c., and during the next week a series of measurements gave from 420 to 425 c.c.; on both occasions the bladder was emptied completely.

This is, however, an unusually favourable case; more commonly, repeated febrile attacks, with or without cystitis, diminish the capacity of the automatic bladder until it holds less than 150 c.c., and even this amount is incompletely evacuated.

Attacks of septicæmia, whatever their origin, greatly delay the establishment of automatic micturition. Thus another patient arrived at the hospital suffering from characteristic pyrexia, due to a foul bed-sore, and, although the bladder-wall responded to between 270 and 280 c.c. within forty-eight days of the wound, no spontaneous involuntary micturition has yet occurred after six months.

Now it is obvious that if a patient suffers both from cystitis and general septicæmia, true automatic micturition may never become established. Usually his bladder is washed out once or twice daily under a fluid pressure of two or three feet or from a large syringe; no attempt is made to determine whether his vesical musculature can respond or not, and he passes to his death as a case of retention with atony. It is therefore of extreme practical importance to discover in every case if the bladder is capable of reacting and expelling its contents; if so, it must be washed out with a suitable lotion under the least possible pressure. As soon as the fluid begins to rise in the tube it must be allowed to escape freely. In this way we can not only treat the cystitis, but at the same time encourage the muscular response of the bladder, even before the complete act of involuntary micturition has been established.

Apart, however, from the evil effect of toxæmic states on the automatic bladder, all febrile conditions tend to diminish the responsive power of the severed spinal cord. The distal end, separated to a greater or less extent from the influence of the higher centres, is peculiarly susceptible to the devitalising influence of long-continued toxæmia.

This is strikingly evident in the behaviour of the reflexes. The receptive field diminishes and at the same time a stronger stimulus is required to evoke a response. At one period in the progress of the case it was perhaps possible to produce a flexor spasm by scratching almost any part of the lower extremity; but after long-continued fever it may be difficult to obtain a reflex even from the sole of the foot. The knee-jerk may diminish, ankle clonus disappear and even the so-called "spontaneous" spasms of the legs may become negligible. In cases of partial lesions of the spinal cord any extensor activity that may have existed is first eliminated; then the flexor contractions decrease in severity and frequency. All the signs point to progressive diminution of the tonic activity of the distal end of the injured cord.

With this deterioration in function the facilitating influence of extravesical reflexes disappears; a flexor response no longer makes it easier for the automatic bladder to discharge its contents. The sphincter mechanism is very little affected and passive dribbling of urine and fæces occurs just before death only. Thus it is possible for a patient subject to prolonged febrile attacks to pass through, in the terminal phase, a period of retention of urine, owing to diminished detrusor activity associated with want of inhibition of the sphincter.

This downward progression under the influence of toxæmia is the reverse of the stages by which the lower end of the spinal cord regains its functions during recovery from the shock of the original injury. From the first the sphincters are little affected; there is complete retention of urine and the anus is not patulous; knee-jerk, ankle jerk and ankle clonus are absent; the plantar reflex either cannot be obtained at all or consists of a downward movement of the great toe. Then involuntary micturition appears and the deep reflexes turn. The plantar reflex assumes the abnormal form, and the field from which it can be obtained widens until it can be elicited by scratching almost any part of the lower extremity.

If the injury to the spinal cord has not been very severe, sensation and voluntary power may return and the phenomena of facilitation may never appear. But if the cord is completely divided or very grossly injured, the reappearance of tone, as shock passes away, may be accompanied by the conditions we have described as facilitation. All reflex activities have then lost their local signature. A flexor spasm of the leg can be excited by scratching not only the sole of the foot, but almost any part below the lesion or even by injecting fluid into the bladder or rectum. Any sufficient stimulus to any receptive surface is liable to evoke a massive response, which overflows widely into regions of the spinal cord normally associated with other reflexes. This development of the spinal tone and the advent of a condition in which an effective stimulus facilitates all reflex activities of the severed cord, are hindered or rendered impossible by general toxic states. Then the phenomena associated with the first period of shock do not wear off, and the patient may die without having presented any of those reactions which are of primary interest to us in this paper.

CHAPTER II

EXCESSIVE SWEATING

§ 1.—Description of the Phenomenon of Excessive Sweating

Excessive sweating usually appears in its most striking form when the lesion is situated in the lower cervical region. Let us choose a case where sufficient time has elapsed since the injury for the deep reflexes to have become exaggerated and for involuntary movements, of which the patient is unconscious, to occur, especially on manipulation. The period of shock has passed and the patient's general condition is sufficiently good to permit of the return of reflex excitability in the spinal cord below the lesion.

When the patient sweats excessively he usually does so intermittently; there are periods in which the skin is no moister than it should be normally. In such cases it is possible to make direct observations on the causes which evoke the hyperidrosis. These are remarkably various and we have found that there is scarcely a stimulus, cutaneous, proprioceptive, or visceral, that may not be followed by an outburst of sweating over the area appropriate to the lesion in each patient.

So long as the weather is cool and he is undisturbed, the skin of the head and neck may be moist to the normal degree but no more. If, however, the hand is placed under the bed-clothes and flexor spasms, which the patient cannot appreciate, are evoked, either by scratching the sole of the foot or by grasping the lower extremity, beads of sweat may appear on his forehead. He knows nothing of the movement and stimulation of the feet can cause no sensation; and yet it may be sufficient to evoke profuse sweating limited to an area which is constant in each case and is determined by the site of the lesion and not by the situation of the stimulus.

Such patients usually require catheterisation and, in many cases, the bladder must be washed out daily. These manipulations may be associated with extreme sweating over the head and neck. Moreover, the patient recognises that if the bladder is allowed to become too full and the passage of the catheter is delayed, the sweating will certainly begin. In the same way, at a time when the bladder is evacuating itself automatically, any obstruction to the flow of urine starts the local sweating, and we have been able to evoke it experimentally by the injection of fluid during our systematic observations on the reflex capacity of the automatic bladder.

Any intestinal disturbance such as flatulence, and more particularly the manipulations for administering an enema, may start sweating in every way identical with that described as arising spontaneously.

When fully developed, the sweating in such cases is incredibly profuse; a dry sponge used to wipe the face and neck can be wrung out, as if it had been dipped into water, and blankets and pillows are soaked through with the moisture in a few minutes. So much fluid may be lost that the patient suffers from thirst and the urine is diminished in amount.

The extent of the area occupied by the excessive sweating differs according to the situation of the lesion; when the injury is in the lower cervical region it occupies the whole head, neck and arms, extending to about the level of the umbilicus, decreasing in amount from above downwards, and the legs may remain dry. A lesion at the level of the third thoracic segment may cause profuse sweating over both arms, over the whole trunk from the second rib down to the toes, with a maximum hyperidrosis in the upper dorsal region, steadily diminishing as we pass downwards towards the feet. The head and neck do not participate in the sweating.

If the lesion lies in the region of the sixth thoracic segment sweating may occur from about the fifth rib downwards with some moisture of the palms of the hands. Arms, neck, and head, however, remain unaffected.

With a lesion at the level of the eighth thoracic segment, sweating may occur from the ensiform down the thighs, diminishing greatly to the feet.

When the injury is situated at about the ninth thoracic segment, the area occupied by the hyperidrosis corresponds almost exactly to that of the analgesia, whilst at any point in the spinal cord below this the area of sweating is less extensive than that of the loss of sensation. Thus in a case where the left half of the spinal cord was completely divided at the level of the tenth dorsal segment, excessive sweating extended on the left lower extremity up to Poupart's ligament, but was never observed on the right leg. Here the left-sided sweating could be particularly easily evoked by any abnormal tension in the bladder.

§ 2.—Conditions which excite it

We will now consider these definite causes for an outburst of excessive sweating one by one.

(*a*) *Reflex spasms.*—These can be studied in their simplest form when the period of involuntary automatic action has been fully established after complete division of the spinal cord. Thus, in the case of No. 1, where the lesion was situated in the mid-dorsal region, excessive sweating began forty-five days after the injury. It occupied an area extending from about the fifth rib downwards, with some moistening of the palms of the hands. If, when the skin was dry, the sole of the foot was stimulated, as he lay quietly in bed, a series of flexor spasms could be evoked; the toes became extended, the ankle dorsiflexed and both knee and hip were vigorously bent. After two or three such spasms the sweating began and continued for a considerable time after he had been left at rest.

In No. 5, the lesion, though severe at the level of the seventh cervical segment, was not complete; but the association between the sweating and reflex spasms was most definite. If a suitable opportunity was chosen when the skin was in a normal condition, it was only necessary to scratch the sole of the foot under the bed-clothes for the most profuse sweating to break out over the whole of the head and neck in association with the flexor spasms. These reflex movements could be evoked by stimulating almost any part of the skin of the lower extremity or abdomen by pressure, as in turning or moving him in bed, or even by lifting the bed-clothes. No matter how the spasms were produced, they were associated with an intense outburst of sweating over the head and neck.

No. 2 was another example of the close association between hyperidrosis and the existence of these spasmodic involuntary movements. The spinal cord was completely divided in the region of the fourth thoracic segment, and the sweating occurred on the trunk from the level of the second or third rib downwards to that of the ensiform and usually affected the greater part of both upper extremities. Scratching almost any part of the lower extremity, grasping the foot or the muscles of the thigh, even removing the bed-clothes would start flexor spasms which were immediately followed by an outburst of sweating.

We could quote many other examples of this association between spasmodic movements and excessive sweating which may appear when the activity of the spinal cord has reached this stage of functional recovery. Analysis shows that in this condition the reflexes have lost their preponderant local signature; scratching the sole of the foot leads, not to a simple withdrawal, but to a universal flexor spasm which may extend to the opposite leg and is usually associated with a strong contraction of the abdominal muscles. Stimulation of almost any part evokes a spasmodic " mass-reflex " which remains more or less identical in character whatever the stimulus and wherever it is applied.

It is the production of this undifferentiated " mass-reflex " which in suitable cases is associated with the appearance of excessive sweating, but the reflex spasms are one only of its many associated conditions.

(*b*) *The activity of the bladder.*—It has long been known, at any rate to intelligent patients, that the condition of the bladder has a direct bearing on the sweating. But it was not until we began our systematic measurements of the capacity of the automatic bladder that the truth of this view could be demonstrated under experimental conditions.

For example, take the case of No. 2, where the spinal cord had been completely divided at the level of the fourth thoracic segment. A catheter was passed and after the bladder had been emptied warm fluid was allowed to enter slowly from the burette. When 250 c.c. had passed into the bladder, fluid began to return and he evacuated in all 135 c.c.; a further 130 c.c. was ejected by pressure on the abdomen. Two further observations under the same conditions showed that evacuation occurred at 250 c.c. and 290 c.c.

He was entirely unconscious of any of these manipulations; but as soon as we evoked automatic bladder action he began to sweat profusely from the clavicles downwards, the head and neck remaining dry. The whole extent of the arms sweated profusely; the trunk became wringing wet from the clavicles to the groin: thighs, soles and the back of the legs were also sweating heavily, but not so profusely as the arms, chest, abdomen and back. Here we were able to induce the hyperidrosis experimentally, over an area corresponding to the parts below the lesion, by distending the bladder with fluid.

No. 5 was another instance of this close association between vesical tension and the onset of sweating. His lesion, though not mechanically a complete division of the spinal cord, was an extremely grave one in the region of the seventh cervical segment. By the time he reached the London Hospital, three days after the accident, the urine, though acid, contained thick ropy pus and several false passages had been made from which he bled when the catheter was passed. He had absolute retention of urine and it was necessary to pass a catheter every eight hours.

Shortly after his admission we began to notice outbursts of the most intense sweating, probably more profuse than in any other instance that has come under our observation. Sweat ran together into huge beads which rolled off his face and neck, and moisture could be wrung out of a sponge, passed over his skin, almost as if it had been dipped into water. A towel used to dry his face was wetted through in a few moments. Gradually it became apparent that one of the most fruitful causes of these outbursts of sweating was a full bladder. He would become gradually conscious of a " fulness " in the head and of the increasing moisture of his face; by the time the house physician arrived to relieve him, the paroxysm was fully developed; but the sweating ceased as soon as the tension within the bladder was removed by the passage of a catheter.

It must not, however, be supposed that the bladder was an inert bag. For although no urine could be voided without the help of a catheter, we found that with the catheter in situ vigorous evacuation occurred when fluid was allowed to run into the bladder. Thus forty-three days after the injury fluid was briskly ejected through the catheter when 300 c.c. had been slowly passed into the bladder, and of this amount he succeeded in evacuating 150 c.c. On a second observation he responded to 180 c.c., extruding 125 c.c. One hundred days after the accident a more extensive series of observations was carried out. A time was chosen for passing the catheter when he was perfectly comfortable, and the skin was in a condition of normal moisture; 190 c.c. of urine were drawn off. On pouring fluid into the bladder the column began to oscillate at 150 c.c.; at 200 c.c. automatic evacuation began and he passed 120 c.c. A further 80 c.c. were recovered from the bladder by pressure on the abdominal wall. The first signs of sweating appeared on the forehead when 50 c.c. had entered the bladder and steadily increased up to evacuation. His face and neck were then dried and after some minutes the sweating had greatly diminished. Fluid was again poured into the bladder; the oscillations in the column began at 50 c.c., and at the same moment a fresh outburst of sweating occurred. At 120 c.c. the bladder contracted vehemently and extruded 70 c.c.; a further 95 c.c. were recovered by pressure on the abdomen, showing that some urine must have entered the bladder in the meanwhile from the kidneys.

Two further observations were made, after a sufficient pause during which his face and neck were carefully dried. He evacuated at 150 c.c. and at 125 c.c., passing 100 c.c. and 65 c.c. respectively. On the first occasion the sweating began when 100 c.c. had entered the bladder, whilst in the second it started at 70 c.c. One of the most striking features of this experimental series was the way in which the steady inflow of fluid was checked and began to oscillate at a definite point, showing that the bladder was no longer a passive receptacle, but was responding tonically to the stimulus of pressure. This was the signal for the outburst of sweating.

He was able to recognise with extreme accuracy the moment at which sweating first began. Thus, although he could not appreciate any of our manipulations, he would call, "Now the sweating is beginning"; and this corresponded to the moment at which fluid no longer flowed freely into the bladder. When fully developed, the hyperidrosis occupied the head, neck, arms, and extended in an intense degree to the level of the ensiform; to a less degree it was found as low as the umbilical line.

In this case other peripheral stimuli could be made to evoke an outburst of sweating, but abnormal conditions of tension in the bladder were the most frequent and potent cause of "spontaneous" hyperidrosis. The urethra had been injured before he came under our care by unskilled catheterization; this had induced local irritation of the sphincter, which fell into spasm, and did not relax when the automatic contractions of the bladder came on. Consequently, when a certain amount of urine had collected, and the tension had been raised sufficiently, the vesical musculature responded, but, as the sphincter did not relax, no urine was passed. Then began a steadily increasing stream of afferent impulses, which started the sweating. We found experimentally that the bladder-wall responded to about 150 c.c. of fluid: had the sphincter been uninjured, it might have relaxed at about this point, and urine would then have been voided automatically. But the irritability of the sphincter led to perpetually recurrent obstruction, with distension of the bladder, above the amount at which reflex evacuation should have occurred. This was why the recurrent attacks of hyperidrosis could be infallibly relieved by passage of a catheter. Finally, we tied a catheter into the bladder, and fixed a cork into the orifice; the nurse could then allow the urine to flow whenever he complained of the sweating. This gave great relief, the irritability of the sphincter gradually subsided, and he began to pass urine automatically two hundred and eight days after the injury, and after the catheter had been in position permanently for nearly eight weeks.

No. 8 was another example of the close connection between exaggerated sweating and the condition of vesical tension. Here the lesion in the neighbourhood of the eighth cervical segment was functionally incomplete; he was, in fact, an instance of modified Brown-Séquard paralysis, with some diminution of power in the left hand and total loss of sensibility to pain, heat and cold over the right half of the body from the level of the fourth dorsal segment downwards. The want of appreciation of vibration was, however, complete on both sides up to the level of the iliac crest, and on the left half of the body extended to the fourth rib.

This patient was much more conscious of our manipulations, and not only recognised that fluid was passing into the bladder, but could tell when it was about to empty itself. He knew that the urine was coming, and when it passed experienced the normal pleasure, but he had no direct desire to micturate. When, however, there was any difficulty or obstruction in the passage of the water, sweating began at once. Thus it was not unusual for a plug of muco-pus to obstruct the orifice, so that the flow was rendered more difficult, and he would then begin to sweat profusely over the head and neck, the arms, and upper part of the chest. During the first three weeks this was confined to the right side, but later it became almost equally profuse on both halves of the head and neck.

Experimentally his bladder was found to respond to from 100 c.c. to 115 c.c., and the whole amount was ejected automatically. So long as the catheter was properly inserted, and the fluid could be evacuated freely, at the moment when the bladder-wall began to contract, no sweating occurred; but as soon as there was any obstruction, it began profusely over the whole head and neck. After the bladder had been opened suprapubically, all excessive sweating ceased, except when the box ("tortoise") shifted, or the free flow of urine was checked by some mechanical defect. On one occasion the drainage tube became blocked by a small calculus, and the hyperidrosis came on again in a violent form to our profound bewilderment.

This patient also showed that the excessive sweating is not correlated with that "thrill," or "shiver," which normally accompanies evacuation of a full bladder. In fact, this sensation seems to be evoked by the opposite condition to that which caused sweating. He could tell with remarkable accuracy when his bladder was about to empty itself during our experimental observations, and contended that he "always knew by a nervous wave, which seemed to start in his abdomen, and passed up to the head and down his arms"; it was "a sort of shiver," and it immediately preceded passage of urine automatically into the bottle or evacuation of the fluid inserted through the catheter. With this sensation he never sweated; it was always associated with an easy passage and free outflow. Any obstruction destroyed this sensation, and replaced it by sweating, which was accompanied by a definite feeling of discomfort.

(c) *Intestinal conditions.*—The patient (No. 1), who has been throughout our classical example of the consequence of a total transverse lesion of the spinal cord, soon discovered that he was completely ignorant of anything that happened within his gastro-intestinal canal below the stomach. He fully appreciated the passage of food down the œsophagus and, being a heavy eater, recognised when his stomach was distended; but beyond that point nothing that happened affected his consciousness directly. We observed, however, that the injection of an enema was a potent cause of sweating. The lesion was at the level of the sixth dorsal segment, and head, neck, shoulders and arms, with the exception of the hands, always remained dry. But from the level of about the fourth rib downwards and on the palms the sweating broke out profusely when fluid was injected into his lower bowel.

Like the bladder, the rectum evacuated its contents automatically. Dribbling of fæces was never known to occur. When an enema was given the amount of fluid necessary to start an evacuation depended on the quantity of fæcal matter already in the rectum; it varied from 50 to 250 c.c. (2 to 9 oz.). As soon as a sufficient quantity of fluid had been injected, the sphincter relaxed and fluid and fæces were voided together; sometimes however, several small evacuations occurred but there was no constant dribble. The rectal wall contracted on its contents and expelled them vehemently. Sweating rapidly ceased as soon as the rectum was acting freely.

No. 5 was another splendid example of the relation between intestinal tension and hyperidrosis; for not only was the sweating infallibly evoked in profuse quantity by an enema, but any collection of wind would also tend to produce an outburst. In the earlier days, before the catheter was tied into his bladder, he was peculiarly liable to periodic gastro-intestinal attacks associated with nausea and the collection of intestinal flatus; the abdominal muscles became rigid, flexor spasms increased in the legs and the sweating became very severe. Anything that eased this flatulence or the advent of the natural termination of the attack was associated with a diminution in the sweating. But, whatever the reflex cause, the distribution of the hyperidrosis was the same: it occupied the head, neck, arms and the trunk to the umbilical level.

In the case of No. 8, where the clinical picture was that of a modified Brown-Séquard paralysis, this relation between intestinal tension and excessive sweating occurred only when evacuation was not completely free. He was analgesic and thermo-anæsthetic over the right half of the body as high as the nipple level, but was sensitive to pain and thermal stimuli over the left half of the trunk. When an enema was given in my presence he said he could feel the insertion of the nozzle of the syringe. Then after the first few ounces of fluid were pumped in, he said: "I have a feeling as if the passage were being forced open;" after receiving about 300 c.c. he said: "I've got a nervous feeling which runs up the body down my arms into the back of my head and over the front of the scalp: it also runs down the front and inner aspect of both thighs more on the left (sensitive) side than on the right. This thrill is not unpleasant, but as the injection goes on it becomes unpleasant, just as it is unpleasant when you have to strain at stool." No sweating occurred until this thrill became converted from a pleasant to an unpleasant sensation, a condition exactly analogous to the similar phenomena produced by obstructed evacuation of urine. The pleasant visceral thrill is not associated with a stimulus to sweating; but obstruction, with its natural discomfort, evokes hyperidrosis.

(*d*) *Heat.*—Changes in external temperature are liable to influence the amount of this local hyperidrosis. Thus No. 1 sweated less when he was sitting up in a chair, and the act of putting him back to bed and wrapping the blankets around him caused a profuse outburst of moisture over the whole of the usual area. When he was lifted out of a warm bath sweat poured from the lower half of the chest, abdomen and palms.

But as soon as the change in temperature is due to some general febrile cause, such as septic infection from the bladder, kidney, or a dirty bed-sore, the sweating becomes general. It is true that in some instances the area peculiar to each case is still found to be moister than the other parts of the body; but the difference between the condition produced by a hot bath and that which accompanies a febrile attack is most striking.

Thus in one patient, where the left half of the spinal cord was divided at the level of the eleventh thoracic segment, the sweating occupied under normal conditions the left lower extremity only. He suffered from a febrile rise of temperature, and the sweating was universal, though more profuse over the left leg. Similarly aspirin causes general sweating in these patients, although at the time they may be free from fever.

§ 3.—Distribution of the Sweating and its Significance

It is now universally recognised that the secretion of sweat is brought about by the sympathetic system, and that the connector fibres, conveying these motor impulses to the sympathetic chain, pass from the central nervous system by way of the anterior roots. Langley [65] showed that all the fibres capable of evoking sweating left the spinal cord between the second thoracic and third lumbar roots, that is in the thoracico-lumbar outflow, to which he strictly confines the term sympathetic. This use of the word has now become so universal amongst physiologists that we shall adhere throughout this paper to his nomenclature; whenever we speak of "sympathetic" we shall signify some activity or structure pertaining to the thoracico-lumbar outflow.

It will be obvious that if a patient sweats excessively after an injury to the spinal cord, the impulses on which the hyperidrosis depends must pass out between the second thoracic and third lumbar segments. Now, in such a case as No. 5 the lesion was situated in the sixth and seventh cervical segments of the spinal cord and sweating of the most profuse character occupied the whole head, neck and trunk as far down as the umbilical level. The essential cause of this phenomenon must, therefore, have lain in the spinal cord below the injury.

We have also been able to demonstrate that this sweating can be evoked by the most various afferent impulses affecting the spinal cord below the lesion only. For scratching the soles of the feet or filling the bladder with fluid are stimuli which can act solely on the distal parts of the divided cord.

It is thus obvious that, in the instance we have given, the cause of the hyperidrosis must be sought below the lesion, and when we examine case by case the area occupied by the excessive sweating in the light of our present knowledge of the sympathetic system, we are driven to the same conclusion, however improbable it may seem on superficial consideration. In the two patients (No. 2 and No. 3) where the cord was divided at the level of the fourth thoracic segment, the sweating was profuse over the upper extremities, the post-axial being moister than the pre-axial parts, and over the trunk from just below the clavicles to the thighs, or even to the toes; the head and neck were entirely unaffected.

Now Langley had shown that in the anterior extremity of the cat sweating is determined by fibres which leave the spinal cord from the fourth to the ninth thoracic roots. Thus the distribution of the hyperidrosis in our two cases where the cord was divided at the fourth thoracic segment also points to some cause below the lesion, in spite of the fact that sweating occupied the upper extremities.

In No. 1, the patient with complete transection of the spinal cord at the level of the sixth thoracic segment, the sweating occupied an area from the fifth rib downwards, and to a less degree affected the palms of the hands. Now, of the seven thoracic roots which govern the upper extremity, three are certainly at or above the lesion in this case; four are, however, below and account for the moisture of the palms.

When the lesion lies at about the eighth or ninth thoracic segment the sweating corresponds almost exactly with the analgesia; it no longer extends far above the parts that are insensitive, as in the previous cases.

As soon, however, as the injury lies at a point below about the ninth thoracic segment, the hyperidrosis, should it occur, does not extend as high as the corresponding loss of sensation. Thus, in a case where the left half of the spinal cord was divided at the level of the eleventh thoracic segment, the sweating occupied the left leg and lay entirely below Poupart's ligament, whilst the analgesia extended to just below the umbilicus.

This, again, corresponds exactly with Langley's results in the cat; for he found that the posterior extremity was supplied from the eleventh, twelfth and thirteenth thoracic, and first and second (slightly third) lumbar roots.

Our observations show that, in every case belonging to the group we have described in this paper, the excessive sweating must have been due to processes occurring in the spinal cord below the lesion. For not only could it be evoked by the most diverse stimuli to the lower limbs, but also by changes in tension within the bladder or lower part of the intestine. Moreover, analysis of the distribution of the excessive sweating in each case shows that it corresponds to some abnormal activity in parts of the central nervous system below the injury. Here will be found the key to the final causation of this curious condition.

CHAPTER III

THEORETICAL

§ 1.—The "Mass-Reflex" and its Various Effects

(*a*) *Conditions under which it appears.*—Under normal conditions every reflex shows signs of the receptive field from which it originated. Not only can we say that stimulation of a certain part will evoke a series of predetermined and orderly movements, which Sherrington has called a "type reflex," but the motor reaction may be modified by the position of the stimulus within the receptive field. Thus the sole of the foot forms the most favourable situation for inducing the flexion reflex consisting, in its full form, of flexion at the hip and knee and dorsiflexion of the foot. If, however, the outer aspect of the sole is scratched the foot is somewhat everted, whilst stimulation of the inner side leads to inversion; and yet throughout the total movement of the lower extremity remains true to type. This is no more than an example drawn from clinical experience of Sherrington's experimental results on the scratch reflex. For whatever part is stimulated within a certain saddle-shaped area on the dog's back, the foot of the same side rises to perform the act of scratching; and yet the actual direction of the thrust is determined by the situation, within that area, of the spot that has been scratched. This gives the peculiar purposeful character inherent in so many reflex movements.

This tendency to modification in form according to the locality of the stimulus has been called by Sherrington the "local sign" of a reflex. The more accurately it is developed, the smaller will be the receptive field from which one set of movements can be evoked and the more certainly will those movements alone make their appearance. A discriminative and strictly regulated response to stimulation points to a high level of neural activity, and upward progress in the nervous system is shown in the replacement of diffuse "mass-reflexes," endowed with little local signature, by a highly organised and specific response. On the other hand, the tendency to answer by a stereotyped and diffuse outburst of motor energy, to stimuli differing widely in place and kind, is a sign that lower mechanisms are set free from control.

This lower grade activity is manifest in all the phenomena we have gathered together in this paper. Scratching almost any part of the lower extremity, or even the abdomen, may evoke a characteristic flexor spasm. Some remains of the old discriminative response may still be visible in the greater flexion at the hip, when the groin is scratched, than if the sole of the foot is stimulated; and there are other minor differences in the mass-reflex depending on the situation of the stimulus. But these are of little account in comparison with the stereotyped uniformity of the response, however widely the stimulus may have differed in nature and situation.

Moreover, the energy evoked overflows into channels with which the reflex manifestations are not associated normally. Stimulating the sole of the foot aids evacuation of the bladder, and conversely injection of the bladder with fluid evokes a flexor spasm. Such "mass-reflexes" form an excellent answer to noxious stimuli in lower organisms, but are useless for discriminative action. The whole tendency of development in the central nervous system is in the direction of restricting the diffusion of afferent impulses and controlling the form and extent of their reflex reaction.

When the spinal cord has been completely divided, without widespread destruction or septic infection, the lower end may, under favourable conditions, regain its tonic influence and reflex excitability. As shock disappears its various functions gradually return; but they now assume a form in which the reflexes have lost, to a great extent, their local signature, and the reaction is massive rather than specific. In order to study this condition experimentally, we have used three indicators: we have noted the change in the reflexes, more particularly from the lower extremity; we have measured the effective reaction of the bladder, and, when possible, have induced a reflex outburst of sweating by the application of various stimuli. All these methods of research have revealed the same alteration of functional activity in the separated end of the spinal cord. It will be well, therefore, to summarise our results under each of these headings before passing to more theoretical conclusions.

Shortly after the cord has been completely divided no plantar reflex may be obtainable, or, in the earlier stages, the great toe may move downwards. This form of response has been described by Gordon Holmes [53], and as it is discussed by Riddoch [96] it need not detain us here. Somewhere about the fourth week, in a favourable case, the great toe begins to move upwards when the sole is scratched. About the same time, or even before, contraction of the inner hamstrings can be felt. Step by step, as the condition of the lower end of the spinal cord improves, the response comes to consist of a vigorous flexion at the hip and knee, dorsiflexion of the foot, upward movement of the great toe and splaying of the other toes of the stimulated foot. As time goes on the rectus and other abdominal muscles participate and some crossed movement, usually flexion, occurs.

Not only does the reflex from the sole of the foot throw into action an abnormally large group of muscles, but the receptive field from which the reflex can be evoked is enormously extended; it can be produced by scratching almost any part of the lower extremity, especially the groin, inner side of the knee and outer aspect of the leg. Moreover, the great toe can usually be made to move upwards, and the inner hamstrings to contract by stimulating the wall of the abdomen, and not infrequently injection of fluid into the bladder or rectum produces a characteristic flexor spasm.

In the same way the abdominal reflex undergoes analogous changes. At first it may be possible to produce a local segmental reflex only. This gradually gives place to a vigorous general contraction of one half of the abdomen, in which the rectus takes part, and to this may be added all those phenomena in the lower extremity which otherwise follow scratching of the sole of the foot. At this stage it matters little whether the abdomen, groin, knee or sole be stimulated; the response evoked is a "mass-reflex," or "flexor spasm," consisting of a series of widespread muscular contractions mainly, but not entirely, on the same half of the body as the site of the stimulus. The superficial reflexes have to a great extent lost their local signature; stimulation of one part of the body no longer causes its appropriate movement, but calls up much the same response, whatever may be the receptive field.

This indiscriminate activity in the lower end of the severed cord is also manifest in our measurements of the functional capacity of the automatic bladder. Provided there is little cystitis, pyelitis or general toxæmia, the bladder-wall rapidly recovers the power of expelling its contents through a catheter, when they have reached a certain amount. This condition can be reached in a bladder cut off from the central nervous system. But it is established more quickly and perfectly if it remains in connection with the lower end of the severed spinal cord. Once in full activity, under such conditions, the automatic bladder becomes a valuable index of the widespread effect of any adequate stimulus, applied to the parts below the lesion. Scratching the sole of the foot induced a bladder, which otherwise responded to 420 c.c., to eject its contents at 160 c.c. The same facilitation may occur whatever part of the body is stimulated, provided a flexor spasm is evoked, and, in some cases, the abdomen may be as effective a receptive field as the sole of the foot.

Deep breathing has a profound effect upon the activity of the bladder-wall. Of this we have given numerous instances; for example, No. 1 ejected 25 c.c. of fluid through the catheter under the influence of deep breathing, although the usual unaided response did not occur until the contents of his bladder had reached 420 c.c.

Pinching or otherwise stimulating the glans penis may also cause premature micturition, provided it does not produce erection. If, however, the penis becomes turgid under these manipulations, the sphincter mechanism is not relaxed and the bladder is not emptied.

Injection of fluid into the rectum, as during the administration of an enema, will also cause involuntary micturition. At the same time such distension of the lower bowel may evoke a characteristic flexor spasm.

When we examine the underlying causes of hyperidrosis in these cases of spinal injury, the facilitating influence of almost any afferent impulse, affecting the lower portion of the cord, is strikingly evident.

An outburst of sweating can be evoked by stimulating the sole of the foot, or any part of the lower extremity capable of producing a flexor spasm. Injection of fluid into the bladder is a most effective stimulus and sweating is peculiarly liable to appear if the fluid has not free means of exit. Thus, when the bladder was opened suprapubically in No. 8, all paroxysmal sweating ceased, until the exit tube became blocked, when it reappeared as violently as ever. In the same way the injection of fluid into the rectum frequently evokes an outburst of sweating over the area customary to each particular case.

Such are the conditions which may arise in the lower end of an injured spinal cord. In order that it may fall into this manner of reaction the lesion must be gross, but need not be anatomically complete, and it is at first sight puzzling to discover the factors which determine its appearance. Some cases, where all sensation and power of voluntary movement are lost, do not show this general diffusion of reflex energy to a degree sufficient to hurry evacuation of the bladder, whilst others, with apparently less severe disturbance, show all these phenomena of facilitation.

In the next subsection we shall describe the reflex reactions in cases where the spinal cord was gravely injured, and yet no facilitation occurred, in the hope of determining the factors which underlie the assumption of this condition.

(*b*) *Conditions under which it does not appear.*—Before any hypothesis can be suggested, to explain why this overflow of reflex activity occurs in some cases and not in others, although interference with the functions of the spinal cord may appear, at first sight, to be equally severe, it will be necessary to compare one by one the characteristic manifestations of the two groups of cases. In those patients in whom we knew that the spinal cord was anatomically divided, and also in those where we had reason to believe that all conduction had been permanently abolished by the lesion, certain reactions failed to make their appearance in the lower extremities, even after the period of shock had passed away. Such are the cases which tend under favourable conditions to exhibit diffuse reflex activity and excessive facilitation. On the other hand, all voluntary power may be abolished and the patient may be insensitive to every form of stimulus below the level of the lesion; bladder and rectum may be acting automatically, and yet, if certain reflex responses are present, facilitation fails to appear in man, even under the most favourable conditions. (No. 4.)

The most important of these reflexes is primary extension of all the joints of the lower extremity, obtained by stimulating the thigh, groins and abdominal wall. Scratching, pinching, or rubbing any of these parts, to the right or left of the middle line, produces this extensor movement in the lower extremity of the same side; in some cases the reflex movement is bilateral, but it is always more extensive on the stimulated side. A condition, in the lower end of the injured spinal cord, capable of producing such a reflex, is, in our experience, incompatible with that diffuse response and excessive facilitation of visceral activity which form the theme of this paper.

Again, permanent extensor rigidity does not occur in man when the spinal cord is completely divided. Whenever extensor movements appear they are a transitory reaction to flexion in the opposite limb. But in cases of gross injury to the spinal cord, where all voluntary movement and sensation are abolished up to the pelvis and the bladder is acting automatically, one or both legs not uncommonly fall into extensor spasm and may even remain constantly in an extended position. Under such conditions evacuation of the bladder cannot be facilitated by any extra-vesical stimulus in spite of the severity of the spinal injury.

Sherrington ([112] p. 67) described a reflex of the dog's hind limb which he called the "extensor thrust," obtained by mechanical stimulation of the sole. This can be elicited in some cases of gross injury to the spinal cord by gently pushing up the front of the foot when the knee is resting passively in a position of partial flexion; the extensors of the knee and the calf muscles can be seen or felt to contract, and if a strong thrust is evoked the limb is momentarily straightened and the foot plantar extended. This reflex is in no way allied to an incomplete ankle clonus. For the extensor thrust, when fully developed, is a single quick movement extending over two joints, while ankle clonus is essentially a repeated movement due to action of the calf muscles only. We believe that the true extensor thrust can rarely, if ever, be obtained in man where the spinal cord is completely severed anatomically or even functionally. Moreover, the existence of such a reflex is associated with an absence of excessive facilitation, however gross may be the loss of motion, of sensation or of visceral control.

Another condition sometimes present in these cases is the phenomenon of reflex stepping, described by Nothnagel in the frog, and systematically explored by Sherrington ([112] p. 65). In man it takes the following form: If one knee is placed passively into a slightly bent position and the foot is sharply dorsiflexed the knee becomes actively straightened. This is the extensor thrust. It may be accompanied by flexion of the opposite knee and foot. This again may be followed by extension, and the legs may continue for some time to move rhythmically, flexion on the one side being accompanied by the extension on the other and vice versa; in fact, the cord carries out reflexly the movements of stepping. This is another of the phenomena which appear to point to a condition of activity in the lower end of the injured spinal cord incompatible with excessive facilitation of a visceral reflex from a somatic receptive field.

When the cord has been completely divided and the general conditions are favourable for the establishment of a massive response, the receptive field of the flexor spasm spreads widely; not only are foot, knee, hip and abdomen thrown into contraction, but this reflex can be evoked by scratching almost any part below the umbilicus. But, when an extensor reflex can be obtained from the thigh as a primary response, this great widening of the receptive field does not occur, however much the loss of motion and sensation may point to functional division of the spinal cord. Scratching the groin, or even the front of the thigh, will produce a palpable contraction of the quadriceps extensor of the same leg. This reflex has been able to maintain itself against the invasion of its receptive field by the flexor response. Under such circumstances evacuation of the bladder cannot be facilitated from without.

Another curious difference occasionally present between the two sets of cases, grouped by these criteria, seems to be the patient's conception of the position of his legs. Select two men with gross injury to the spinal cord at the same level. Both may be unable to recognise the actual posture and movement, passive or spasmodic, of the lower extremities; and yet, if the extensor phenomena we have indicated are present, the patient tends to think his legs are lying straight out in front of him, whatever their actual position. On the other hand, the man in whom the mass-reflex, flexor spasms and facilitation are well developed usually says that his legs are flexed at the knee and sometimes adds that his feet are drawn up to his hips.

§ 2.—The Physiological Significance of these Conditions

In cases of gross injury to the spinal cord anywhere in the dorsal region we have shown that the presence or absence of sensation is not the determining cause of the subsequent development of a massive response. Consciousness appears to play no essential part in determining whether it shall appear or not: for the patient may be insensitive to all forms of stimulation, however intense, and may be unable to appreciate the posture or movements of his lower extremities, and yet all signs of diffusion and undue facilitation may be absent. Reflex local signature is still maintained in spite of the grossest interference with every aspect of sensation.

In the same way voluntary power may be lost, including control of the bladder and rectum, without this condition necessarily making its appearance, even though sensation is also completely abolished. The key to the problem lies, we believe, in the significance of the extensor phenomena, which alone of necessity distinguish the cases of gross lesion to the spinal cord, where local signature is maintained, from those in which it is largely abolished.

Sherrington has shown that these extensor reflexes are associated with the maintenance of postural tone and the act of standing and walking. But he has also shown that the mechanism, on which they depend primarily, consists of intraspinal (proprio-spinal) arcs; the activity of this system cannot be immediately affected by stimulation of any one afferent root. The maintenance of postural tone demands an adjustment of the whole body and limbs. An essential feature of locomotion is the alternation of two converse phases of contraction and relaxation in the same muscle. This is beautifully seen in the reflex stepping of such a patient as No. 4; but it is equally apparent in the extensor thrust, which can be obtained in all that group of cases to which he belonged. The contraction of the muscles of the calf, which occurs when the foot is pressed upwards, is followed in the same extremity by a definite flexion of the foot: the reflex is in reality a biphasic movement.

We have every reason to believe, from Sherrington's experiments on animals and from Walshe's researches on man [131], that the control of these movements is situated somewhere in the midbrain and pons. It is closely associated with impulses from the semicircular canals. This ultimate controlling centre, presiding over postural tone in the absence of consciousness, acts on the spinal centres and is responsible in man for the appearance of primary extensor manifestations after injury to the spinal cord.

We should like to suggest that it does not act on the spinal centres for the fore-limb and hind-limb independently, but that these proprio-spinal systems are linked up intimately together. The functional state, induced by the higher controlling centre, is not a movement of one limb, but a change of posture of the body as a whole, requiring readjustment of every part of the animal. In the class of case with which we are dealing, we do not see this change elsewhere than in the lower extremities, because the parts above the lesion are still under the control of the will, which prevents any such purposeless manifestation.

But although the stimulus evoking these extensor phenomena has failed entirely to reach consciousness it has acted on the mechanism for postural tone; the synaptic resistance of the common path has been raised against undue flexor activity. There is no longer a straight and uninterrupted road from afferent receptor to flexor movements, but the synapse may be set towards extension or flexion according to the situation and nature of the stimulus. As at a junction on the railway, the points are locked, in many cases automatically, according to the nature of the message received.

Such automatic regulation of the approach to the common efferent path demands some difference in quality on the afferent side according to the site of the stimulus. This difference need not reach consciousness; the patient may not recognise that anything whatever has happened to his lower extremities, and yet the impulses generated by scratching the sole still differ from those caused by scratching the thigh by the fundamental characteristics due to their diverse locality. That is to say, they still maintain their local sign, and this gives to each reflex a form consonant with the local signature of the impulses which evoked it.

We agree entirely with Walshe in his view that primary extensor activity is not, in man, a function of the lower end of the transected spinal cord. The human lower extremities are so exclusively used for maintaining the upright position and for locomotion that the dominant activity of their neuro-muscular mechanism is the production of changes in postural tone. This requires a nice balance between flexion and extension and represents a high order of central control.

Uncontrolled flexion, on the other hand, as far as the lower extremities are concerned, still maintains its close relation with impulses, which would underlie pain or discomfort, if consciousness were present. The sole of the foot, even in man, must still be protected from injuries by stones and thorns, and the response is an immediate withdrawal of the limb that has been hurt. This is the essential flexor spasm, and it still retains many of the marks of its origin; it is more easily evoked from the front of the sole, and the most effective stimulus is a prick or a scratch. Such protective reflexes are the oldest in the phylogenetic scale, and, wherever they still remain in the human organism, betray their primitive origin. Although the movements they evoke are normally strictly under the influence of higher control, the reflex mechanism upon which this influence acts belongs to the more lowly centres in the nervous system.

When, therefore, shock passes away, after complete division of the spinal cord, these lowly centres in the distal end recover their functions if the conditions are favourable. But, in man, this recovery does not occur as a part of the restitution of postural tone, but as an isolated capacity of responding to noxious influences (Sherrington's "nociceptive reflexes").

Now, intense pain or discomfort not only evokes a withdrawal of the lower extremity, but also leads to definite visceral reflexes; urine is passed, the rectum is emptied, and the sufferer sweats. This is particularly evident in fear, which plays upon the whole of this nociceptive reflex mechanism.

According to our view, the massive flexor response, which can be evoked from almost any part below the lesion after complete transection of the spinal cord, is not a part of the normal postural reflexes, but belongs to the ancient nociceptive mechanism. It has in this form nothing to do with standing or walking. Its nearest ally among the reflexes is not primary extension, but evacuation of the bladder and rectum.

On the other hand, when primary extensor activity reappears in the distal end of the spinal cord, flexion becomes controlled and modified as its direct co-relative in postural tone. Flexion may still be evoked under suitable excitation as a nociceptive response, but there is now a block on the reflex synapses to viscera, such as the bladder and rectum. This raised synaptic resistance may be overcome, as in normal life, if the stimulus is extremely violent, or if an emotion such as fear supervenes. But under usual conditions the calling up of a flexor reflex in one lower extremity is followed by an extensor phase, and vice versa. Flexion in the presence of even automatic extensor activity is linked up with postural tone. Flexion in the absence of local signature and of postural tone reappears in the spinal cord as a nociceptive manifestation only, closely associated with visceral reflexes, such as evacuation of the bladder or rectum and excessive sweating.

The explanation we have put forward in this section is in the direct line of thought from the views enunciated by Hughlings Jackson from 1864 onwards. He laid down in many communications and in his clinical teaching, that in lesions of the nervous system positive symptoms were usually the result of removal of control, normally exercised by higher over lower centres. When speaking of rigidity in hemiplegia he says: "My speculation is that the rigidity is due to unantagonised influence of the cerebellum. I believe that in health the whole of the muscles of the body are doubly innervated both by the cerebrum and cerebellum, there being a co-operation of antagonism betwixt the two great centres. Whilst the cerebrum innervates the muscles in the order of their action, from the most voluntary movements (limbs) to the most automatic (trunk), the cerebellum innervates them in the opposite order. . . . This is equivalent to saying that the cerebellum is the centre for continuous movements and the cerebrum for changing movements.

"The muscles which, on the above suggestion, are chiefly innervated by the cerebellum are those which have the fewest different, the most tonic, the most confluent movements; the reverse for those which the cerebrum chiefly innervates. Thus in walking the cerebellum preserves the equilibrium of the body, tends to stiffen all the muscles; the changing movements of walking are the result of cerebral discharges overcoming in a particular and orderly way the otherwise continuous cerebellar influence. This is what is meant by a co-operation of antagonism."

These views had little general influence on neurology until Sherrington's remarkable series of experiments led to a coherent conception of the relation of the innervation of flexors and extensors, particularly in the lower extremity. He proved that in the decerebrate animal all those muscles which maintain posture are in a condition of tone; these are mainly the extensors. But if the spinal cord is divided, even in the upper cervical region, all the reflex reactions which can be obtained are flexor; they do not lead to the assumption of posture, but are phasic movements. Now since the one form of activity is seen when all cerebral influence is removed by a lesion across the cerebral peduncles, whilst after transection of the cord the primary reaction in the stimulated limb is uniformly a flexor movement, it follows that the centre governing postural tone in the hind legs of the dog must lie somewhere in the midbrain or pons. On the other hand, the centre for the primary flexor response must lie in the spinal cord.

Such conceptions of integration within the nervous system had a profound effect on the younger English neurologists and led to the production of Walshe's paper [131] on reflex phenomena in paralysis of the lower limbs in man. His conclusions can be summarised as follows:—

"(1) The reflex movements of the lower limbs in spastic paralysis are almost entirely movements of flexion of the limbs; with flexion is included dorsiflexion of foot and toes, more especially the hallux. These movements occur as the well-known flexor spasms in certain cases of paraplegia. . . .

"(2) The 'receptive field' of this reflex commonly includes the whole limb, skin and deep structures. The form of stimulus most effective is that having a nocuous or harmful character. . . .

"(3) Of this reflex flexion, dorsiflexion of the hallux is an integral and inseparable part. . . .

"(4) The physiological significance of the flexion reflex is that of a defensive reflex and it has no relation to 'spinal stepping.' . . .

"(10) The conditions of paraplegia in flexion is an example of unantagonised flexor reflex action."

Such are some of the conclusions drawn by Walshe from his study of the effects of cerebral and spinal lesions in man. It will be seen how directly they are based on the views of Hughlings Jackson and Sherrington.

The hypothesis we have put forward in this section, to explain the phenomena of excessive facilitation, follows directly on the work of our predecessors. We hold that, so long as certain primary extensor reactions can be evoked from the lower extremities, the flexion reflex retains its double character. On the one hand it is a phase in change of posture and locomotion, and on the other a defensive movement of withdrawal. It does not matter how gravely motion, sensation and visceral control may be disturbed provided there is sufficient connection between the lower end of the spinal cord and the higher centres to maintain postural tone. So long as extension can be obtained as a primary reaction, energy does not overflow into visceral channels when moderate noxious stimuli are applied to the lower extremity, nor is it possible to evoke flexor spasms by allowing fluid to run into the bladder (cf. Case No. 9).

When, however, after shock has passed away, the lower end of the spinal cord regains its activity uncontrolled by any influence above the lesion, the only response is a nociceptive reflex. This takes the form of a vast outburst of motor energy not confined to the parts stimulated, overflowing into visceral channels, a profound shrinking away of the animal from harmful stimulation. Not only is the spread of this reflex activity greater than under normal conditions, but the receptive field from which it can be evoked is unlimited below the lesion in favourable cases. This is the "mass-reflex," and we have attempted to show that in it is revealed a primitive method of response which cannot occur under normal conditions of higher neural control. All traces of such primitive reaction have not been eliminated from the normal nervous system, because withdrawal of the limbs and trunk with evacuation of bladder and rectum may still occur under violent effective stimuli as with the emotion of fear. But the synaptic resistance against such an occurrence must be extremely high in man.

It is an essential condition for the development of the mass-reflex in its complete form with visceral facilitation that the reflexes should to a great extent have lost their local sign. But so long as flexion can be evoked by scratching the sole of the foot and extension by stimulating the thigh, it is obvious that the site of the stimulus still determines the specific character of the reflex response. Now we have shown that the absence of sensation does not of necessity destroy this local signature; it is obvious that afferent impulses must reach the spinal cord marked by some characteristic indication of their place of origin, but it is in no way necessary that they should affect consciousness. In the same way a total absence of voluntary movement does not necessarily lead to a massive response and visceral facilitation. In order that this mode of reaction may appear the mechanism for postural co-ordination of the trunk and limbs should have undergone such gross injury that no impulses can pass across the damaged region.

But if these proprio-spinal paths have been destroyed, or their functions abolished, the mass-reflex may appear in its complete form even though some sensation and voluntary movement are still present below the level of the lesion. Should this form of response follow stimulation of one lower extremity and not of the other, facilitation of the detrusor activity of the bladder may be evoked from the former limb only; in this case the overflow of reflex energy on to the visceral system appears to be independent of the relative condition of voluntary power in the two lower extremities [cf. Case No. 8].

In this discussion we have not yet mentioned the large body of French research on the nature of the reflexes. For our attitude can only be understood clearly by the close study of the development of English thought and particularly of Sherrington's conceptions as set forth in the "Integrative Action of the Nervous System." We cannot, however, close this paper without showing how we stand in relation to the work of the French authorities.

In 1898 Babinski described the "phénomène des orteils" or, as it is usually called, the "extensor response." This he considered to be a thing apart from limb flexion, which he called a movement of defence. The nature of the "extensor response" was wrapped in mystery but it was of the greatest diagnostic value as a sign of pyramidal affection.

Marie and Foix [79], on the other hand, insisted that when the spinal cord was set free from control three groups of reflexes made their appearance as the direct expression of spinal automatism. These are: (1) the "phénomène des raccourcisseurs" [flexors]; (2) the "phénomène des allongeurs [extensors]; and (3) the "reflexe d'allongement croisé." They pointed out that the Babinski reflex of upward movement of the toes was a part of the flexor phenomenon and had no connection with extension except by a confusion of anatomical nomenclature. They say: "Cette activité propre de la moelle . . . constitue l'automatisme médullaire, automatisme dont l'importance s'exagère dès que la moelle est 'libérée' de l'action des centres encéphaliques. . . . Aussi losqu'une lésion sectionne plus ou moins complètement la continuité des neurones qui retient les centres encéphaliques aux centres médullaires, on assiste à la *libèration de la moelle* et on la voit développer une activité propre demeurée latente chez le sujet normal . . . le terme *automatisme médullaire* exprime l'ensemble des mouvements co-ordonnés dont la moelle isolée est susceptible. . . ." [78].

Now Sherrington had shown that, after shock had passed away, the spinal dog could stand to a certain extent; but the posture assumed was unstable. In the same way some primary extensor manifestations could be obtained, under favourable conditions, but there was nothing comparable to the extensor rigidity of the decerebrate animal. This, however, applies to the dog; the spinal monkey cannot stand and exhibits little or no extensor activity.

The higher development of man has evidently robbed the spinal cord of still more of the functions with which it was originally endowed. Under the most favourable conditions we have discovered a vigorous activity in the divided spinal cord. But all postural activity has disappeared and does not return; "spinal man" cannot stand, and shows no primary extensor activity.

Evidently Marie and Foix were dealing with a different group of cases from those on which we have based the main argument in this paper. They described many of the phenomena which occur when the spinal cord has been grossly injured. But they attribute all these conditions, flexor or extensor, "mass-reflex" or response endowed with local signature, to automatic action of the spinal cord.

We, however, believe that so long as local reflex signature is not destroyed, and so long as primary postural reflexes can be obtained, the lower end of the spinal cord has not been liberated from control of the parts above the lesion. All voluntary motion and sensation may be destroyed and bladder and rectum may be acting automatically, but excessive facilitation and the overflow of reflex energy into visceral channels will be inhibited. Thus, although we in no way under-estimate the value of these researches of Marie and Foix, the very existence of many of the phenomena in which they are interested precludes the appearance of those which form the theme of this paper.

Summary of Conclusions

The Automatic Bladder.

(1) When the spinal cord has been completely divided, the bladder may begin to expel its contents automatically as early as twenty-five days after the injury, under favourable conditions.

In unfavourable cases, where the patient suffers from chronic septicæmia, due to a bed-sore, grave cystitis or pyelitis, automatic micturition may never become established, however long the patient survives the injury.

(2) If a catheter is passed after automatic but involuntary micturition has become established, and fluid is allowed to run into the bladder under the least possible pressure, it will be expelled after a certain volume has entered. This volume varies between about 100 and 600 c.c.

We wish, however, to insist that this expulsion of fluid through a catheter, owing to the contraction of the muscles of the bladder-wall, can be evoked at a time when the patient is unable to micturate automatically, that is to say during the period of complete retention. This retention is due to spasmodic contraction of the sphincter mechanism, which does not relax although the muscular wall of the bladder is capable of vigorous contraction.

Later, however, under favourable general conditions, true automatic micturition may become established even though the spinal cord is completely divided. When the contents of the bladder reach a certain amount, its muscular wall contracts, the sphincter relaxes and urine is passed involuntarily.

(3) The form assumed by the activity of such an automatic bladder is entirely independent of the site of the lesion in the spinal cord.

(4) If the spinal cord is gravely injured and even if it is completely divided anywhere above the lumbar region, automatic evacuation and the complete act of micturition may be facilitated by the most various afferent impulses passing into the lower portion of the spinal cord.

When the sole of the foot, the thigh or the abdomen is scratched, a flexor spasm may be evoked. If this is so, the bladder may empty itself when its contents scarcely reach one half of the amount otherwise necessary to produce a contraction of the muscular wall.

(5) After destruction of the lower lumbar and sacral roots, the bladder may act automatically in an identical manner, except that it can no longer be influenced reflexly by any afferent impulses.

(6) When the lesion is confined to the lower end of the spinal cord or to the lower lumbar and sacral nerve roots, the patient may be conscious of tension within his bladder, may recognise the occurrence of contractions in its muscular wall, and may experience that pleasure which normally accompanies evacuation. But these sensations have no effect on the automatic activity of the bladder.

(7) When the bladder is acting automatically, deep breathing may cause the muscular wall to expel its contents before they have reached sufficient volume to be otherwise an effective stimulus.

In the same way, pressure on the abdominal wall not only tends to expel the contents of the bladder mechanically, but also acts as a stimulus to otherwise premature evacuation.

(8) When washing out a bladder, in order to treat the cystitis, so frequently present in patients with spinal lesions, it is most important to avoid exercising undue tension on the bladder-wall. The fluid should be allowed to run in under the smallest possible pressure; the vessel containing the wash must not be raised, as is so commonly done, some feet above the bed, nor must the bladder be injected from a syringe. Such methods are positively harmful: for the tone and contractile capacity of the vesical musculature are overcome by such pressure, and the power of spontaneous evacuation thereby diminished. In every case where an automatic bladder is to be washed out for therapeutic purposes, the volume of fluid should be determined at which evacuation occurs, and the bladder should always be allowed to empty itself, as far as possible, in response to endovesical stimuli.

Excessive Sweating.

(9) In most cases of hyperidrosis, associated with gross lesions of the spinal cord, the outburst of sweating represents the activity of the nervous system *below* the lesion.

Thus, when the injury is situated in the lower cervical segments, the whole head and neck may be covered with sweat, because all the fibres which produce sweating leave the spinal cord in the thoracico-lumbar region. A lesion at the level of the third thoracic segment caused excessive sweating over both arms and over the trunk below the second rib; in a case where the injury lay in the sixth thoracic segment, hyperidrosis extended from the fifth rib downwards with some moisture of the palms of the hands. When the injury was situated at the ninth thoracic segment, the hyperidrosis corresponded almost exactly with the extent of the analgesia, whilst below this segment the area occupied by the sweating was smaller than that of the loss of sensation. In some cases this sweating may be unilateral.

(10) In favourable cases paroxysmal sweating can be excited by almost any stimulus which sends afferent impulses into the spinal cord below the lesion. For instance :—

(*a*) Scratching the sole of the foot, the abdomen or any part below the level of the lesion, provided it evokes flexor spasms.

(*b*) Injection of fluid into the bladder. Inability to pass urine when the bladder is full is one of the most frequent causes of "spontaneous" hyperidrosis in these cases; sweating ceases when a catheter is passed and the endo-vesical is relieved.

(*c*) Injection of fluid into the lower bowel, as when administering an enema.

Reflex Activity of the Spinal Cord below the Lesion.

(11) It is evident, therefore, that under certain conditions the spinal cord below the level of the lesion may show signs of diffuse reflex activity. Scratching the sole of the foot may not only evoke a flexor spasm, but may cause premature evacuation of the bladder and an outburst of excessive sweating. This we have spoken of as a "mass-reflex."

When the spinal cord has assumed this form of activity, any stimulus giving rise to impulses endowed with affective tone will evoke this diffuse reaction. Not only can evacuation of the bladder and rectum be facilitated by scratching the sole of the foot, but injecting fluid into either of these organs may evoke characteristic flexor spasms.

(12) When the spinal cord reacts with this massive response, it is obvious that the reflexes have, to a great extent, lost their local signature. Not only is the answer the same when diverse parts, such as the sole of the foot, the bladder or the rectum are stimulated, but it matters little what part of the skin is scratched provided it is supplied by the spinal cord below the lesion. Scratching the abdomen or the sole of the foot may evoke the same reflex response.

(13) Should the local sign of the reflexes be retained to such a degree that primary extension can be evoked by scratching the thigh, though flexion is caused by nociceptive stimuli to the sole of the foot, this diffuse and massive response fails to appear. Evacuation of the bladder cannot be facilitated from the limb which yields a primary extensor response to stimulation of the thigh. We believe that the presence of reflex stepping is another indication that the reflexes have not entirely lost their usual local signature.

(14) All voluntary movement, sensation and visceral control may be lost below the level of the lesion, and yet excessive facilitation may not be present. This may be due to the following causes :—

(*a*) The patient may suffer from continuous septicæmia or toxic absorption, due to a foul bed-sore, cystitis, or pyelitis. The lower end of the spinal cord has no chance to recover from the first period of shock due to the injury, and reflex activity does not return to any material extent, however long the patient may live.

(*b*) In spite of the severity of the injury, the centres above the level of the lesion may still exercise sufficient control to prevent this widespread reflex activity. The severity of the injury has not been sufficiently great to prevent the neural mechanism for postural adaptation from influencing the parts below the lesion, though voluntary motion, sensation, and visceral control may be lost. This maintenance of postural activity is shown, in man, by the existence of primary extensor reactions and the presence of local signature in the reflexes which can be obtained from parts below the lesion.

SHORT ACCOUNT OF SOME ILLUSTRATIVE CASES[1]

Case 1.—*Total division of the spinal cord at the level of the sixth thoracic segment. Complete loss of voluntary power and sensation below this level. Automatic micturition. Facilitation of detrusor activity of the bladder by any reflex activity below the level of the lesion. Paroxysmal sweating, which could be evoked by injecting the bladder or rectum, or by producing flexor spasms from parts below the lesion.*

Lieutenant M., aged 28, was wounded by a shrapnel bullet in the spine on August 6, 1916.

On August 16 he was admitted to the Empire Hospital, under the care of Dr. Collier. Next day (eleven days after injury) his condition was as follows :—

Motion.—There was total flaccid paralysis below the level of the sixth rib. The muscles were not wasted. There were no involuntary movements of the lower extremities.

Reflexes.—Arm-jerks were brisk and equal. All reflexes both superficial and deep were absent below the lesion.

Sensation.—Complete loss below the level of the sixth rib. Above this a narrow area of over-reaction could be mapped out occupying mainly the fourth interspace. Vibrations of a tuning fork could not be appreciated above the level of the ninth rib.

Sphincters.—There was complete retention of urine. A catheter was passed every six hours,

[1] Nos. 1, 2 and 3 correspond to the same numbers in Riddoch's paper [96]. No. 4 in this paper corresponds to his No. 6.

and the bladder was washed out with a solution of eusol, 1 in 16,000, night and morning. The anal sphincter was tonic.

Sweating was at this time absent over the trunk and lower extremities.

On August 28, 1916 (twenty-two days after the injury) *motion* and *sensation* were in a similar condition.

Reflexes.—Knee- and ankle-jerks were absent. Abdominal reflexes absent. For the first time on this date upward movement of the toes was noticed on scratching the sole of the foot. Hamstring contraction had not been obtained previously on plantar stimulation; but with the first appearance of this upward movement of the toes the hamstrings could be felt to tighten and contraction also appeared in the anterior tibial group of muscles. The receptive field for this reflex was limited, at this stage, to the soles of the feet and the threshold was lowest on the outer side. No crossed response of any kind could be obtained.

Sphincters.—Retention of urine was no longer complete. A small quantity of urine was passed reflexly on one or two occasions.

Sweating.—He had begun to sweat on the left side of the head and neck, left arm, and down to the level of the third interspace. The skin of the right arm, right half of the face, and all the trunk below the level of the fifth rib was dry.

By the twenty-fifth day after the injury slight periodic movements were noticed in both legs, but not at the same time; these consisted of upward movements of the great toes, tightening of the tibialis anticus and of the hamstring tendons. On tapping the right patellar tendon contraction of the quadriceps muscle, chiefly in the vasti, occurred, and the slack tendon was seen to tighten momentarily. Periodic micturition was more frequent and more urine was voided at a time.

On September 8 (thirty-three days after the injury) a shrapnel bullet was removed from the body of the sixth dorsal vertebra. Opposite the bodies of the fifth and sixth dorsal vertebræ the cord was completely divided and the ends were separated by about 2·5 cm.

When he recovered from the immediate effects of the operation he rapidly assumed a condition which was, in the main, constant. This was interrupted in the early part of 1917 by an attack of cystitis and pyelitis, which led to some weeks of fever. But apart from this period his condition may be summarised as follows :—

Motion.

All voluntary motion was completely absent below the level of the sixth rib. But involuntary movements occurred with great frequency and were very active. All such spasms were invariably of the flexor type; the great toe moved upwards, the foot was dorsiflexed at the ankle, and both knee and hip flexed vigorously. At the same time the thigh became adducted and the rectus abdominis of the same half of the body fell into spasm. In some cases the involuntary movement might begin in the muscles of the abdominal wall and spread rapidly to the lower extremity. Sometimes the legs flexed alternately; more often, however, two or three flexion movements of one leg occurred in quick succession before the other leg moved. On one day the right leg might "jump" more often than the left, and on the next the left be more active than the right.

From the forty-fifth day after the injury the extensors of the opposite limb to the one in flexor spasm could be felt to contract; but at first this movement did not produce any effect upon the position of the limb. By the 259th day, however, each flexor spasm in one leg was accompanied by definite movement of the quadriceps cruris and calf muscles of the other, so that the limb would shoot out extended in front of him as he sat in his chair. The flexors showed no signs of wasting, but the extensors were certainly smaller than normal.

When the lower extremities were not in motion the tone of the physiological flexors was below normal, but that of the extensors was relatively much less developed. During contraction, however, the tone of the flexors was greatly raised, whilst the tone of the extensors of the limb was greatly diminished. When the extensors were contracting the converse was true; a flexion reflex was induced and the crossed extensors contracted; their tone was increased, but it was never so great as that of the contracting flexors.

Reflexes.

Knee- and ankle-jerks became greatly exaggerated shortly after their return. No definite ankle clonus appeared, but on thrusting up the foot a few brief jerks occurred. It was, however, difficult to examine for ankle clonus satisfactorily owing to the flexor spasm, so easily evoked by touching or holding the foot. This flexion reflex could be obtained by stimulating any part of the lower extremities. Its reflexogenous area extended from the abdomen to the foot, although the threshold was somewhat lower on the sole than elsewhere. The most effective stimulus was one which would have possessed some affective element, had the parts been sensitive; scratching the abdomen or lower extremity and grasping the foot or muscles of the thigh would at once evoke spasmodic flexion.

By no manipulation could we produce a primary extension in the stimulated limb.

Stimulation of the glans penis, the external genitalia, the skin of the perineum, and for a short distance down the inner aspect of the thighs produced a strong flexion reflex with contraction of the abdominal rectus and slow drawing up of the testicles. This is a remarkable contrast to the extension reflex so commonly obtained in less complete lesions of the spinal cord.

When the outer part of the abdomen was scratched a slow local contraction might occur in the external oblique, following the direction of the fibres of this muscle upwards and outwards. This response was delayed and was never associated with a crossed movement of the abdominal wall.

But when the abdomen was briskly scratched over a wider area, or when the parts over the rectus were stimulated, a vigorous contraction of one or both recti associated with a full flexor spasm of the lower extremity, including upward movement of the toes.

Sensation.

The loss of sensation to touch, pain and temperature remained complete below about the sixth rib. Vibration of a tuning fork was not appreciated below the level of the ninth rib. Deep pressure with the hand produced a vague discomfort over the epigastrium, and he seemed to be aware of flatulent distension of his stomach.

He had no sensation of the movements of his lower extremities and usually thought of them as flexed to a varying amount. Passive movements were entirely unappreciated.

He had no abdominal sensations except from the epigastric region after food. He could not recognise distension of his bladder and had no desire to pass urine, or relief when the bladder was emptied.

Observations on the Bladder.

On January 11 (158 days after the injury) the following observations were made :—

Two minutes before the catheter was inserted he passed automatically 110 c.c. of urine as soon as the swab with antiseptic fluid was placed on the glans penis. The catheter drew off 340 c.c. of urine.

On allowing a solution of eusol, 1 in 16,000, to run into the bladder he evacuated at 650 c.c., passing in all 610 c.c. No more could be recovered by pressure. On a second occasion he evacuated at 600 c.c., passing 595 c.c. Nothing was recovered by pressure. On a third experiment he evacuated at just short of 600 c.c., passing 590 c.c.

Throughout these observations the column of fluid showed oscillations which, on asking him to stop breathing, proved to be respiratory. After about 400 to 500 c.c. of fluid had entered the bladder a bigger oscillation began, which culminated in the backflow. About 300 c.c. were evacuated at once; then came a pause followed by a further passage of 200 c.c., then another pause, and so on.

Throughout these manipulations he was unconscious of fluid distending the bladder, of desire to make water, or of the passage of fluid.

The urine was acid and free from pus or albumin.

On April 22 (259 days after the injury) the following series of observations was made : During the month of February he had suffered from an attack of pyrexia with nausea and occasional vomiting, probably due to an attack of cystitis, with some infection of the pelvis of the kidney. This passed away and he returned to his previous condition of robust general health.

On passing a catheter 420 c.c. of urine were drawn off. A solution of eusol, 1 in 16,000, was allowed to run into the bladder and evacuation occurred at 325 c.c.; he passed 300 c.c. On rubbing the glans penis 10 c.c. came away and an additional 10 c.c. were recovered by pressure over the abdomen. Fluid was again allowed to run in and evacuation occurred at 195 c.c., just after he had taken a long breath. He passed 190 c.c.; 5 c.c. were recovered by rubbing the glans penis, and 5 c.c. by pressure on the hypogastric region. At another experiment he emptied his bladder at 295 c.c., passing 300 c.c.; a further 5 c.c. were obtained by rubbing the penis, and nothing more by pressure.

It is obvious from a comparison of these observations with those made in January that the capacity of the bladder had diminished. This was probably due to the febrile attack through which he had recently passed. As before, respiratory oscillations were seen in the column of fluid in the tube, which were distinct from the bigger oscillations that immediately preceded the backflow.

When the catheter was passed along the urethra, considerable resistance was offered to its passage as the point came against the sphincter. With gentle and steady pressure this resistance yielded and the catheter entered the bladder. It was then held tightly by the sphincter, as shown by the force required to withdraw it.

On April 29 (266 days after the injury) another series of measurements was carried out. When the penis was swabbed preparatory to passing the catheter 85 c.c. of urine were voided, and the catheter then drew off a further 200 c.c. No more urine could be recovered by rubbing the glans or by pressure on the abdomen. Dilute eusol solution was allowed to run into the bladder and backflow began at 180 c.c.; he passed 180 c.c. and nothing more was recovered by rubbing the glans or by pressure. Again the fluid was run in and evacuation began at 210 c.c.; he passed the full amount and nothing was recovered on pressure. A third observation was made and the fluid returned at 240 c.c.; the whole 240 c.c. were passed and nothing recovered on pressure.

The next observation was carried out as follows: 100 c.c. were allowed to run into the bladder and a flexion reflex was induced by scratching the left sole. A few bubbles came up through the fluid in the tube and the column remained stationary for a few seconds, but no backflow occurred. A similar result followed scratching the right sole. 10 c.c. of fluid were then added, making in all 110 c.c. On scratching the right sole, strong flexion occurred and the bladder evacuated 105 c.c. of fluid. This experiment was repeated and 115 c.c. allowed to run into the bladder, and flexion was induced by scratching the sole; the column of fluid remained stationary for a time, but no backflow occurred. 10 c.c. were added, making in all 125 c.c., and the production of a flexor spasm was at once accompanied by evacuation of the bladder; 130 c.c. were passed.

These manipulations produced a profuse outburst of sweating over the trunk and limbs below the level of the fourth rib.

Another series of observations was made on June 27 (325 days after the injury). A catheter was passed and 190 c.c. of urine drawn off. Fluid was then allowed to run in from the burette in the usual way and evacuation occurred at 425 c.c.: he passed 420 c.c., and nothing was recovered by pressure. Fluid was again run into the bladder and evacuation occurred at 420 c.c.; he passed the whole amount, and nothing was recovered by pressure.

The patient was now asked to breathe deeply from time to time during the entry of fluid into his bladder. He evacuated when 58 c.c. only had entered, passing 60 c.c. in all. He was told to repeat this procedure, and this time he returned the fluid when 25 c.c only had entered, passing 30 c.c. in all.

When fluid was run in and flexion reflexes were evoked rhythmically from the right foot, every spasm caused hesitation in the movement of the column after 50 c.c. had entered the bladder; but evacuation did not occur until 160 c.c had entered. He then passed the whole amount.

Thus it was obvious that the effective stimulus to the muscular wall of the bladder was a volume of about 420 c.c. of fluid. But deep breathing so greatly facilitated evacuation that contraction occurred when from 30 to 60 c.c. only had entered the bladder. Flexor spasms evoked from the sole of the foot caused evacuation at 160 c.c. We were therefore anxious to ascertain if such stimuli could facilitate automatic micturition when the catheter was removed and a measured quantity of fluid left in the bladder. We knew that the patient was able to induce micturition by scratching his thigh if he had not passed urine for several hours. This was, however, technically an extremely difficult experiment, for when 200 c.c. were left in the bladder and the catheter removed neither deep breathing nor scratching the sole of the foot led to automatic micturition. When 350 c.c. were left in the bladder the very slight stimulus of removing the catheter was usually sufficient to cause evacuation of the whole amount. But a few days before we had succeeded in passing 400 c.c. into the bladder and removing the catheter without provoking evacuation; then scratching the thigh caused a flexion reflex and 80 c.c. were passed in a fine strong stream. Thus we were able to show, in spite of the technical difficulties of the experiment, that a volume of fluid incapable of evoking the act of micturition could be converted into an effective stimulus on calling up a "mass-reflex" by scratching the thigh. This exactly corresponded with the patient's practical experience. Thus before he got up in the morning he would ask for the bottle, scratch himself and empty his bladder. Subsequent manipulations, such as dressing himself, could then be carried out without the discomfort of the involuntary passage of urine.

Sweating.

At first, as has been mentioned above, the parts below the lesion were dry, but he sweated over the left side of the head and neck, left arm, and down to the level of the third interspace. This steadily decreased as the weather grew cooler, and on September 20 (forty-five days after the injury) the parts below the level of the lesion were noticed to be damp.

By October 6 (61st day) sweating over the face, neck and shoulder had ceased, but sweating below the level of the lesion was definite; the palms of the hands, the trunk below the fourth interspace and the legs were distinctly moist. By November 4 (90th day) this had become a definite hyperidrosis and all abnormal sweating had ceased over parts that received their nerve supply from the spinal cord above the lesion.

By December 28 (144th day) it was noticed that the hyperidrosis was associated with the passage of a catheter and the subsequent manipulations for washing out the bladder. Administration of an enema was also found to evoke an outburst of sweating over parts below the lesion.

During the month of February, 1917, he passed through a febrile attack due to urinary infection, and during this time the skin of the whole of the face, neck, body and limbs was damp in the normal manner, and during the night he sweated freely, as is so commonly the case with pyrexia of this character. But he always sweated more profusely from the palms of the hands and from the skin below the level of the lesion than from the rest of the body.

With the disappearance of the fever the general sweating ceased, but the local reaction, representing the parts supplied from below the lesion, sweated more profusely than ever.

Thus on April 22 (259 days after the injury) the following note was made: (*a*) In extent the sweating occupied the palms of the hands, the skin of the trunk below the fourth rib, and the legs. The arms have never been noticed to participate in this excessive sweating. (*b*) Effective stimuli for bringing on sweating were: (1) Spasms of the legs; the repeated induction of flexion reflexes was accompanied by increased sweating over the usual area. (2) An enema, administered whilst lying on his side, always evoked sweating. (3) Catheterisation. (4) Change of temperature; thus, when he was lifted out of his bath sweat poured from the palms, lower half of the chest, abdomen and legs. He also began to sweat profusely shortly after he was put to bed; he sweated less when up in a chair. It was as profuse as ever and the distribution had not changed. Then head, neck, shoulders and arms, except the hands, were always perfectly dry. No change in the pulse or pupils had ever been noticed to accompany the hyperidrosis.

Before we began our observations on April 29 (266th day) the skin of the body was examined and found to be perfectly dry. The various experiments on the activity of the bladder occupied three-quarters of an hour; at the end of that time the skin was again examined. The legs up to the thighs were pouring sweat and the skin of the trunk below the fourth rib, together with the palms, was distinctly damp. The rest of the surface was dry as before. He declared he could usually tell when sweating was about to begin by the onset of "drumming in the head or a feeling of fat-headedness."

Case 2.—Complete anatomical division of the spinal cord at the level of the fourth thoracic segment. Total loss of voluntary movement and sensation up to the level of the nipples. All involuntary movements of the flexor type. Flexor "mass-reflex" evoked by nociceptive stimulation of abdomen or lower extremities. Automatic micturition. Expulsion of contents of the bladder through a catheter at from 250 to 290 c.c. Facilitation on producing a "mass-reflex" led to evacuation at 150 c.c. Paroxysmal sweating, greatly increased by filling the bladder with fluid.

Private H., aged 24, was wounded in France on July 21, 1916, and admitted in August to King George Hospital, under the care of Dr. Buzzard.

On September 11 (fifty-two days after the injury) a shrapnel bullet was removed from the theca. This had completely divided the spinal cord at the level of the third and fourth dorsal vertebræ, and there was a gap of $\frac{3}{4}$ in. (2 cm.) between the two ends.

A full account of this patient will be found in Riddoch's paper [96], and we shall therefore confine this account to the observations made on February 24, 1917 (218 days after the injury), when we examined him together. His condition was then as follows:—

Motion.—There was total paralysis of voluntary movement below the level of the nipples. When not in spasm, the legs lay on the bed a little flexed at the knee and at the hip. The feet pointed somewhat downwards, but the left great toe looked somewhat upwards.

All involuntary movements, evoked by stimulation, even by removing the bed-clothes, were flexions. There was no evidence of a crossed response accompanying the flexor spasms.

Reflexes.—The arm-jerks were brisk and normal. Knee- and ankle-jerks were greatly exaggerated, but no definite ankle clonus was obtained.

On scratching the sole of the foot a characteristic flexor spasm was evoked with an upward movement of the great toe and splaying of the four outer toes. This reflex could also be produced by scratching the inner aspect of the knee or the groin, more strongly from the left than from the right lower extremity. This response was produced most easily by pricking and grasping the sole or by squeezing the thigh. There was occasionally distinct bilateral flexion, but no crossed extensor movement.

On dragging a pin across the abdomen it was possible to evoke a localised undulation running from the rectus sheath outwards and upwards to the ribs. This movement was somewhat micular and slow to appear; it was not part of a "mass-reflex," but seemed to follow the line of the abdominal muscles at the level of the stimulus. Associated with this reflex there was no movement of the toe or flexion at the knee.

Not infrequently, however, the abdominal reflex was of a different character. The rectus of the stimulated half contracted, and that side of the abdomen was pulled in and rendered concave as a whole. Whenever this form of reflex was evoked the great toe tended to move upwards and there was a complete flexor reflex of the leg. The occurrence of this form of response on one side might be accompanied by a contraction of the rectus and abdominal wall on the other half of the abdomen.

Sensation.—There was total loss of sensation below a line at the level of the nipples.

Bladder.—He was passing all his urine involuntarily and unconsciously. The following observations were made: A catheter was passed and 175 c.c. were drawn off. The burette was attached directly to the mouth of the catheter and normal saline solution was allowed to run into the bladder. At 250 c.c. evacuation occurred and he passed 135 c.c.; a further 130 c.c. were passed after pressing on the abdomen.

The same procedure was repeated and he evacuated at 290 c.c., passing 175 c.c. The glans penis was then rubbed with a swab and he voided another 57 c.c. Pressure over the bladder caused the passage of another 70 c.c.

On the next occasion he evacuated at 250 c.c., passing 140 c.c. This flow was started by accidentally rubbing the glans penis. Stimulation of the sole caused the evacuation of another 50 c.c., and pressure 90 c.c. Again 100 c.c. were allowed to flow into the bladder. Stimulation of the glans caused no evacuation; but when the amount had been made up to 150 c.c. and the penis was stroked he passed 30 c.c. Pressure evacuated another 100 c.c. 150 c.c. were then allowed to flow into the bladder and the flexion reflex evoked by scratching the sole of the foot. The bladder was immediately emptied.

Sweating.—We were told that he sweated profusely from the second rib downwards, for a varying distance, to about the ensiform level with a maximum over the upper thoracic region. On the occasion of these observations this was a strictly accurate description of the condition in which we found him. When we started to fill his bladder he was slightly moist over this area, but as soon as his bladder began to expel its contents automatically he sweated profusely. The head and neck remained dry, but from the clavicles downwards all over the arms and chest he became wringing wet. The sweating extended to the groins and the thighs, soles and back of the legs, but not so profusely as over the arms, chest and abdomen. The pupils did not dilate and the face was not flushed.

Case 3.—Complete division of the spinal cord at the level of the fourth thoracic segment. Total loss of voluntary motion and sensation below the level of the fifth rib. Gradual development of increased tendon reflexes but no definite ankle clonus. Characteristic "mass-reflex" obtained from the abdomen and lower extremities associated with facilitation of the detrusor activity of the bladder-wall.

Captain F., aged 29, was wounded on April 6, 1917, by a shrapnel bullet in the back.

He was admitted to the Empire Hospital on April 10, 1917, under the care of Dr. Buzzard.

On April 13, 1917 (seven days after the injury) his condition was as follows:—

Motion.—Total flaccid paralysis below the fifth rib. No involuntary movements. The legs were not wasted.

Reflexes.—Arm-jerks were brisk and equal. Knee- and ankle-jerks were absent. A bulbo-cavernous reflex could be obtained by pricking either side of the glans penis.

On scratching the sole a downward movement of the toes occurred with no palpable tightening of the hamstring tendons.

Scratching the skin of the abdomen over the external oblique caused a localised movement of this muscle. A sharper scratch applied over a larger area evoked a massive response in all the muscles of the same half of the abdomen, including the rectus.

Sensation.—There was total loss of sensibility below the level of the fifth rib, with a broad area of over-reaction to painful stimuli extending from the second thoracic segmental area on the arms to the upper level of the loss of sensation.

Sphincters.—Complete retention of urine and fæces.

Vasomotor and trophic.—No excessive sweating. There was no bed-sore.

On April 20 (fourteen days after the injury) laminectomy was performed, and a shrapnel bullet was removed from within the dura at the level of the lamina of the fourth dorsal vertebra, which was fractured. The spinal cord was completely divided and the two ends were separated by a gap of 1 cm.

On May 5 (twenty-nine days after the injury) his condition was as follows:—

Motion.—Involuntary movements were of rare occurrence, but consisted of upward movement of the toes with contraction of the inner hamstrings; this was not, however, sufficient to flex the knee. The legs were not appreciably wasted, but the tone of both flexors and extensors was below normal. The abdominal recti frequently fell into spasm without any corresponding movement of the lower extremities.

Reflexes.—Tendon jerks: Some contraction of the left quadriceps could be evoked by tapping the patellar tendon twenty-one days after the injury, but it was not sufficient to move the leg. In the same way the left ankle-jerk could be obtained, but the right was absent. On the twenty-third day both knee- and ankle-jerks were obviously present. On the twenty-ninth day three or four brief clonic movements of the calf muscles were obtained when the foot was jerked up sharply; there was no true ankle clonus.

Plantar reflex: The threshold value was high even on the sole, but scratching, pinching and squeezing the foot evoked upward movements of the toes, slight dorsiflexion at the ankle, flexion at the knee and hip and adduction of the thigh. There was no active after-extension and no crossed flexor or extensor movement could be observed. The receptive field for this reflex extended from the sole of the foot to just below the knee.

Abdominal reflex: A pin-prick over the external oblique still resulted in a delayed local contraction. More vigorous stimulation, especially near the middle line, led to widespread contraction of the abdominal muscles which was sometimes bilateral. Upward movement of the toes and flexion at the knees sometimes accompanied this massive response evoked from the abdomen.

Sensation was lost as before.

Bladder.—To-day (thirty days after the injury), the patient passed some urine, when his penis was swabbed before passing the catheter. This was followed during the night by active involuntary micturition.

A solution of 1 in 16,000 eusol was allowed to run slowly into the bladder and he evacuated at 365 c.c., passing in all 320 c.c. On pressing the abdomen 80 c.c. more of fluid were voided. Two days later, on May 7 (thirty-two days after the injury), these observations were continued. On passing a catheter 230 c.c. of urine were drawn off. When fluid was allowed to run in slowly he evacuated at 350 c.c., passing 350 c.c.; pressure led to the voiding of 5 c.c. only. At a second observation he evacuated at 375 c.c., passing 370 c.c.; pressure brought away 15 c.c.

Fluid was then poured in to the amount of 200 c.c., and the flexion reflex evoked by scratching the sole of the right foot. He immediately evacuated 150 c.c., and 50 c.c. in addition were recovered by pressure. Fluid to the amount of 100 c.c. was run into the bladder, and a flexion reflex evoked by squeezing the right foot. Fluid came back into the burette to a small amount and then remained stationary; after a few seconds the burette began again to empty itself into the bladder. At 150 c.c. the flexion reflex was again evoked and again the fluid rose in the tube, remained stationary for a time, and then again entered the bladder. The impulse was not strong enough to cause complete evacuation even against this small pressure of fluid.

From this time onwards the involuntary flexor spasms increased, but we never saw any primary extensor movement. Any crossed movement which might occur was flexor, and there was no "extensor thrust." The tendon reflexes increased, but no true ankle clonus was obtained. Stimulation of the abdomen or almost any part of the lower extremities would evoke a characteristic flexor spasm which caused premature evacuation of the bladder. The following observations were made on June 6 (sixty days after the injury):—

He had passed no urine for four hours; on swabbing the penis no urine came away, but the penis began to become erect. A catheter drew off 250 c.c. of urine. Sterile warm water was allowed to flow into the bladder, and at 300 c.c. he passed 305 c.c. Pressure led to the passage of a further 15 c.c., showing that he had passed some urine into the bladder during these manipulations. At a second observation he evacuated at 395 c.c., passing 390 c.c.; pressure brought away 5 c.c. only. Again fluid was allowed to run into the bladder and was passed at 380 c.c.; he voided the total amount, no fluid being recovered on pressure. Then 100 c.c. were run into the bladder and the sole stimulated by scratching, without result on the flow of fluid. At 165 c.c. the column of fluid began to hesitate with each flexor spasm and at 185 c.c. he evacuated, passing just under 190 c.c. On pressing the abdomen 4 c.c. came away. This experiment was repeated, and at 170 c.c. the column of fluid hesitated; evacuation occurred at 180 c.c., and the whole amount was passed. Fluid was now run into the bladder, and the patient was asked at each 10 c.c. to take a deep breath. At 60 c.c. the column moved up a little; at 80 c.c. evacuation occurred, and the whole amount was passed. This experiment was repeated; at 60 c.c. the column again rose a little, and at 70 c.c. evacuation occurred with the passage of 75 c.c.

Case 4.—Bullet wound of the chest and spine not completely dividing the spinal cord. Paralysis of motion and sensation below the sixth rib. Involuntary "steppage" movements. Crossed extension. Extensor thrust in the stimulated limb with bilateral extension reflexes. "Mass-reflex" absent. Automatic evacuation of bladder and rectum. No facilitation.

Captain P.,[1] aged 30, was wounded by a machine-gun bullet on October 2, 1916.

On October 14, 1916, he came under the care of Dr. Batten at the Empire Hospital for Officers. A small entry wound was found 4 cm. to the right of the fourth dorsal spine, and an exit wound 7 cm. to the left on the same level. He was completely paralysed and had lost sensation below the sixth interspace. He was extremely ill with hæmothorax, and no full examination could be made until December 15 (seventy-four days after injury).

Motion.—There was complete paralysis below the level of the sixth interspace. The muscles were flabby and somewhat wasted. At intervals involuntary "steppage" movements occurred in both lower extremities; with flexion of one limb, extension occurred in the other, and vice versa.

Reflexes.—The knee-jerks were brisk and equal on the two sides. Ankle-jerks were less easily obtained and there was no ankle clonus.

On scratching, pinching or squeezing either foot the toes moved upwards, dorsiflexion occurred at the ankle, with flexion at the knee and hip. This was invariably accompanied by crossed extension. The threshold value of the stimulus for this reflex was lowest over the outer part of the sole.

Scratching the skin of the abdominal wall caused a contraction of the muscles on the same side, but a bilateral response could be obtained by stimulating the middle line. No crossed reflex was obtained by scratching the flank.

Cremasteric reflexes were evoked by scratching the inner aspect of the thigh.

Sensation.—All sensation was lost below the level of the sixth rib.

Sphincters.—Bladder and rectum evacuated their contents automatically. Urine was voided about every two hours, and from 50 c.c. to 120 c.c. were expelled on each occasion. The urine was acid but contained albumin and some pus. Cultures grew Bacillus proteus profusely with a few colonies of B. coli.

On March 6, 1917 (155 days after the injury), his condition was as follows :—

Motion.—Total paralysis below the level of the sixth rib was present as before. Involuntary "steppage" movements were of frequent occurrence. There were no violent flexor spasms.

Reflexes.—Knee- and ankle-jerks were exaggerated and a poorly sustained ankle clonus was present. Scratching the sole produced an upward movement of the toes, dorsiflexion of the foot and flexion at knee and hip. At the same time the opposite leg became extended at the knee, the foot was plantar extended and the toes moved down. This crossed extension reflex was at once overcome and transformed with flexion by the application of a nociceptive stimulus to the sole of the extremity in which it had occurred. No crossed flexion reflex or bilateral flexion could be evoked by stimulating the perineum. The reflexogenous area for the flexion reflex extended from the sole, which was the focal area of the field, to the junction of the upper and middle third of the leg; the further from the sole the higher became the threshold before the stimulus was effective.

Light scratching of the thigh, groin and perineum evoked an extension reflex; the knee became extended and foot and toes moved downwards. From the lower part of the field the response was almost entirely in the stimulated limb, whilst from the groin it tended to become bilateral. From the perineum and external genitalia it was symmetrical on the two sides. Scratching the skin of the flank caused a localised contraction, and a similar strictly unilateral reflex could be evoked from almost any part of the abdomen. Abdominal reflexes were not associated with any movement of the feet or legs.

Sphincters.—The rectum was acting automatically, and the sphincter ani was tonic. The bladder was emptying itself automatically, and catheterisation had been stopped for three weeks. Six days later (161 days after the injury), the following observations were made: Sterile warm

[1] This is No. 6 of Riddoch's series [96].

water was allowed to run in, and at 170 c.c. the bladder contracted, evacuating 180 c.c. Fluid was again allowed to flow in and was returned at 154 c.c. to the amount of 140 c.c.; a further 42 c.c. were recovered by pressure, showing he had passed urine in the meanwhile into the bladder. Again the experiment was repeated and at 168 c.c. he evacuated the whole amount. Again 56 c.c. were introduced, and the penis pinched without result. In spite of repetition of this stimulus no facilitation occurred, and he voided at 168 c.c. to the amount of 140 c.c.; 28 c.c. were recovered by pressure.

A further set of observations were made on July 25 (296 days after the injury):—

Bladder.—On cleansing the glans no evacuation occurred, but erection was produced. A catheter drew off 280 c.c. of urine.

On passing fluid into the bladder it was held for some time at 280 c.c., and evacuation occurred at 295 c.c. He voided 290 c.c. By pressing deeply on the abdomen about 7 c.c. were recovered. On again passing fluid into the bladder a long delay occurred at 320 c.c., but evacuation did not occur till 350 c.c. had been reached. He passed 330 c.c., and 20 c.c. were recovered by pressure.

Fluid was now allowed to run in and the sole rhythmically scratched. Backflow occurred at 275 c.c., and he passed 270 c.c.; pressure recovered 10 c.c. This experiment was repeated, and he evacuated at 285 c.c., passing 280 c.c. Fluid was now passed in, and the patient was told to take a deep breath at intervals. He evacuated at 260 c.c., passing 230 c.c.; pressure recovered 30 c.c. These observations show that in this case there was no facilitation of reflex evacuation.

Rectum.—The sphincter ani was tonic and contracted as soon as the anal mucous membrane was touched with the finger. As it was allowed to rest in the canal the muscle held it with a slight steady tonic contraction. It was as if the sphincter had taken up a new posture to accommodate the contents of the canal. Like the bladder the rectum evacuated its contents automatically. Passive dribbling was unknown.

Case 5.—Fracture dislocation of the fifth and sixth cervical vertebræ. Paralysis of the trunk and limbs below the level of the third rib and of most of the movements of both upper extremities. All involuntary movements were primary flexor spasms, in which the abdominal muscles frequently participated. There were no simultaneous bilateral extensor movements. Knee-jerks and ankle-jerks were brisk and ankle clonus could be obtained. There was no primary extensor thrust. A flexion reflex with extension of the wrist was obtained by scratching the palms. The abdominal reflexes were easily obtained. Scratching any part of the lower extremity evoked a flexion reflex with upgoing toes. There was complete loss of cutaneous sensibility below the level of the fifth cervical segment. Vibration was appreciated over the upper extremities, but was lost on the trunk below the level of the third rib. The pupils dilated perfectly to shade. For many months there was complete retention of urine owing to contraction of the sphincter, probably due to injury during catheterisation. During this time the bladder-wall could expel its contents actively through a catheter, when they reached a sufficient volume. Automatic micturition was finally established. Profuse sweating over the head, neck, arms and trunk to the umbilicus, occasionally, when severe, reaching to the knees. This could be excited (1) *by flexor spasms,* (2) *by tension within the bladder,* (3) *on injecting fluid into the rectum.*

Air Mechanic H., aged 23, fractured his spine in the cervical region about midday on September 14, 1916, owing to the crash of an aeroplane. He was admitted to the London Hospital on September 17, 1916, under the care of Dr. Head.

On admission he showed total flaccid paralysis of both upper extremities and of all the parts below. No reflexes could be obtained even in the arms, and sensation was lost up to the level of the lower border of the fourth cervical segment. There was complete retention of urine, and by the time he reached the London Hospital it contained thick, ropy pus, though acid in reaction. Several false passages had already been made by previous catheterisation, which greatly added to our difficulties in relieving the tension in his bladder. He stated that a catheter was passed for the first time on the evening of September 14, and then not until midday on the 16th; it was passed once on the boat coming across during the night of the 16th to 17th. A radiograph in lateral view showed that the fifth cervical vertebra had gone forward on the sixth, which was extensively fractured. There was palpably some defect in the fifth and sixth cervical vertebræ, and, in consequence, the spine of the seventh cervical seemed to be unduly prominent, with an abnormal hollow above it.

On October 10, 1916 (twenty-six days after the injury), his condition was in the main unaltered. Both arms were still in a condition of complete flaccid paralysis, but distinct flexor spasms were now produced by uncovering his legs or by manipulations of his lower extremities. The right arm-jerk could just be obtained, but the left was absent. Both knee-jerks could be evoked without reinforcement and the ankle-jerks were present. The abdominal reflexes were obtained in all four segments, but the plantars showed an interesting condition. On scratching the sole of either foot with the legs lying passively extended on the bed in front of him, the great toe either remained stationary or moved slightly downwards; the remaining toes closed up and flexed, but at the same moment the inner hamstrings contracted and the knee was sharply flexed. If, however, the knee was slightly bent passively and the sole was stroked with the point of a pin, the great toe moved definitely upwards at the moment when the hamstrings contracted.

The upper limit of the loss of sensation extended on the left side as before to the lower border of the fourth cervical segment, but on the right arm the whole of the fifth cervical segmental area was now sensitive to prick, heat and cold. The loss to touches with cotton wool corresponded almost exactly with the limits of the analgesia. Vibration was not appreciated on the trunk up to the level of the third rib in front and the spine of the scapula behind; over the left upper extremity it was lost to the elbow, over the right the loss of sensibility occupied the hand to the wrist, but was also defective over the right forearm.

Retention of urine was absolute, and it was necessary to draw off his urine three times in the twenty-four hours. But the bladder was certainly not atonic; for when 300 c.c. of the washing fluid had entered he ejected it through the catheter, passing 150 c.c. In the same way the rectum responded briskly to an enema.

About fifty days after the injury, or a little earlier, he began to be troubled with profuse sweating over the head, neck, arms and down to about the level of the third rib on the trunk. It gradually became so profuse that it poured from his face and neck and soaked the blankets on his bed. This hyperidrosis was peculiarly liable to be associated with a full bladder or with intestinal distension.

No material change occurred in his physical condition during the next ten months, but we gradually became more certain of the causes which underlay the outbursts of excessive sweating and were able to make repeated measured observations on the expulsive activity of his bladder. We shall therefore summarise his symptoms and physical signs under the headings of motion, reflexes, sensation, of observations on the bladder, intestinal and rectal states, and excessive sweating.

Motion.—There has been no return of voluntary power to the trunk or lower limbs, but the motor condition improved somewhat in the upper extremities.

The arms usually lay slightly flexed at the elbow and three-quarters supinated; the wrist was strongly extended, the fingers somewhat flexed with the thumbs adducted and bent into the palm. On the right side he could make all movements at the shoulder and could flex the elbow, but could not extend it. Extension of the wrist was possible but not flexion. Beyond slight adduction of the thumb, all voluntary movement was lost in the parts below the wrist. In the left upper extremity the motor condition was identical except that slight flexion became possible in the fingers.

Respiration was purely diaphragmatic; the abdominal muscles were completely paralysed, but frequently fell into spasm.

No voluntary movement was possible in either lower extremity, but frequent involuntary contractions occurred in which the abdominal muscles participated. Whenever the legs were manipulated—as, for instance, by flexing the knee passively with the hand under his thigh—the limb fell into flexor spasm accompanied by typical crossed extension in the opposite extremity;

this, again, was followed by crossed flexion with extension in the limb originally stimulated by passive movement. Primary extension and simultaneous bilateral extensor spasms never occurred. There was no permanent rigidity.

Reflexes.—On scratching the palms of the hands a characteristic reflex could be evoked; the fingers and thumb became flexed, the wrist was extended but no movement occurred at the elbow or shoulder.

All the chief arm-jerks, except the triceps-jerk, were exaggerated.

The abdominal reflexes were easily obtained from all parts and the rectus and oblique muscles participated in the movements evoked.

The knee-jerks consisted of a quick contraction with no tonic prolongation; the ankle-jerks were of the same character and ankle clonus could be obtained in both legs. No extensor thrust could be evoked at any time; the primary response to manipulation of the foot was always flexion at the knee.

On scratching the sole of the foot the first movement to appear, on the smallest effective stimulation, was an upward movement of the great toe. A moderately strong stimulus evoked a full flexion reflex, consisting of flexion at the hip and knee, adduction of the thigh, dorsiflexion at the ankle and upward movement of the great toe; the other toes "fanned." No crossed reflex could be felt or seen.

A similar flexor spasm could be evoked by scratching or squeezing the thighs, and no extension, unilateral or bilateral, was ever seen as a primary response to such stimuli.

Sensation.—Sensibility to prick, heat and cold was abolished up to the level of the second rib, and over the greater part of both arms; the limits of the loss to light touch almost exactly corresponded to the analgesia, but were slightly less extensive, especially on the outer aspect of the arms.

Vibration was not appreciated up to the same level on the trunk, but was recognised over both upper extremities. All power of appreciating passive movement and posture was lost in the lower extremities.

Pupils, etc.—The pupils reacted perfectly to light and to accommodation, and dilated normally to shade. The palpebral fissures were equal and of normal size. There were no signs of sympathetic paralysis.

In the earlier days, when the paroxysms of sweating were extremely frequent and often very profuse, the pupils seemed to dilate in the attacks; but at this time he was greatly distressed by the headache and general discomfort with which they were associated. Later, when hyperidrosis did not occur unless it was excited by some definite manipulation, we could not satisfy ourselves that an induced attack of sweating was associated with definite enlargement of the pupils.

Observations on the bladder.—He was admitted with complete retention of urine and the catheter was passed every six hours. But it soon became evident that this rigid system was unsatisfactory. The bladder would fill to the same amount more rapidly sometimes than at others, and, as soon as its contents became an adequate stimulus, he would sweat profusely. This excessive sweating was accompanied by a feeling of fulness and discomfort in the head and made him feel weak and ill. So great was his distress, that he would clamour for the catheter to be passed more often; this was, however, difficult and inadvisable on account of the injuries to the urethra present on his admission to the hospital. Finally, 153 days after the injury (February 14, 1917), as the sphincter showed no sign of relaxing, a catheter was tied into the bladder. Whenever he complained of discomfort in the head or of excessive sweating, the mouth of the catheter was set free and urine was allowed to pass. This was a brilliant success, and in two days the sphincter had begun to relax, so that there was no difficulty in removing the gum-elastic catheter and replacing it by one of india-rubber. From this time onwards he began to improve in the most extraordinary manner; nausea, vomiting, abdominal distension ceased, and excessive sweating became of much rarer occurrence. Various attempts were made to get rid of the catheter, but the sphincter was liable to fall back into permanent tonic contracture. Finally, 207 days after the injury (April 10, 1917), we were able to remove the catheter altogether, and from this time he passed his urine automatically; that is to say, the sphincter now participated in the complete act of involuntary micturition.

But throughout this long period of retention, before the establishment of automatic micturition, we were able to show, by repeated observations, that the bladder-wall was capable of expelling its contents actively when they reached a certain volume. Thus, as early as forty-three days after the injury, we found that contraction occurred at about 300 c.c., and half this amount was returned through the catheter in a stream of considerable strength.

On December 23, 1916 (100 days after the injury), we were able to make a more extended series of observations. On passing the catheter 190 c.c. of urine were drawn off, acid in reaction and containing mucus and a small quantity of pus, but no blood. The warm fluid used for washing out the bladder was then allowed to run in through the catheter. At 150 c.c. the column began to oscillate, and at 200 c.c. he evacuated 120 c.c.; a further 80 c.c. were regained by pressure on the abdomen. After 50 c.c. had passed into the bladder sweating began, and became excessive when the abdomen was pressed to evacuate the remains of the fluid. He was then dried and allowed to remain quiet until there was little or no excessive moisture of the head and neck. Fluid was again passed into the bladder, and he began to return it at 120 c.c., passing 70 c.c. The next observation gave 150 c.c. as the effective volume, and he evacuated 100 c.c.; on another occasion he responded to 125 c.c., passing 65 c.c.

Throughout this series of observations we noticed that, at some definite volume between 50 c.c. and 100 c.c., the fluid began to oscillate in the tube, showing that it was no longer running into the bladder freely; these oscillations were not respiratory and evidently corresponded to abortive waves of contraction. Their occurrence was the signal for the sweating to begin.

During the time the catheter was tied into the bladder, we were able to make almost daily measurements, and the power of the muscular wall to expel the whole of that volume, to which it reacted, steadily increased. Thus 170 days after the injury (March 3, 1917) the following observations were made: He reacted to 150 c.c., expelling 155 c.c., to 130 c.c. and to 100 c.c., in each case emptying the bladder completely. We then ran in 50 c.c., and, on stimulating the glans penis, the whole amount was evacuated. Again 50 c.c. were passed into the bladder and the sole of the right foot was scratched; a flexor jerk was evoked and he at once evacuated 38 c.c. Finally, as a control, fluid was allowed to run in and care was taken to cause no reflex of any kind; he then evacuated at 100 c.c.

Thus an automatic bladder, which responded to about 100 c.c., could be excited to contraction by half this volume if, at the same time, afferent impulses were thrown into the lower end of the spinal cord from either the sole of the foot or the penis.

Sweating.—In this case the sweating was incredibly profuse; a sponge used to wipe the face and neck could be wrung out as if it had been dipped into water, and blankets and pillows were soaked through in a few minutes. At times, so much fluid was lost that the patient suffered from thirst and the urine was diminished in amount.

The area occupied by the excessive sweating comprised the whole head and neck, both upper extremities and the trunk to the level of the umbilicus; when the outburst was extremely severe or prolonged the sweating might extend to the knees, but was steadily less profuse from the ensiform level downwards. Legs and feet always remained absolutely dry.

In the earlier days, before we were able to relieve the tension in his bladder and before the advent of automatic micturition, he was scarcely ever dry, and was subject to recurrent waves of sweating. They were accompanied by much mental distress and by dilatation of the pupils; at the same time he complained of a painful fulness in the head, occupying the whole occipital region and vertex. As soon as the bladder was relieved, or the bowels were emptied by the passage of fæces or flatus, this headache disappeared.

Later in the course of the case, when paroxysms of sweating did not occur unless induced by some peripheral stimulation, we could study these phenomena more accurately. This sensation of painful distension in the head was then found to be strictly related to the onset of sweating;

it appeared with the hyperidrosis and disappeared shortly after reflex stimulation was removed, as, for instance, when the bladder ejected its contents or flexor spasms subsided.

We have already described how closely the onset of sweating was associated with bladder tension. Any stimulus which evoked flexor spasms was also a potent cause of hyperidrosis. If a suitable opportunity was chosen when the skin was in a normal condition, it was only necessary to scratch the sole of the foot under the bed-clothes for the most profuse sweating to break out over the whole head and neck in association with the flexor spasms. The reflex movements could be evoked by stimulating almost any part of the skin of the lower extremity, by pressure, as in grasping the foot or placing the hand firmly on the abdomen and even by lifting the bed-clothes. No matter how the spasms were produced, they were associated with an outburst of sweating.

Another potent cause for hyperidrosis was abnormal intestinal tension; for not only was the sweating infallibly evoked by an enema, but any collection of flatus also tended to produce an outburst. In the earlier days, before the catheter was tied into his bladder, he was peculiarly liable to periodic gastro-intestinal attacks associated with nausea and the collection of flatus; the abdominal muscles became rigid, flexor spasms increased in the legs, and sweating became very severe. Anything that eased this flatulence, or the passage of the enema with its accompanying relief of tension, was associated with a diminution of the sweating.

Some ten months after the accident, he had reached a condition in which sweating no longer troubled him, because involuntary micturition occurred without effort, enemata were rarely necessary and flexor spasms were seldom excited. But an attack of hyperidrosis could still be evoked experimentally by injecting fluid into the bladder or rectum, or by repeated excitation of a series of flexor spasms.

Case 6.—Gross injury to the lower end of the spinal cord from the lower lumbar segments downwards (right fourth lumbar). All voluntary movement lost below the knees. Ankle-jerks obtained but plantar reflexes absent. Automatic micturition accompanied by consciousness of a full bladder, desire to make water and recognition that the bladder was contracting, but no appreciation of the passage of urine or power to influence the flow. Automatic contraction of the bladder-wall could be facilitated by inducing the cutaneous anal reflex, but not by reflexes evoked from the thighs and abdomen.

Pte. M., aged 38, fell and gravely injured his spine on March 29, 1915. He was a marine, and whilst passing between decks in the dark fell into the open hold of the ship in consequence of the removal of some of the planks which covered the opening. At first he was completely paralysed in both lower extremities, with profound loss of sensation. In this condition he arrived at Netley in October, 1915, and was sent on to the London Hospital on March 6, 1917, for investigation and treatment. His condition was as follows :—

Motion.—All movements were perfect down to the level of the groins, and there was complete paralysis in both legs below the knee. He could extend but could not flex the left knee, and abduction of the thigh and flexion and extension of the left hip were possible. He could not, however, flex or extend the right knee or hip; slight adduction was possible but not abduction. The abdominal muscles acted well, but there is no doubt that the lower muscles of the back were weak, especially on the right side, and he could not raise himself from his bed without the use of his hands.

The muscles were much wasted below both knees and over both thighs, especially in the lower half, particularly in the right thigh. There was no spasticity or increase of tone in any group of muscles; involuntary movements were absent.

Reflexes.—The knee-jerks could not be obtained, but an ankle-jerk was elicited on both sides; that from the right was stronger than that from the left leg. There was no ankle clonus. The abdominal reflexes were brisk and normal. No plantar reflex of any kind could be obtained.

Sensation.—All sensibility to light, touch, prick, heat and cold was lost over the area shown in Fig. 155. The borders of the area insensitive to cotton wool did not differ materially from those of the loss of sensation to prick, heat and cold.

He could not appreciate the pain of pressure with the algometer (base 0·75 cm. in diameter) over either foot or over the anterior aspect of the right shin. Over the left shin 6 kg. was painful. Pressure was recognised as contact over the right foot at 15 kg., over the right shin at 10 kg.; whilst over the left foot he was sensitive to 8 kg. and over the left shin to 2 kg.

He was insensitive to the vibration of a tuning fork (C° = 128) over both feet, and on the right leg this insensibility extended to the knee. On the left side, though profoundly affected, he could just appreciate the vibration for a short distance below the knee.

The bladder.—When first injured he had complete retention of urine, but about four months later he began to micturate automatically. Whilst in the London Hospital he passed urine unconsciously at somewhat frequent intervals; sometimes he had a feeling that he wanted to make water and he then pressed with his abdominal muscles. Urine was voided in a definite stream but he was unconscious of its passage.

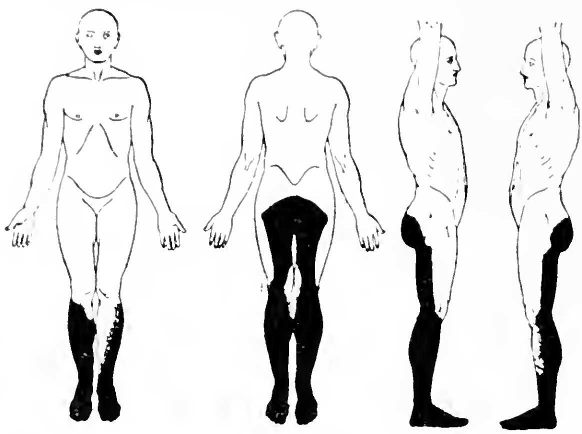

FIG. 155.
To show the extent of the loss of sensation in Case 6.

On May 11, 1917 (two years and forty-three days after the injury), the following series of experiments were carried out by us:—

A catheter was passed and he had no sensation until it was pushed home into the bladder, when he said: "I feel something"; 105 c.c. of clear acid urine, free from pus, were drawn off. Warm sterile water was allowed to run into the bladder, and at 105 c.c. he called out: "Now it is coming"; at 107 c.c. he evacuated the total quantity and nothing could be expelled by pressure. At the next observation he expelled the fluid at 98 c.c., and it returned in a vigorous stream; he passed 96 c.c. in the first effort, followed by the remainder in a final spurt. At a third observation the bladder voided its contents at 75 c.c., and again at 85 c.c.

He was astonishingly accurate in recognising when the return of fluid was about to take place. He said: "I suddenly feel the pleasant desire to make water, just as you feel when the bladder is full." Some sensation was produced by the point of a catheter when it reached the bladder and he was conscious of vesical contraction. But he was insensitive to the actual passage of the urine down the urethra and was entirely unable to control it in any way.

No plantar reflex could be obtained in this case, and the superficial reflexes obtainable from above the level of the lesion had no effect on the volume of fluid which formed an effective vesical stimulus. Thus when the left thigh was repeatedly scratched he evacuated through the catheter at 98 c.c., passing 95 c.c., and when the abdominal reflex was evoked rhythmically, first from one half and then from the other half of the abdomen, he evacuated at 70 c.c., passing the whole amount.

At this stage we did not recognise the physiological significance of the anal reflex, evoked from the skin over the gluteal area. Some months later we repeated these observations on the bladder and found that this reflex had a profound effect upon the activity of the bladder. At that time he evacuated his bladder completely when 120 c.c. of fluid had run in through the catheter. But if the anal reflex was evoked by scratching the analgesic skin of one or other buttock, the bladder was emptied as soon as 10 c.c. only had entered. When the foreskin of the penis was pricked evacuation occurred at 10 c.c., 15 c.c. and 25 c.c.

Sphincter ani.—When the point of the finger touched the anus the skin was felt to wrinkle up and the resistance in front of the finger increased. This steady resistance was felt as long as the finger was being pushed onwards; but when the finger was allowed to rest quietly in the canal, the sphincter relaxed and held it with a light steady contraction. As the finger was withdrawn the sphincter closed down tightly upon it.

Over an area round the anus extending for 6 cm. in either direction the prick of a pin produced a contraction of the sphincter although the skin was entirely insensitive to touch, pain and thermal stimuuation.

Spine.—A radiograph showed that there had been some injury to the body of the fifth lumbar vertebra.

Case 7.—Destruction of the nerve-roots and conus medullaris from the first lumbar downwards on the left and the second lumbar on the right side. Total flaccid paralysis and loss of sensation below these levels. Complete abolition of reflexes. Automatic micturition; vesical contraction excited at from 220 to 230 c.c. No facilitation by outside stimuli. Anal sphincter tonic. No cutaneous peri-anal reflex.

Gunner P., aged 21, was wounded on August 14, 1917, by the fragment of a large shell which burst behind him. He felt as if both legs had been suddenly lopped off. He spent that night in a field ambulance, and was removed next day to No. 24 Casualty Clearing Station. A fragment of metal had entered in the left lumbar region and was found adhering to the pedicle of the twelfth dorsal vertebra. This in turn had been driven across the theca. On August 17 the lamina of the left half of the twelfth dorsal vertebra was removed. The dura was torn at this level and that portion of the pedicle which had been driven across the theca could be removed in part only. (Captain Chisholm, R.A.M.C.)

He was admitted to the London Hospital, under the care of Dr. Head, on August 21, 1917. He then showed a gaping granulating wound extending from the middle line at the level of the twelfth dorsal spine outwards to the left loin. From this wound two sinuses ran downwards and inwards for a considerable distance impinging on bone; one of them seemed to be in connection with the spinal canal, and exuded thin pus in considerable quantities.

Both lower extremities were in a condition of complete flaccid paralysis from the hips downwards, with total loss of sensation below the level of the first lumbar segment, and abolition of all reflexes, superficial and deep.

It was not, however, until the middle of September, 1917, that he was in a suitable general condition for complete examination, and the following observations were made between September 17 and October 6.

Motion.—Both lower extremities below the hips were in a condition of complete flaccid paralysis. He could make no movement at the left hip-joint, but could flex the right feebly. All the muscles of both legs, including the glutei and the right iliac muscles, were wasted; they showed a tendency to fall into fibrillary contraction when stimulated in any way. There were no involuntary movements.

Reflexes.—All reflexes were normal above the level of the umbilicus. Below this level the abdominal reflexes could be obtained, but were feeble compared with those from the supra-umbilical level.

Knee- and ankle-jerks and ankle clonus were absent. No plantar reflexes could be obtained.

Sensation.—Sensibility to prick, heat and cold was lost up to the lower border of the twelfth thoracic segment on the left side and of the first lumbar on the right. The loss to cotton wool corresponded almost exactly to these limits. Pressure was not appreciated almost up to the groin on the left side and as high as the lower third of the right thigh. All recognition of vibration was lost below the great trochanter in both lower extremities, and passive movement was not appreciated up to and including both knee-joints. He was, however, sensible of movement in the right hip-joint and to a much less extent in the left; here, however, the movement had to be of considerable range to be appreciated.

The bladder mechanism.—A catheter was first passed ten hours after he was wounded, and from that time at varying intervals, about twice daily. On admission to the London Hospital he was passing urine involuntarily, but catheterisation was carried out three times a day. The urine was acid and contained no albumen or pus.

On September 17 (thirty-four days after the injury) the following observations were made: The bladder was emptied and 190 c.c. of urine withdrawn. When the warm washing fluid was allowed to run in he evacuated at 225 c.c., passing 230 c.c.; nothing could be recovered by pressure. The second time the bladder contracted at 220 c.c. and the whole was ejected. On repeated deep breathing he evacuated at 230 c.c., and when the abdominal reflexes were evoked ejection took place at 220 c.c.: in both cases he passed the exact amount run in from the burette. No reflexes could be evoked by scratching the soles, and this stimulus had no effect on the activity of the bladder. No peri-anal reflex could be obtained.

Thus at the end of a month, at any rate, automatic micturition had been established and contraction of the bladder-wall could not be influenced by stimuli from without.

Sphincter ani.—An enema was administered every night and he felt nothing until his abdomen became uncomfortable. He was not conscious of the return of fluid and fæces, except by the feeling of relief from discomfort.

The anal sphincter was tight, but yielded to continuous pressure applied slowly, even without the exercise of much force. On withdrawing the finger a firm vigorous contraction occurred as the volume in the rectum decreased; this ended on complete removal of the finger in a permanent normal tonic contraction.

No anal reflex could be excited by stimulating the skin.

Case 8.—An instance of modified Brown-Séquard paralysis due to a wound of the left side of the neck injuring the spinal cord in the lower cervical region. Weakness and some loss of sensation in the left arm and hand. Total loss of sensation to pain, heat and cold, over the right half of the body from the nipple level downwards. Much over-reaction to uncomfortable stimuli over the left half of the body during the first few months after the injury. Profound want of appreciation of the vibrating tuning fork over the left half of the body from the level of the fifth rib downwards; on the right half this loss extended to just above the hip joint. No affection of light touch or pressure over the trunk or lower extremities. Voluntary movement rapidly returned in both lower extremities, but was always better in the right than in the left. Flexion reflexes evoked from both lower limbs. But from the right leg a flexor spasm of the massive type was evoked which facilitated the evacuation of the bladder, whilst from the left the characteristic flexion reflex had no effect on vesical activity. Primary extension could be produced reflexly in the left leg but not in the right. The bladder acted involuntarily and automatically, but the patient knew when fluid was about to pass. Excessive sweating, mainly over the head and neck, which could be evoked by visceral afferent impulses affecting the spinal cord below the lesion.

Lieutenant G., aged 24, was wounded in the neck by a fragment of a high-explosive shell on August 24, 1916. He lost power immediately in the left arm, and was paralysed from the level of the nipples downwards.

He was hit at 4.30 p.m., as he was moving along the trench to empty his bladder. No catheter was passed until midday on August 25, nineteen and a half hours after the injury, but he felt no distension. Retention of urine was complete, and a catheter was passed every twelve hours until about a week after he was wounded, when the intervals were reduced to every six hours, in consequence of the discomfort associated with distension of the bladder. Urine began to pass in small quantities automatically about fifteen days after he was wounded, and within the next two days catheterisation was stopped altogether.

The condition of this patient during the fortnight following his admission to the Empire Hospital, under the care of Dr. Head, on September 24, 1916 (thirty-one days after the injury), was as follows:—

The wound consisted of a minute horizontal slit, 1 cm. in length, situated on the left side of the neck, 11 cm. below the tip of the left mastoid process. It had closed, but was surrounded by some staining from extravasated blood, which subsequently developed into a huge yellow bruise, occupying the whole of the left supra-clavicular fossa.

A radiograph showed no foreign body, and as there was no exit wound it is suggested that the injury may have been due to a piece of aluminium.

Motion.—The right arm was in every way normal, but there was considerable loss of power and want of co-ordination in the movements of the left upper extremity; this was particularly evident in the small muscles of the hand.

He was completely paralysed from the level of the fourth rib downwards on both sides. There was, however, a tendency to involuntary flexor movements in the left leg, and a tremor of the left leg, which did not either flex or extend the limb.

Reflexes.—At this stage there was no great difference between the jerks obtained from the two upper extremities. The knee-jerks and ankle-jerks were absent, and ankle clonus could not be obtained. No response was evoked when the right sole was scratched; but stimulation of the left sole produced a distinct flexion and adduction of the left thigh, with no movement of the great toe.

Sensation.—Over the whole left half of the body and pre-axial half of the left arm he reacted excessively, and complained bitterly when he was pricked. This made it extremely difficult to discover to what extent sensation was lost over these parts; but it was certainly greatly diminished over the left leg below the knee and over all the sacral areas on the buttock and back of the thigh. On the right half of the body sensation to prick, heat and cold was abolished up to the nipple level.

Cotton wool and deep pressure were universally appreciated and well localised. The vibration of a tuning-fork was not recognised over the whole of both lower extremities, and as high as the iliac crests; at this stage we could not determine with certainty the loss on the thorax, but this form of sensibility was not normal until the nipple level was passed on either side. Passive movement could not be recognised in the lower extremities, except, perhaps, at the hip when it was very extensive.

Pupils, etc.—The left pupil was smaller than the right and dilated less to shade. Moreover, the left palpebral fissure was perhaps a little smaller than the right.

Urinary system.—He had no voluntary control over micturition, but passed about 150 c.c. at varying intervals, amounting in all to between 1700 and 2200 c.c. in twenty-four hours.

He could recognise the passage of urine, and knew when fluid was being injected into his bladder. When about 280 c.c. had entered he experienced "a nervous wave" which seemed to start in the abdomen, pass up the body, down the arms and into his head. This "sort of shiver" preceded evacuation, whether he passed urine automatically or whether he was ejecting fluid from his bladder through a catheter in the course of vesical lavage. He knew when he was about to evacuate fluid and experienced that pleasure which normally accompanies the passage of urine; but he had no desire to micturate.

The urine was alkaline and contained a good deal of pus; the amount of albumen corresponded roughly to the quantity of pus.

Sweating.—There was a good deal of sweating over the right half of the head and neck; the left half was almost dry.

The subsequent observations we made on this patient up to the end of July, 1917, will be summarised under the following headings of *Motion*, *Reflexes*, *Sensation*, *Urinary system*, *Sweating*, etc. On February 15, 1917, his bladder was opened suprapubically and the condition of the urine greatly improved; but the kidneys were infected and he died somewhat suddenly, after a short period of pyrexia, on August 21, 1917. The suprapubic wound was allowed to close on April 15, and from that date the bladder was washed out through a catheter only.

Motion.—Voluntary power slowly returned, appearing first in the right leg. By the eighty-seventh day after the injury (November 19, 1916) he could flex and extend the right knee; the left knee could be extended, but not flexed voluntarily. He could plantar extend the right foot, but was unable to dorsiflex at either ankle. All involuntary movements consisted of flexor spasms, which adducted the thighs; these were evoked by removing the bed-clothes or by any manipulation of the lower extremities. Both limbs were somewhat wasted and flabby unless they had been thrown into spasmodic flexion.

By the one hundred and seventy-fourth day the condition had somewhat changed. The left upper extremity had wasted considerably, especially the interossei and thenar muscles. All movements could be performed, but abduction of the fingers was weak and tremulous. The left arm was inco-ordinate and he used it little in his daily life.

He could voluntarily flex and extend the right hip and knee and strongly plantar extend the right foot. But he could not dorsiflex it or make any movement of the toes. All the movements of the left lower extremity were feeble. Dorsiflexion of the foot and movements of the toe were impossible, but he could plantar extend, though less strongly than on the right side. At the knee and at the hip flexion was feeble, but extension relatively strong. Involuntary flexor movements occurred in both limbs, but were more frequent and more pronounced in the right than in the left. If he straightened the left leg it fell into rigid extension; this did not occur in the right leg.

Two hundred and eighty-six days after the injury (June 6, 1917) the condition was as follows: The left arm was still wasted and inco-ordinate but was much more useful in daily life; he could not use it to change his position in bed and to move objects on the bed-tray.

Voluntary power had greatly improved in the right leg. He could flex, extend, adduct and abduct it at the hip; flexion and extension at the knee and plantar extension at the ankle, together with downward movements of the toes, were strongly performed. We were doubtful if there was any true voluntary dorsiflexion or upward movement of the toes.

In the left lower extremity, extension, abduction and adduction of the hip were well performed but flexion was weak. He could flex and extend the knee, but, whilst flexion was weaker than in the right leg, extension was quite as strong. He could plantar extend but could not dorsiflex the foot; both upward and downward movements of the toes were possible, but the latter were the stronger. Apart from extension, voluntary movement was throughout weaker in the left lower extremity than in the right.

All involuntary movements in the right leg were of the flexor type, with active extension as a secondary phase. In the left leg a flexor spasm was the most common, but extension could occur as a primary motor reaction.

Reflexes.—Within fifty-two days after the injury, the left knee-jerk had appeared, though the right was still absent. The ankle-jerks were not obtained and there was no ankle clonus. The plantar reflex from the right foot was a slight downward movement of the toes with no hamstring contraction, whilst that from the left sole caused distinct flexor contraction at the knee but no movement of the foot or toes. Seven days later both knee-jerks were present, but the other reflexes were exactly as described above.

Within eighty-seven days from the injury a great change had occurred. Both knee-jerks were greatly exaggerated, the ankle-jerks were brisk, and ankle clonus was present on the right side, but absent on the left. When the right sole was scratched the great toe moved upwards, the other toes became separated and a true flexor spasm was evoked, which affected the abdominal muscles. Scratching the left sole caused contraction of the inner hamstrings, but the great toe remained stationary; the abdominal muscles did not contract with the production of this reflex. No reflexes could be obtained by direct stimulation of the abdomen, except on the right side above the umbilicus.

By the two hundred and forty-first day after the injury the difference between the reflexes from the two lower extremities had become accentuated; this period is important, because it was on this day that the striking series of measurements were carried out on bladder capacity which are detailed below. Scratching the sole of the right or insensitive foot evoked a full flexor spasm with upward movement of the toe and contraction of the right half of the abdomen. This was accompanied by crossed extension in the left leg; the toe moved downwards, the foot was plantar-extended and the quadriceps contracted sufficiently to pull up the patella.

On the other hand, scratching the left sole led to a flexion reflex of the left leg unaccompanied in most cases by any definite abdominal contraction; any movement of the rectus abdominis which occurred was feeble compared with that evoked by stimulating the right sole. The flexion in the left lower extremity, produced by scratching the left foot, was associated with slight but definite contraction of hamstrings in the opposite (right) limb.

Thus stimulation of the analgesic foot (right) produced a full flexor spasm accompanied by strong contraction of the abdominal muscles and associated with a crossed extensor reflex; stimulation of the left foot, evoking painful sensations, produced flexion accompanied by little or no abdominal contraction and associated with crossed flexion at the right knee. The first of these reflex responses (from the right foot) was associated with facilitation of detrusor activity, whilst the second (from the left foot) had no effect on the bladder.

Sensation.—The over-reaction to painful stimuli on the left half of the body gradually passed away, and it became possible to determine more accurately the condition of sensibility.

Over the inner border of the left forearm sensation was definitely duller than elsewhere, both to pricking and light touch, but was nowhere lost completely.

The whole of the right half of the body and the right lower extremity below the level of the nipple was insensitive to painful and thermal stimuli. Touches with cotton wool were everywhere appreciated and correctly localised. Vibration was not recognised, apart from the contact of the tuning-fork, over any part of the right lower extremity; it was, however, appreciated over the anterior superior spine and crest of the ilium. He also failed to recognise passive movements in the right lower extremity below the hip-joint.

The left half of the body and left lower extremity were sensitive to light touch, pricking, heat and cold, except that sensibility to prick was a little dulled on the outer aspect of the left leg and dorsum of the foot. On the other hand, vibration was not appreciated from the level of the fifth rib downwards, and recognition of passive movement was lost in the left lower extremity.

Pupils, etc.—Within eighty days of the injury the pupils became equal and dilated well to shade; the palpebral fissures were about equal in size.

Urinary system.—He never regained voluntary control over micturition, although he was conscious of distension of his bladder, knew when it was about to evacuate its contents, and recognised that urine was passing.

On April 22, 1917 (241 days after the injury) the following measurements were made. He felt the passage of the catheter, which withdrew 150 c.c. of urine. On allowing sterile warm water to enter the bladder it contracted at the following volumes: (1) At 115 c.c., and he passed 120 c.c.; (2) at 70 c.c., passing the same amount; (3) at 90 c.c., passing 105 c.c.; (4) at 100 c.c., passing the full quantity. Then, after 30 c.c. had been permitted to run into the bladder, the right (insensitive) sole was stimulated, and he immediately evacuated the whole amount; 30 c.c. were again allowed to run in, and the left (sensitive) sole was stimulated, but no evacuation occurred, in spite of the appearance of a powerful flexion reflex. More fluid was allowed to enter, and at 40 c.c., 50 c.c. and 60 c.c., the left sole was repeatedly scratched. No effect whatever was produced on the activity of the bladder-wall, and at 70 c.c. he called out: "It will fire off by itself now!" At that moment the fluid began to return, and he passed

70 c.c. in all. Thus, scratching the sensitive foot had no effect on the contraction of the automatic bladder, whilst stimulation of the insensitive (right) foot greatly facilitated the return of fluid before it reached one-half the volume that usually formed an adequate stimulus.

These observations were repeated on July 26, 1917 (336 days after the injury), with the following results: (1) When 135 c.c. of sterile water had run in, he passed 135 c.c.; (2) at 160 c.c. he passed the full amount; (3) at 150 c.c. he passed 145 c.c. When the right sole was stimulated during the inflowing of the fluid, he evacuated at 70 c.c., passing the full amount; but, on stimulating the left foot in the same way, he did not evacuate until 160 c.c. had run in, an amount to which he would have reacted without evoking any somatic reflex. Deep breathing caused evacuation at from 30 to 80 c.c.

Sweating.—During the first three weeks excessive sweating occurred on the right half o the head and neck, but not on the left; gradually a similar hyperidrosis appeared to the left of the middle line, and, finally, no definite difference could be noticed between the two sides.

Usually the sweating was profuse over the head and neck, and died away rapidly towards the ensiform level on the trunk; but when the manipulations which evoked it were long continued it extended to the feet. The lower extremities and lower half of the trunk, however, always sweated less profusely than the head and neck.

An outburst of sweating could be evoked most rapidly and most certainly from the bladder. If the catheter was inserted properly, and the bladder-wash could flow back freely at the moment of contracting, he did not sweat; but if for some reason, such as blocking of the catheter by a plug of mucus, free return was hindered, he burst into intense sweating over the face and neck. After the bladder had been opened suprapubically on February 15, 1917 (175 days after the injury), all excessive sweating ceased, except when the box ("tortoise") shifted on the abdomen, or the free flow of urine was checked by some mechanical defect. On one occasion the drainage tube from the bladder, passing through the suprapubic wound, became blocked by a small calculus, and hyperidrosis came on again in a violent form to our profound bewilderment.

Excessive sweating was not correlated with that "thrill" or "shiver" which normally accompanies evacuation of a full bladder. In fact, this sensation seemed to be evoked by the opposite condition to that which caused sweating. Before the operation he could tell with remarkable accuracy when his bladder was about to empty itself, during our experimental observations, and contended that he "always knew by a nervous wave, which seemed to start in his abdomen, and passed up to the head and down his arms"; it was "a sort of shiver," and it immediately preceded passage of urine automatically or evacuation of the fluid inserted through the catheter. With this sensation he never sweated; it was always associated with an easy passage and free outflow. Any obstruction destroyed this sensation, and replaced it by sweating, which was accompanied by a definite feeling of discomfort.

Sweating could also be evoked by the manipulations necessary to administer an enema. When an enema was given in our presence, he could feel the insertion of the nozzle of the syringe. Then after the first few ounces of fluid were pumped in, he said: "I have a feeling as if the passage were being forced open." After receiving about 300 c.c., he said: "I've got a nervous feeling which runs up the body, down my arms, into the back of my head and over the front of the scalp; it also runs down the front and inner aspect of both thighs, more on the left (sensitive) side than on the right. This thrill is not unpleasant, but as the injection goes on it becomes unpleasant, just as it is unpleasant when you have to strain on stool." No sweating occurred until this thrill became converted from a pleasant to an unpleasant sensation. The pleasant visceral "thrill" was not associated with a stimulus to sweating; but obstruction, with its necessary discomfort, evoked hyperidrosis.

Whenever an outburst of sweating was produced, from whatever cause, the pulse tended to become slower, more forcible, and somewhat irregular. We could not satisfy ourselves, however, that there was any certain coincident change in the pupils.

The following case forms so good an example of the disappearance of visceral facilitation with the advent of extensor phenomena, that we have added it to this section whilst passing through the press (June 1919).

Case 9.—A case of gross injury to the spinal cord in the region of the fourth and fifth thoracic vertebræ. Total paralysis of motion and sensation below the middle of the trunk. Flexor mass-reflexes elicited from both lower extremities. No extensor phenomena of any kind. Facilitation of bladder activity on stimulating the sole of either foot.

Laminectomy.—Thirty-four days afterwards extensor reflexes evoked. Three days later the contraction of the bladder could no longer be facilitated from the soles of the feet.

Lieutenant W., aged 24, crashed in an aeroplane on November 1, 1918, when taking off. The under-carriage caught in another machine on the ground, and he was thrown out, striking his back as he was shot from his seat.

He was not unconscious and knew he had injured his spine, because he "felt he had a head and shoulders only."

In half an hour he was admitted to a Military General Hospital in this country. A catheter was passed two hours afterwards and then twice daily until Christmas, 1918; from that date it was passed once in the twenty-four hours. He received no other treatment.

On February 27, 1919, he was admitted to the R.A.F. Hospital, Bryanston Square, and I was asked to see him by Mr. Warren Low.

The following observations were made during the first fortnight of March, 1919.

The upper extremities were in every way normal. But the spine showed a definite angular curvature backwards, with the summit formed by the fifth dorsal spine. A radiograph showed signs of an old fracture of the fourth and fifth ribs on the right side close to their posterior angles.

His general condition was extremely good and he remained free from fever throughout.

Reflexes.—Both knee-jerks were obtained and the ankle-jerks were brisk. There was no ankle clonus.

Scratching the soles of the feet caused a flexor spasm in the stimulated limb, associated with upward movement of the great toe. This reflex could be evoked not only from the sole and outer side of the leg, but also from the thigh and less certainly from the abdomen. The abdomen, however, participated in the mass-reflex.

All involuntary movements were flexor; there were no extensor spasms, spontaneous or evoked, and no crossed extension followed flexion in the opposite limb.

Motion.—He was completely paralysed below the ensiform level. There was some general wasting of both legs, but it was not extreme.

Sensation.—He complained of pain and a "feeling of tightness" round the trunk from the nipples to the ensiform level. At the extreme upper border of this girdle sensation was an area more definite on the right than on the left half of the chest which was tender to the dragged point of a pin. This marked out in a perfect form the distribution of the fourth thoracic zone especially on the right side.

Sensation was completely abolished to pain, heat and cold below the level of the caudal border of this tender zone. The loss to cotton wool extended from the ensiform cartilage downwards, whilst sensibility to pressure was lost below the level of the umbilicus.

Both legs seemed to him slightly flexed and sometimes one appeared to be crossed over the other. He had no power of recognising their true posture and was totally insensitive to passive movements of the lower extremities.

Bladder.—Micturition was automatic and the following observations were made on March 7, 1919 (126 days after the injury).

When we began our manipulations, the receptacle placed in the bed four hours before was still empty. The catheter drew off 350 c.c. of urine, which was acid and contained a faint cloud of albumen, but no pus. He was unaware of the cleansing of the glans penis or of the passage of the catheter. No priapism or turgescence was evoked by these manipulations.

When 200 c.c. of sterile fluid were passed into the bladder the wall contracted and evacuated the full amount. On a second observation the flow began at 225 c.c. and again he emptied his bladder completely.

When the sole of the foot was gently scratched he evacuated the bladder completely, on the first occasion at 95 c.c., on the second at 70 c.c. This latter observation was particularly successful and showed considerable facilitation on evoking a mass-reflex.

On March 15, 1919, he was transferred to the Empire Hospital for Officers under the care of Dr. Head.

On March 26, 1919, Mr. Wilfred Trotter performed laminectomy. On removing the spines the laminæ showed obvious signs of injury; the fourth dorsal was telescoped into the fifth and the spinal canal was bent with a convexity to the right. The lamina of the fourth had been driven under that of the fifth dorsal, and the lumen of the canal was reduced to extremely small proportions, the narrowest part being at the juncture between these two vertebræ. Here there was a tough fibrous band 0·5 cm. in breadth, evidently constricting the contents of the theca. The spinal cord was badly crushed, but was not anatomically discontinuous.

The patient made a perfect recovery from the operation, and on April 7 a special examination showed that no extensor phenomena could be elicited by any form of stimulation from any part of the lower extremities. A crossed flexion reflex was present and this affected the abdomen on both sides.

But on April 30, 1919, thirty-four days after the operation (180 days after the injury), undoubted extensor spasms could be evoked by tapping the patellar tendon or by pinching up the tissues of the thigh; a slight extensor thrust could be produced from the foot. The flexor reflex obtained on one side was now accompanied by extension in the opposite limb.

Bladder.—On May 3, 1919, thirty-seven days after the operation, the following observations were made upon the bladder.

The receptacle placed in the bed four hours before contained 200 c.c. of urine and the catheter drew off 165 c.c. It was slightly acid and contained no pus.

When 160 c.c. of sterile fluid had entered the bladder, it emptied its contents completely. On a second observation evacuation occurred at 130.

When the sole was scratched he evacuated at 132 c.c., passing 150 c.c. tinged with urine, which had evidently entered the bladder during the observation. The next time the contents were returned at 140 c.c. in spite of vigorous stimulation of the sole; he passed this exact amount and emptied his bladder completely.

All signs of facilitation of vesical activity had ceased with the appearance of primary extensor reflexes.

PART IV

THE BRAIN

SENSORY DISTURBANCES FROM CEREBRAL LESIONS [1]

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AND

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We must begin by craving the indulgence of our readers for the form in which the following paper is cast. The nature of the sensory changes produced by lesions of the cerebral cortex and other parts of the brain has been the theme of innumerable works by the acutest intellects in medicine of the last fifty years. Our research would have been impossible but for their labours. and yet we can never acknowledge what we owe to them. Many, whose views have helped to make our work fruitful, are known to us through their publications, and to them we can repay our debt by referring at suitable points to the similarity of our results to those of our predecessors.

Others have been our teachers and the masters for whom we have gladly worked. To them our debt can never be repaid, for much of the identity in outlook comes from personal intercourse and cannot be fixed by citation. First amongst this group must always stand the name of Dr. Hughlings Jackson.

This is a preliminary communication in which we put forward a general view of the mode of action on the afferent side of the nervous system. Any such generalisation must not only contain much that is common to the views of others, but also many things incompatible with the conceptions, even of those with whom we are otherwise in harmony. Where possible, we shall always acknowledge our concurrence with those who have preceded us, but in the small space at our disposal we cannot enter into criticism of work with which we are not in agreement. In many cases, although our theoretical conclusions may coincide with those put forward by other workers, our experimental results may differ fundamentally. In the same way, similar clinical observations may lead us to other conclusions, but it will be impossible to stop our exposition in order to discuss these differences.

We shall attempt to put forward in the following chapters a general conception of the mechanism underlying sensation, based upon a study of human

[1] The substance of this work formed the Croonian Lectures delivered before the Royal College of Physicians on June 13, 15, 20 and 27, 1911.

beings in whom disease, accident or surgical interference has produced some stationary lesion. Many of these patients have occupied our attention from time to time for many years, and it will be impossible in this communication to give a complete history of all our cases. We have, however, added an abbreviated account of the physical signs of certain patients, to which we shall frequently allude for the sake of illustration.

Cases of disease may be studied from two aspects. More commonly, it is our business as physicians to consider their relation to clinical types, and to discuss the diagnostic significance of certain signs and symptoms. But, in this paper, disease is simply the means by which certain laws are demonstrated and certain physiological activities are laid bare. It is not the disease which occupies our attention, but the opportunities it gives for analysing the processes underlying sensation. We shall therefore begin by tracing sensory impulses from the point where they enter the spinal cord, and follow them to those centres where they form the basis of that psychical process we call sensation.

For this investigation, exact knowledge of the site of the lesion is less important than a precise determination in selected cases of the nature of the sensory changes. We are occupied in this research with certain forms of sensory loss and with certain dissociations of sensibility; our aim is to discover the grouping of afferent impulses at different levels of the nervous system and not to determine the regional diagnosis of organic lesions. The most definite sensory grouping and dissociation are exhibited in cases where the lesion is stationary and the patient otherwise in perfect health, whilst in many instances where the lesion could be determined post-mortem the patient was entirely unsuitable for sensory examination. It is only by the exact study of these affections of sensation that we can obtain any knowledge of the nature of cerebral activity and of the form in which impulses reach the higher centres to underlie the production of sensation.

The material on which this research is based includes twenty-four patients in whom the clinical symptoms justified us in assuming certain affections of the optic thalamus. A second group consists of sixteen patients with limited lesions of the surface of the brain, most of which resulted from successful removal of a cerebral tumour or other cortical disease. In them, the site of the lesion was known with more or less accuracy, and we have included solely those in whom the disease was stationary, examined months or years after operation. We have also observed the effects produced upon sensation by acute destructive lesions and advancing cerebral tumours; in this way we have studied the effects of the condition called by von Monakow "diaschisis." Finally, we have employed the same methods to investigate many instances of disease in the neighbourhood of the internal capsule and deeper parts of the brain.

CHAPTER I

THE GROUPING OF AFFERENT IMPULSES IN THE SPINAL CORD AND BRAIN-STEM

§ 1.—The Spinal Cord

It is a matter of universal belief that man has been evolved from the lower animals; and yet, when we deal with sensation and sensory processes, we speak as if he were created with peripheral end-organs, each capable of reacting to one of the sensory qualities of human experience. The impulses starting in these end-organs are supposed to pass unaltered to the brain, there to set up that peculiar and unknown change which underlies a specific sensation.

Spots were found on the skin sensitive to touch, to pain, to heat or to cold only. With the discovery of these highly developed end-organs, the doctrine of specific nerve-energy seemed to be proved in the strictest manner. All other forms of sensory appreciation were supposed to be produced by the psychical transformation of these primitive sensory elements, in association with an ill-defined faculty called the "muscle-sense." Recognition of the locality of a stimulus and the posture of the limbs were attributed to "judgment" and "association."

But alongside the systematic investigation by von Frey and others of the capabilities of these specific areas in the skin, the clinicians were discovering the importance of "muscular sensibility." Sherrington's demonstration of afferent fibres in muscles and tendons placed the existence of the "muscle-sense" beyond a doubt, and the use he made of these afferent impulses from deep structures, in his theory of the proprioceptive system, necessitated a complete exploration of the nature of deep sensibility.

By their experiment directed to this end, Rivers and Head showed that beneath the skin, independent of all "touch-" and "pain-spots," lies an afferent system capable of a wide range of functions. Pressure, that in ordinary life would be called a touch, can be appreciated and localised with considerable accuracy. Increase of pressure, especially on bones and tendons, can cause pain. Moreover, it is from the impulses of this deep afferent system that we gain our knowledge of the posture of the limbs and the power of recognising passive movements.

Evidently, therefore, the peripheral mechanism of sensation is less simple than was at first supposed. For there are two sets of end-organs that can respond to tactile stimuli, and two independent mechanisms for the initiation of pain. Further analysis showed that the peripheral apparatus in the skin, by which we become conscious of the nature of external stimuli, is highly complex. No one sensory quality is subserved by a single set of end-organs, but every specific sensation is the result of the combined activity of more than one group. This is exactly the result that might have been expected, when we bear in mind that the structure of man is the product of a long evolution.

But it is equally obvious, from an evolutionary standpoint, that these diverse impulses could not pass uncombined to the highest physiological level. Within the spinal cord, the opportunist grouping of the periphery gives place to an arrangement according to quality (Head and Thompson). All impulses capable of generating pain become grouped together in the same path, and can be disturbed simultaneously by an appropriate lesion of the spinal cord. In the same way, sensibility to heat or to cold may be lost independently of one another, showing that all the impulses upon which they are based have been sorted out into two functional groups, each of which passes by a separate system in the spinal cord.

The most remarkable condition revealed by an intramedullary lesion is the complete separation of the impulses underlying the appreciation of posture, the discrimination of two points and their correlated faculties from those of other sensory groups. All painful and thermal impulses, coming from the periphery, undergo regrouping after entering the spinal cord, and, whether they arise in the skin or in deeper structures, become arranged according to functional similarity. Then, after a longer or shorter course, they pass away to the opposite side of the spinal cord.[1]

This process of filtration leaves all the impulses associated with postural and spacial recognition to continue their course unaltered in the posterior columns; they are the survivors of peripheral groups broken up by the passing away of certain components into secondary afferent systems. At any point in the spinal cord, these columns transmit not only impulses from the periphery which are on their way, after a longer or shorter passage, to regrouping and transformation, but at the same time they form the path for impulses, arising both in the cutaneous and deep afferent systems, which undergo no regrouping until they reach the nuclei of the medulla oblongata.

Thus, a lesion confined to one half of the spinal cord, even at its highest segment, may interfere with the passage of sensory impulses, some of which are travelling in secondary paths, whilst others are still within the primary level of the nervous system. All impulses concerned with painful and thermal sensations from distant parts, disturbed by such a lesion, will be travelling in secondary paths and have come from the opposite half of the body; for,

[1] Tactile impulses seem to run in two paths: one in the same half of the spinal cord to that by which they entered, the other on the opposite side of the spinal cord (Petrén [90, 92], Head and Thompson [50]).

after regrouping, they have passed across the spinal cord. But those impulses underlying the appreciation of posture, the compass test, size, shape, form, weight, consistence and vibration are affected on the same half of the body as the lesion. They still remain in paths of the peripheral level and have undergone no regrouping.

In such a case the parts on the side opposed to the lesion may be insensitive to pain, heat and cold; but all the postural and spacial aspects of sensation are perfectly maintained. Yet, all power of recognising position, of estimating size, shape, form and weight, or of discriminating the two compass points, will be lost in the limbs which lie on the side of the lesion, although tactile sensibility and localisation of the spot stimulated may be perfectly preserved.

This remarkable arrangement enables us to analyse the nature of the peripheral impulses upon which depend our power of postural and spacial recognition. Obviously, even at the periphery, they must be independent of touch and pressure. The power to distinguish two points applied simultaneously and to recognise size and shape requires as a preliminary the existence of sensations of touch; but the patient may be deprived of all such powers of spacial recognition without any discoverable loss of tactile sensibility. In the same way our power to appreciate the position of a limb, or to estimate the weight of an object, is based upon impulses which, even at the periphery, exist apart from those of touch and pressure called into simultaneous being by the same external stimulus.

This long delay of the postural and spacial elements in reaching secondary paths enables them to give off afferent impulses into the spinal and cerebellar co-ordinating mechanisms, which lie in the same half of the spinal cord. The impulses which pass away in this direction are never destined to enter consciousness directly. They influence co-ordination, unconscious posture and muscular tone, and, although arising from the same afferent end-organs, they never become the basis of a sensation.

Finally, the last survivors of these impulses from the periphery become regrouped in the nuclei of the posterior columns and cross to the opposite half of the medulla oblongata in secondary paths. So they pass to the optic thalamus and thence to the cortex, to underlie those sensations upon which are based the recognition of posture and spacial discrimination.

The following case is an example of the effects produced by a lesion situated in one half of the spinal cord just below the point at which the postural and spacial impulses become regrouped in the nuclei of the posterior columns.

Case 1.—*Brown-Séquard paralysis.*

On the right—

Weakness of arm and leg.

Reflexes exaggerated; ankle clonus and extensor plantar reflex.

Loss of painful sensibility over right cheek (*Fig.* 156), *though touch, heat and cold were unaffected.*

On the body and limbs, tactile, painful and thermal sensibility were perfect ; but in the right arm and leg, posture, passive movements and vibration of a tuning fork could not be appreciated within normal limits, the compass test was defective, and he could not recognise size, shape, form, weight, or consistence of objects in the right hand. Localisation was not affected.

On the left—

Motion perfect.

Reflexes normal.

Loss of sensation to pain, heat and cold as in Fig. 156.

All other forms of sensibility, including localisation, perfectly preserved.

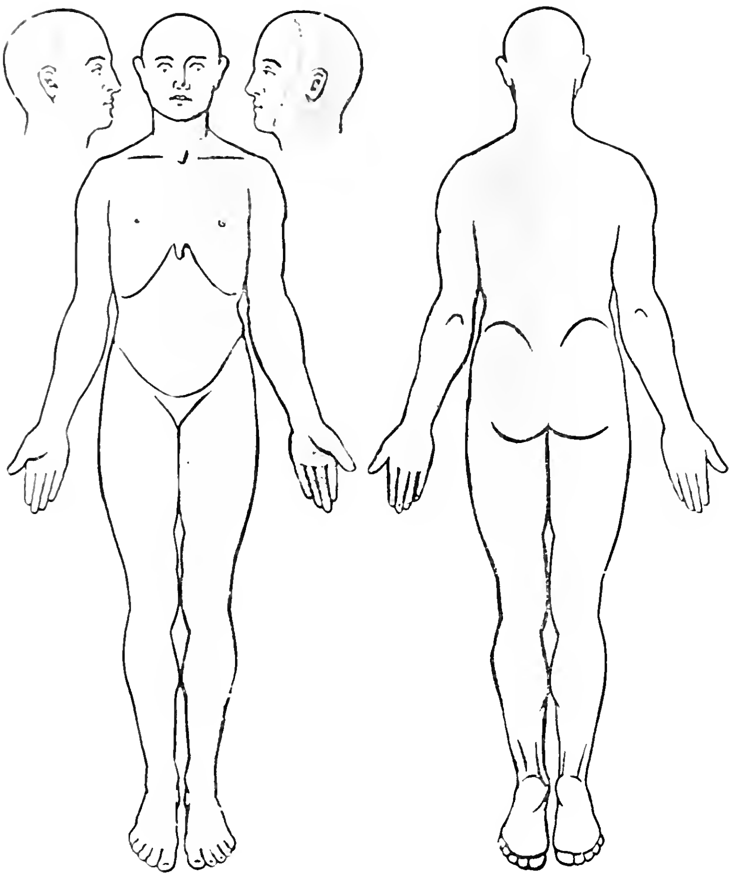

Fig. 156.

To show the loss of sensation in Case I. The shaded area on the right half of the face corresponds to the parts over which sensibility was diminished or lost to prick. Over the left half of the body the dark parts were insensitive to prick, heat and cold. Over the left arm and leg, pressures of 15 to 18 kg. on the pressure algometer produced no pain.

W. C.,[1] a man, aged 34, was in perfect health until he was thrown from his van in consequence of a collision on May 30, 1908. He was concussed and did not regain consciousness until three weeks after his accident, when he found he was unable to move his right arm and leg. Speech was in no way affected and movements of his face were never impaired. Slowly he regained

[1] We owe the opportunity of examining this man to the kindness of Dr. James Collier.

power over the right arm and leg, and about two months after the accident he was able to walk. From the first he knew he could not recognise the position of the right arm, but was unconscious of the loss of painful and thermal sensibility on the left half of the body.

When we first examined him nearly two years later (February, 1910), all movements of his right arm could be performed within a normal range, but they were distinctly weaker than those of the opposite side. The tone of the muscles of the right upper extremity was increased, but there were no organic contractures.

His gait showed a certain awkwardness, but he did not drag the right foot. All movements could be readily carried out, although his strength was slightly less in the right than in the left lower extremity. The tone of the muscles of the right leg was not increased.

All reflexes on the left half of the body were normal, but the arm-, knee- and ankle-jerks on the right side were much exaggerated and the plantar reflex gave an extensor response. Slight clonus was obtained at the right ankle.

Ocular movements and the reactions of the pupil were in no way affected, and the face, tongue, and palate moved equally on the two sides. But on the right cheek and in the occipital region sensation was disturbed (Fig. 156). Over the greater part of this area, the patient was insensitive to a prick, but the borders were not sharply defined, merging gradually into parts of normal sensibility. Over the occipital region 15 kg. of pressure, applied with the algometer, produced no pain, whereas on the left half of the skull he responded to 5 kg. Cotton wool was appreciated everywhere; but over the central parts of the area, on the right cheek and ear, the tickling sensation, easily evoked from the left half of the face, was absent. The patient recognised the touch of a hair of 21 grm. mm.^{2} within the affected area, and no difference could be discovered between the two halves of the face to measured tactile stimuli. Sensibility to heat and cold was not disturbed, the compass points were readily distinguished at 2·5 cm., and localisation was perfect.

This loss of sensation on the right half of the head formed the local manifestation of a lesion situated in the right half of the spinal cord. As in most Brown-Séquard paralyses, the remote effects of this destruction appeared as a loss of sensation to painful and thermal stimuli on the opposite (left) half of the body. This loss was absolute to every form of pain and to all degrees of temperature over the area shown in Fig. 156. Not only was the patient insensitive to prick, but pressures of from 15 to 18 kg. produced no pain over the left arm or leg. All forms of tactile sensibility were, however, completely preserved. The compass points could be accurately distinguished and localisation was perfect. The position of all portions of the left arm and leg was recognised with ease, and passive movements were appreciated within normal limits.

When we turn to the condition of the right half of the body, that is, to the parts on the side of the lesion, we find almost the exact converse. All sensibility to touch, pain and temperature was perfectly preserved, but the patient was unable to recognise the posture of his right arm and leg, and could neither name nor imitate correctly the position into which they had been placed. Movements made passively were not recognised, until they exceeded from five to eight times the normal range.

Thus, for instance, movements of the index finger on the right and left hands, which could be appreciated subtended the following angles measured in degrees :—

Left	Flexion		2½		2	2½				2	2½			
	Extension	3		2½			2½		2½			2½		
Right	Flexion		15		15	17x		15x						22x
	Extension	17		17					30x		27		28	

But, although movements of the right index were appreciated, when the finger had been moved through the number of degrees on this formula, the direction of movement was wrongly given in those cases where an x is added to the figure.

The vibrations of a tuning-fork were appreciated badly or not at all over the right arm and leg, in spite of the complete integrity of tactile and pressure sensibility, and the compass points were not perfectly distinguished on the right palm, even at a distance of 6 cm. from one another. On the left palm a perfect reading was obtained at 2 cm.

All power of recognising size, shape and form in three dimensions was absent in the right hand, in spite of the existence of perfect tactile sensibility. The power of estimating weight and the relative amount of pressure exerted by two otherwise similar objects was lost on the right hand. Moreover, the patient was unable to recognise the difference between even the hardest and the softest of the objects used to test consistence, when they were compressed between the fingers and thumb of his right hand.

And yet, in spite of this sensory disturbance localisation was perfect in the limbs of the right half of the body, and the two points of the compasses, if applied to the skin one after the other, were perfectly appreciated on the two hands.

This case is an excellent illustration of the principles laid down in this section, and the retention of muscular power in the right hand enabled us to test the faculty of recognising size, shape, form in three dimensions, weight and consistence with an accuracy otherwise impossible.

In conclusion, we believe that at the extreme upper end of the spinal cord, just below the formation of the posterior column nuclei, afferent impulses pass upwards in three main divisions :—

(1) The impulses underlying sensations of pain, of heat and of cold are travelling in secondary paths, in the opposite half of the spinal cord from that by which they entered.

(2) Those impulses, upon which depend postural recognition and spacial discrimination still remain uncrossed in the posterior column. They consist of one group, arising in the deep afferent system, upon which depends our recognition of posture, passive movement, weight, consistence and vibration. A second group arises in the end-organs of the skin and these impulses underlie the discrimination of two points applied simultaneously, and the allied appreciation of size, shape and form in three dimensions.

(3) Contact sensibility evoked by touch and by pressure may remain entirely undisturbed. Apparently it depends upon impulses which run in a double path and it is therefore unaffected by a purely unilateral lesion (Rothmann [98], Petrén [90], Head and Thompson [50]). This group, formed by the union of tactile impulses within the cord, carries with it the impulses which underlie the power of recognising with accuracy the situation of the stimulated spot, and localisation therefore remains unaffected.

§ 2.—The Brain-stem

The larger number of afferent impulses traverse the spinal cord, grouped, according to their sensory qualities, in paths that can be isolated by disease. This enables us to analyse the nature of the groups formed, either by specific selection at the first synaptic junction, or by gradual filtration away into secondary tracts, of impulses arising originally in the same peripheral system. But, in their further passage through the brain-stem to the optic thalamus, the impulses run in paths which are anatomically more closely associated. This makes any analysis of the grouping of afferent impulses in this region unusually difficult.

Impulses underlying sensations of pain, heat and cold seem alone to run unaltered between the upper end of the spinal cord and the optic thalamus.[1] They receive the accession of the regrouped secondary impulses from the face, which cross to join the specific paths for pain, for heat or for cold. These paths are so situated that they can be interrupted without disturbance of any other form of sensation on the body, and the analgesia and thermo-anæsthesia so produced resemble in quality the loss to pain, heat and cold caused by a lesion of the spinal cord.

Thus, when a lesion of the bulb interferes with sensations of pain, not only may the skin be insensitive to prick, but the readings of the pressure algometer may be raised on the analgesic side. In the same way, the affected area on the body may be insensitive to all degrees of heat and to all stimuli capable of evoking normally a sensation of cold.

It is, however, important to remember that although the uncomfortable sensation produced by excessive pressure is greatly diminished, a lesion in this situation does not usually abolish completely all painful pressure (Case 2, Case 3). Thus it would seem that the grosser forms of pain and discomfort may possibly find their way by another path, if the usual one is closed; whereas, an equivalent lesion in the spinal cord blocks all painful impulses whatever their origin.

Not only can these three forms of sensibility be affected together, but any one of them may escape or be affected alone. Thus von Monakow [82] described loss of sensation to heat and cold without analgesia, and in the case recorded by Mann [75] and later by Kutner and Kramer [63] sensibility was lost to pain and to heat, whilst that to cold was unaffected (cf. also Wallenberg [130] and Marburg [76]).

The following case shows that, with a lesion of the bulb, the opposite half of the body may become analgesic and yet the threshold values of sensibility to heat and cold may be equal on the two sides.

Case 2.—October, 1906, sudden onset of pain in the right lower jaw. Since June, 1907, he has noticed loss of sensation on the left half of the body and right half of the face. First seen by us June, 1909, and since then his condition has not changed materially.

Motor power and reflexes unaffected.

Diplopia in all directions. Pupils unaffected. Optic neuritis in both eyes. Hearing diminished in right ear.

Sensation on the face.—Loss to prick with no loss to pressure-pain over the area in Fig. 157. No

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[1] This does not necessarily mean that the impulses are carried by uninterrupted fibres. It has been suggested by Long [70], Cajal [21], Kohnstamm [61], that the nuclei of the formatio reticularis are intercalated in the course of the afferent conduction tracts. Such anatomical relay would not interfere with the above physiological conclusions, as it does not necessarily imply any regrouping of sensory impulses.

other change in sensation to measured stimuli, but touch seemed "less vivid," heat "hotter," and cold "less cold," over right than left half of the face.

Sensation on the body. The left half, except the perineum and scrotum, was insensible to prick (Fig. 157). Pressure-pain was also diminished. Otherwise sensation was unaffected.

F. C. F., aged 34. (This patient was first seen by us when he was in the National Hospital, under the care of Sir William Gowers, in June, 1909.) He was a teetotaler, a married man, and denied all venereal disease.

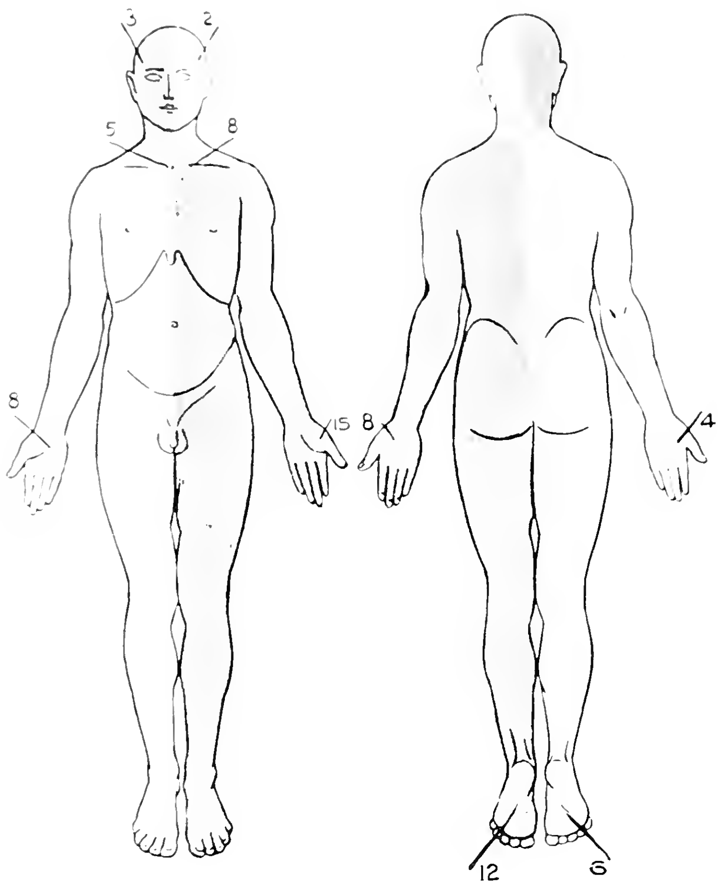

FIG. 157.

To show the loss of sensation in Case 2. The right half of the face was analgesic to prick, but pressure-pain was not lost. The left half of the body was insensitive to prick, and the readings of the pressure algometer were uniformly higher than over similar parts on the normal side.

In October, 1906, pain came on suddenly in the right lower jaw as he was sitting in the barber's chair. He became pale and faint and "felt queer" for the rest of the day. The pain continued unaltered until May, 1907, when it grew more severe and reached its height in June of the same year. In the following nine months it gradually diminished, but returned in April, 1909.

A sharp, stabbing headache in the occipital region first appeared in September, 1907. This has slowly increased in severity. Vomiting began in July, 1907, and has continued on and off ever since.

He has noticed some disturbance of sensation on the left half of the body and right half of the face since June, 1907.

He has not been definitely giddy, but occasionally sways when walking on the pavement.

In June, 1909, motion was not affected,[1] and the reflexes did not differ materially on the two halves of the body.

He complained of diplopia in all directions, greater on looking upwards, when the images were crossed; with movements to the right or to the left they were uncrossed. The pupils reacted well and were central in position. Movements of his jaw, face, palate and tongue were carried out perfectly on both sides.

Smell was not affected, but the ammonia reflex was almost completely abolished from the right nostril. Taste was lost on the right half of the outstretched tongue. Hearing was slightly diminished in the right ear compared with the left; the tuning fork placed on the forehead was not heard on the right side. The fields of vision were normal and there was no colour loss; but optic neuritis was visible in both eyes, more evident in the right. The discs were pale and the cup filled up.

Sensation on the face.—He complained of occasional spasms of pain in the right half of the face, closely resembling those of tic douloureux. No difference between the sensibility of the two sides could be discovered with cotton wool, von Frey's hairs, Graham-Brown's æsthesiometer, or to the compass test and vibration, but he complained that all forms of touch were "less vivid" over the right than over the left half.

The whole of the area shown on Fig. 157, together with the right half of the tongue, was, however, insensitive to prick, though the algometer gave approximately equal readings on the two sides.

Both heat and cold were appreciated on the two halves of the face, but although the thresholds were the same, all heat seemed hotter over the affected half, while cold stimuli seemed colder over the normal parts of the face.

Sensation on the body.—Localisation, the compass records, the appreciation of size, shape, form and weight, were equally good on the two halves of the body.

Cotton wool was recognised everywhere, and the same measured tactile stimulus was required to produce a sensation of contact on the two halves of the body. There was no difference in the threshold for the appreciation of roughness and the length of time during which vibration could be recognised; but both sensations of touch and vibration were more vivid on the normal than on the left half of the body.

Heat and cold could be appreciated everywhere, but all degrees of warmth seemed hotter over the affected half of the body (left). Any cold stimulus, on the other hand, seemed colder over normal parts.

The whole of the area (Fig. 157) shown on the left half of the body was insensitive to prick; but it will be seen that a small area in the left perineum and the greater part of the penis and scrotum of the same side responded to the prick of a pin. The left testicle was, however, entirely insensitive to pressure, whereas the normally unpleasant sensation could be easily evoked from that of the right side. The pressure of the algometer, necessary to evoke pain, was considerably higher on the left than on the right half of the body (Fig. 157), especially on the palms and on the soles.

The position of the limbs was recognised as well on the one side as on the other, and passive movements of all the joints were perfectly appreciated. And yet in spite of perfect recognition of posture and movement, there was distinct inco-ordination of the left hand. He knew that the movement was not absolutely correct; thus, if asked to touch a spot on a sheet of paper with his eyes closed, the left index finger deviated to a much greater extent than the right. But so sure was he of the position of the affected hand that he could place the normal forefinger accurately upon the wandering left index without opening his eyes.

Thus this case showed (1) a local lesion affecting the sensation of the right half of the face and neck; (2) a remote disturbance of sensibility to pain over

[1] For co-ordination *vide infra*.

the left half of the body with considerable raising of the algometer readings over the analgesic area; (3) with heat and cold the same threshold was obtained on the two halves of the body.

All recent work has shown that the paths for the transmission of the impulses for pain, heat and cold run up in the neighbourhood of the nucleus of the trigeminal nerve. This close local association is particularly well shown by cases of occlusion of the posterior inferior cerebellar artery (Wallenberg [129], Breuer and Marburg [11], Spiller [117]).

In addition to these well-known facts, the following instance of this condition also shows that impulses underlying the appreciation of posture and passive movement have become separated from those concerned with spacial discrimination. The compass test gave identical results on the two halves of the body, and size, shape and form in three dimensions could be appreciated on both hands. And yet the amount of passive movement necessary to evoke a sensation was three to four times greater in the affected fingers. Evidently, a change in grouping has taken place at the posterior column nuclei and the impulses for spacial discrimination now tend to run apart from those of postural recognition.

Case 3. An instance of "occlusion of the posterior inferior cerebellar artery." Sudden onset December 25, 1908. Seen by us first in July, 1909.

Horizontal and rotatory nystagmus, but diplopia had passed off. Left pupil did not dilate fully to shade. Left palpebral fissure smaller than right. Movement of left half of the palate defective, but vocal cords and tongue moved well.

Gait unsteady; he tended to deviate to the left, but fell to the right when his eyes were closed. No paralysis.

Reflexes normal.

Sensation of the face.—Left half insensitive to prick, but sensitive to pressure-pain (Fig. 158). Tactile and thermal thresholds were equal and normal on the two halves of the face, but all temperatures seemed "duller" on the left half.

Sensation on the body.—Loss to prick, to heat and to cold over the right half of the body, right arm and right leg (Fig. 158). Sensibility to pressure-pain diminished over this area but not lost.

Diminished power of recognising posture and passive movement in right arm and right leg.

All other forms of sensation normal.

W. S., a man, aged 50, suddenly fell upon the floor just as he had finished breakfast on Christmas morning, 1908. He was not unconscious but intensely giddy. On trying to rise he fell to the right, helpless and unable to stand. Vomiting came on at once and was almost continuous for thirty-six hours. He was put to bed, where he remained for eight weeks, compelled to lie almost constantly on his left side.

From the beginning, he complained that the right half of the body "felt cold and numb," although he could appreciate "the slightest touch" and knew where his limbs lay in bed. He could always move the right arm freely, but was unable to use it for taking food; he said: "I could hold a spoon in my right hand, but I could not be certain of putting it properly into my mouth." In the same way he found some difficulty in directing the movements of the right leg.

When he left his bed, at the end of eight weeks, he staggered as if drunk and always felt as if he was falling towards the right. But, on the other hand, when sitting in a chair he frequently seemed to be drawn over to the left. This giddiness disappeared completely in seven months, and he recovered sufficient control over the right arm to return to work in July, 1909.

Immediately after the stroke he saw double; the two images appeared side by side, and he believed that the one to the left was the false one. For a time the left upper eyelid "drooped," and he found that the left cheek did not sweat and was colder when he touched it than the right. From the beginning of his attack, he noticed that the left half of the face seemed numb, and this has persisted unchanged up to the present time. All food appeared to be very cold on the left half of the mouth and he lost taste on the same half of the tongue. At first he found considerable difficulty in swallowing; solid food seemed to stick in his throat. His voice became

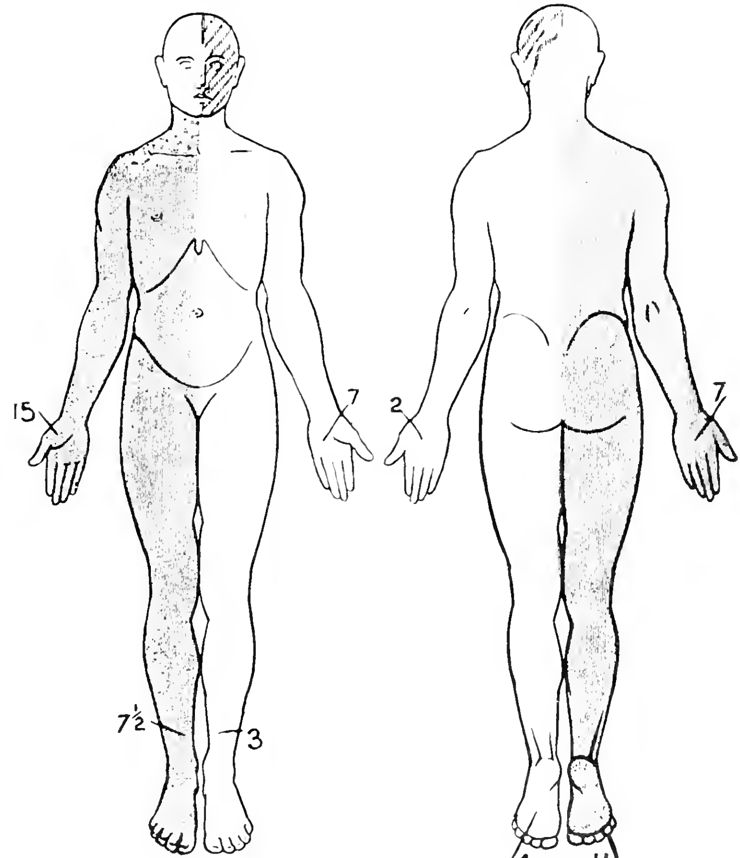

FIG. 158.

To show the loss of sensation in Case 3. The left half of the face was insensitive to prick, but sensibility to pressure-pain was unaltered. Over the darkened area on the right half of the body sensations of heat, cold and pricking was abolished. Pressure-pain, though diminished, was not lost.

hoarse at the time of the stroke. He was never deaf, but since the attack has suffered from tinnitus in the left ear, "like a cricket whistling."

We saw him first in July, 1909, owing to the kindness of Dr. Golla. He was an intelligent, healthy-looking man with somewhat rigid arteries. The left eye was a little more sunken and the palpebral fissure somewhat smaller than on the right side. He no longer saw double, and all ocular movements were normal in range; but, on full lateral movements, slight horizontal and rotatory nystagmus was visible, the rotation having an outward and downward direction. The left pupil was slightly smaller than the right; it reacted well to light and on accommodation, but did not dilate so rapidly and so fully as the right when shaded, or when the skin of the neck and cheek was stimulated.

The muscles of the jaw acted normally, and volitional movements of the face were equal on the two sides, but, when talking or smiling, the left half moved more than the right.

The left half of the palate was less active and the uvula was drawn definitely over to the right. The vocal cords moved well and all difficulty in swallowing had passed away. Movements of the tongue were perfect.

Taste and smell were not affected when we first saw him, but the ammonia reflex from the left nostril was certainly greatly diminished. Hearing and vision were normal.

He could walk without help, although he was evidently careful and afraid of stumbling; no difference could be discovered between the lower extremities, but he tended to keep the legs abducted and to turn the toes a little outwards in walking. Moreover, when walking quickly he deviated to the left and constantly corrected himself voluntarily. But, as soon as his eyes were closed and he was told to walk forwards, he fell to the right in consequence of the defective sense of position and movement in the right leg.

The strength of the movements and the tone of the muscles were almost equal in both arms and no difference could be discovered between the two lower extremities. The movements of the left arm were slightly inco-ordinate, whether the eyes were open or closed. Rapidly repeated movements were equally well carried out with both upper extremities.

There was no material difference between the reflexes on the two halves of the body and both plantars gave a flexor response.

Sensation on the face.—Both halves of the face responded equally well to cotton wool and von Frey's hairs, but the left forehead, temple and cheek were insensitive to prick (Fig. 158); this area merged gradually behind into parts of normal sensibility. Over the temples and malar bones the pressure algometer gave the same readings on both sides ($1\frac{1}{2}$ and 2 kg.). The left cornea was insensitive to a hair of 23 grm./mm.^{2} and the left conjunctiva did not respond to 100 grm./mm.,^{2} whereas 8 grm./mm.^{2} produced a quick reflex and a sensation of sharpness on the right cornea. From the normal conjunctiva 23 grm./mm.^{2} immediately evoked an uncomfortable sensation. The threshold for the appreciation of heat and of cold was the same on the two sides, but the patient complained that all temperatures produced a "duller" sensation on the left half of the face. Both sides responded equally well to vibration and to the compass test.

Sensation on the body.—All forms of tactile sensibility were perfectly preserved, vibration was appreciated and localisation was perfect on both sides. The compass records were equally good from both hands and from the soles of both feet. Weight, size, shape and form were accurately recognised.

Sensibility to prick began to be defective at the line marked on Fig. 158. The loss of sensation gradually deepened until on the right arm, trunk and leg it was complete. Over the whole of this half of the body, the pressure necessary to cause pain was uniformly higher than over similar parts on the other side, as shown by the numbers on Fig. 158. Both testicles were sensitive, but the sensation was more uncomfortable from the left than from the right.

Over the same area on the right half of the body he was insensitive to all degrees of temperature and, although the borders of this loss of sensation corresponded to those of the analgesia, they were more definite.

The power of recognising posture was also certainly somewhat diminished in both the right arm and the right leg. The existence of this loss was confirmed by measurement of the smallest perceptible movement. Thus extension and flexion of the index finger of the left hand were recognised with a movement of just over 2°; whereas on the right hand the average flexion necessary for recognition was 7°, whilst extension of over 8° was required to evoke a sensation of movement.

This typical case of "occlusion of the posterior inferior cerebellar artery" showed :—

(1) A sensory disturbance over the left half of the face representing the local lesion.

(2) Analgesia, with raising of the algometer readings, and complete loss of sensation to heat and to cold over the right half of the body.

(3) Diminished recognition of posture and passive movement in the right arm and leg, but all spacial discrimination was perfect (compass test, appreciation of size, shape, form).

(4) Slight cerebellar inco-ordination in the left arm and leg, which was not increased by closing the eyes.

When all afferent impulses from the face have undergone regrouping and passed, in secondary tracts, to the opposite half of the nervous system, the various sensory paths are gathered closely together in preparation for their ending in the optic thalamus. Every sensory path now lies within the opposite half to that by which the impulses entered the central nervous system.

From the analytical aspect, these mid-brain lesions can give little information as to the grouping of the elements underlying sensation. But occasionally, by watching the gradual disappearance of one form after another, a hint may be gained with regard to the independence or association of any two groups of impulses.

Moreover, the tendency we have already noticed for the grosser forms of pain or discomfort to find a way to consciousness, although the more specific forms of pain, heat or cold are blocked, becomes more evident the closer the lesion lies to the optic thalamus. And yet it is probable that the impulses which evoke these uncomfortable sensations are not conducted by a bilateral path.

The following case, which we owe to the kindness of the late Dr. Beevor, illustrates the concentration of paths just before their entry into the optic thalamus. Incidentally it seems to show that the power of localising the spot touched may be greatly affected at this level with but little loss of tactile sensibility.

Case 4.—Tumour of the mid-brain and optic thalamus verified by post-mortem examination.

Five months before death the following signs were present:—

Loss of power in the left arm and leg, with profound ataxy. Extensor response from left sole with normal response from right.

Athetoid movements of left hand, together with a fine tremor when the left arm was extended.

Eye-movements greatly restricted; nystagmus in all directions; fixed pupils.

The loss of sensation was confined to the left of the middle line. Sensations of prick were diminished over left arm and leg, but lost on the left palm only. Tactile sensibility was very little, if at all, affected during the time he was under observation by us.

Localisation lost over left upper extremity. Compass test gravely affected over left arm and leg. Appreciation of size and weight abolished in left hand.

T. B., aged 24, was admitted to the National Hospital on October 8, 1908, under the care of the late Dr. Beevor, at the request of Dr. Judson Bury. After his death on July 24, 1909, his brain was described by Dr. Judson Bury [20].

In 1905 he began to see double and at the same time the lid of the right eye drooped. He recovered entirely, but in September, 1907, his eyelid drooped again and he became steadily worse. The left leg became weak about May, 1908, and in August involuntary movement began in the left arm. About the same time he noticed deafness in the left ear.

The following account of his condition was compiled from notes made by one of us between December, 1908, and the end of February, 1909.

Speech was not affected and he did not suffer from headache or vomiting. Neither pupil reacted to light or accommodation, and nystagmus was present with every movement of the eyes that could still be carried out. The right eye could be moved outwards but in no other direction; in the left eye movement inwards and outwards was still possible.

Vision in the right eye was $\frac{6}{18}$, in the left $\frac{6}{6}$; the fields were not diminished and both fundi were normal. Hearing was not materially affected either to aerial or bone conduction. Taste and smell were normal.

Movements of the face, jaws, tongue and palate were perfectly executed.

The arm-jerks were normal, but the right knee-jerk was brisker than the left; ankle clonus could not be obtained on either side. The left plantar reflex gave an extensor response, whilst that from the right foot was definitely flexor.

All movements of the left arm and leg were less powerful than those of the right, but there was no paralysis and no increase of tone. Both left arm and left leg were profoundly ataxic and he could not stand on the left leg alone even with his eyes open.

If his eyes were closed or when his attention was distracted from the limb, the fingers of the left hand made characteristic athetoid movements, irregular slow extensions and flexions at the phalangeal and metacarpophalangeal joints. When the arm was extended a fine tremor was also present in the left hand.

Condition of sensation.—The power of recognising posture and passive movements of the left leg and arm was lost; he could not even find the left elbow with his normal hand. Told to open the fingers of his left hand when his eyes were closed, he made a series of irregular movements which partly extended the phalanges but flexed the metacarpophalangeal joints. The order to flex or to extend the fingers was followed by movements of this kind which led to no permanent alteration in posture.

Directly he was allowed to open his eyes, all movements of the fingers were carried out with ease, and, so long as he looked at the hand, posture was maintained to command. Vibration was equally appreciated everywhere.

During the earlier period of our examination, he certainly appreciated the contacts of a test hair of 21 grm. mm.^{2} all over the left upper extremity and on the left foot, showing that tactile sensibility could not have been gravely affected. But when cotton wool or a measured hair were moved gradually from the right to the left half of the body, he said the stimulus became "lighter" to the abnormal side of the middle line.

Tactile localisation was grossly affected over the whole left upper extremity, but on the lower extremity he indicated and named correctly the spot that had been stimulated. Thus, the disturbance of localisation was here out of proportion to the diminution of tactile sensibility.

Spacial discrimination (compass test) was gravely affected on the left upper and lower extremities; he was unable to recognise the two points when separated by 15 cm. on the left forearm and 20 cm. on the left half of the abdomen. On the normal arm 5 cm. and on the right half of the abdomen 8 cm. gave perfect readings.

All power of recognising size was lost in the left hand, and he could not even discriminate the head from the point of a pin.

He could not recognise the difference in weight between 5 and 200 grm. in the left palm.

Sensibility to prick was diminished over the left arm and the left leg, but was nowhere absent except in the left palm. All the algometer readings were a little higher on the left than on the right half of the body, especially on the left palm and sole.

Sensibility to heat was absent on the left half of the body and face, but cold could be appreciated. The left leg, however, was insensitive to all degrees of heat and cold. Thus on the upper extremity temperatures above 45° C. evoked a sensation of paradox-cold, whilst on the leg they caused discomfort only.

Post-mortem five months after these notes were made.—The brain was examined by Dr. Judson Bury, who gave the following account of the condition [20]: "After being hardened in formalin the brain was cut into transverse vertical sections, when it was seen that the tumour occupied the position of the right optic thalamus and the corpora quadrigemina. The whole of the optic thalamus, with the exception of a thin layer on the outer side, was replaced by new growth which extended beneath the floor of the ventricle into the left optic thalamus for a short distance. The right internal capsule appeared to be normal, but no trace of the caudate nucleus could be discovered. The corpora quadrigemina appeared to be entirely replaced by growth; the crura and pons were also invaded. The right crus was considerably involved, so that a layer of the crusta only $\frac{1}{8}$ in. in thickness separated the growth from the basal surface of the brain. The anterior portion of the pons was invaded for about $\frac{1}{4}$ in. in depth on the right side and $\frac{1}{8}$ in. on the left side." The tumour was a large round-celled sarcoma.

Here, then, is a case where a malignant growth affected the corpora quadrigemina and that portion of the mid-brain at a point where the paths for sensory impulses are converging to end in the thalamus. The clinical signs indicate that this lesion started in the mid-brain, although at the time of death the right optic thalamus was also destroyed.

During the course of the disease this case showed that :—

In this situation the impulses underlying postural recognition, spacial discrimination and localisation (spot-finding) may be dissociated from those concerned with touch and pain. At one stage of his illness the patient was therefore able to appreciate contact with von Frey's hairs and cotton wool, but could not localise the spot touched. Nor could he tell the head from the point of a pin, or the relative size and weight of objects placed in his hand.

To sum up the conclusions of this section, we can say that the brain-stem between the nuclei of the posterior columns and the final termination of all sensory paths in the optic thalamus is the seat of the following changes :—

(1) The impulses for pain, heat and cold continue to run up in separate secondary paths on the opposite side of the nervous system to that by which they entered. They receive accessions from the regrouped afferent impulses from the nerves of the head and upper part of the neck.

Although these paths are frequently affected together, they are independent of one another, and any one of the three qualities of sensation may be dissociated from the others by disease.

(2) Lesions of the spinal cord tend to diminish simultaneously all forms of painful sensibility, but with disease of the brain-stem the gross forms of pain and discomfort may pass to consciousness, although the skin is analgesic. This applies not only to painful pressure, but to the discomfort produced by excessive heat.

(3) The impulses concerned with postural recognition part company with those for spacial discrimination at the posterior column nuclei. Up to this point, they have travelled together in the same column of the spinal cord, but as soon as they reach their first synaptic junction they separate. Above

the point where they enter secondary paths, the power of recognising posture and passive movement can be affected independently of the discrimination of two points and the appreciation of size, shape and form in three dimensions.

(4) It would seem as if those elements which underlie the power of localising the spot touched or pricked become separated off from their associated tactile impulses before they have actually come to an end in the optic thalamus. The long connection of localisation with the integrity of tactile sensibility is here broken for the first time.

All these changes are preparatory to the great regrouping which takes place in the optic thalamus, and forms the subject of the following chapter.

CHAPTER II

SENSORY DISTURBANCES ASSOCIATED WITH CERTAIN LESIONS OF THE OPTIC THALAMUS

§ 1.—Introduction

Throughout this work it has been our aim to discover the nature of the abnormal sensations evoked by disturbances at different levels of the nervous system. So far our task has been a comparatively easy one on account of the certainty with which the level of the lesion could be determined even in life.

We know that all afferent fibres passing upwards from the mid-brain end in the optic thalamus. Here lie the synaptic junctions of those paths by which impulses are carried onwards to the cortex; no path passes upwards without undergoing a relay in some part of this organ. We shall now attempt to discover the changes in the grouping of afferent impulses which occur after they have terminated in the optic thalamus, and the part played by this organ in sensation.

It is obvious that, if all afferent impulses undergo a relay in the optic thalamus, a lesion at a point where they enter this organ may interrupt them before they have undergone regrouping: they may be cut off before they have reached the thalamic junction, and the loss of sensation would then correspond to that produced by a lesion of the mid-brain, although the disease might lie in the optic thalamus. On the other hand, sensory impulses may reach the optic thalamus undisturbed and undergo characteristic changes in grouping; but the fibres which conduct them from the thalamus to the cortex may be interrupted by the lesion. Finally, since lesions of the optic thalamus are usually of vascular origin and tend to disturb anatomical areas rather than functional paths, they not infrequently interfere both with the impulses which enter the thalamus and with those which pass away from this organ to the cortex.

Our business is to determine the nature of the sensory changes produced by interruption of sensory impulses at various points in their course, and for this purpose we must be able to recognise that a lesion is situated within the optic thalamus. This we can do, largely owing to the work of Dejerine and his pupils; for he pointed out first with Egger [24] and later with Roussy [25] that lesions, which involve the optic thalamus, are often characterised by a group of symptoms of which pain in the affected half of the body and other sensory disturbances form an integral part. These clinical symptoms and signs have been further elaborated by Roussy [99] and have been erected by him into a "syndrome thalamique." He has shown that a lesion of the optic thalamus may produce the following characteristic changes :—

(1) A persistent loss of superficial sensation of one half of the body and face. This loss to touch, pain and temperature is more or less definite, but the loss of "deep" sensibility is always more pronounced.

(2) Slight hemiataxy and a more or less complete astereognosis.

(3) Acute pains on the same side, persistent, paroxysmal, often intolerable, and yielding to no analgesic treatment.

(4) Slight hemiplegia which produces no contracture and rapidly passes away.

(5) Choreic and athetotic movements in the limbs of the affected side.

He pointed out that the sensory loss and the pains are alone due to the lesion of the optic thalamus, whilst the other symptoms are produced by destruction of surrounding parts.

Roussy has now established the anatomical significance of this "syndrome thalamique" by five post-mortem examinations. Others have been reported which show the truth of Dejerine's original generalisation (Long [71], Winkler and van Londen [135]).

The following case exactly fits into Roussy's category :—

Case 5.—Mrs. C. H., a woman, aged 51, was suddenly seized with pain on May 28, 1908, which spread from the upper part of the chest over the left arm. Twenty minutes later the arm became numb. She then lost consciousness for a few minutes, and, when she came to herself, found she could not move the left arm and leg.

The hemiplegia rapidly passed away, and is now represented solely by the exaggerated reflexes on the left half of the body. There is a tendency to ankle clonus in the left foot, and the plantar reflex is of the extensor type. Both the left arm and the left leg are gravely ataxic, and curious spontaneous movements are of constant occurrence in the left arm. They are particularly liable to be started or aggravated by any stimulus which evokes the unpleasant sensation and then continue apart from further excitation.

Ever since this "stroke," she has suffered from pains in the left half of the body, and an uncomfortable sensation as if something were crawling under her skin. These pains are intense in the hip, the loin and under the left shoulder. They are said "to pump up and down the side" and the left arm and leg "feel as if they were bursting." Whenever there was cause for visceral discomfort, such as the passage of a constipated motion, these pains became particularly severe, and the heart is said to "throb" and the stomach to "work" painfully, but on the left side only.

Sensibility to light touch and to temperature is diminished, but not completely lost over the left half of the body. She is totally unable to distinguish the two points of the compasses when separated to many times the normal distance, and localisation of both tactile and painful stimuli is gravely defective. Discrimination of shape, weight, and consistence is impossible and she cannot appreciate the nature or use of objects placed in her left hand. The power of recognising relative size is affected, but it is possible to obtain a difference-threshold even on the affected side.

Painful or disagreeable stimuli, such as the prick of a pin, painful pressure and the extremes of heat and cold, all produce more discomfort on the left (affected) than on the right half of the body, and are liable to increase the permanent pains and tingling, of which she so greatly complains. And yet the strength of the prick necessary to produce pain, measured with the algesimeter, is the same on the two sides and the readings of the pressure algometer differ little over normal and affected parts.

The recognition of posture and of passive movement is gravely affected in the left arm and left leg, and active movements of both limbs are ataxic.

Here, then, we have an instance which exactly corresponds to Roussy's description of the "syndrome thalamique," for not only were certain qualities of sensation definitely diminished, but spontaneous and intractable pains were present on the affected half of the body.

In the following case, where the site of the lesion was verified by autopsy (No. 6), the loss of sensation was extreme, but the patient suffered from the same intense pains.

Case 6.—A man, aged 49, was suddenly seized with right hemiplegia six months before he came under observation. When he was first seen there was little paresis, and the reflexes, though brisk, were not abnormal. Speech was unaffected. He complained, however, of severe aching cramp over the whole right half of the body, of pain and soreness in the right arm and a crushed feeling in the right foot.

Sensibility both to light touch and to pressure was abolished, and he could not recognise posture or passive movement on the right half of the body; all appreciation of weight was lost in the right upper extremity. He failed to recognise all degrees of temperature, but ice and water at 60° C. produced intense discomfort, much greater on the affected than on the normal side.

A stronger prick and greater pressure of the algometer were required to cause pain on the affected parts, but, when once evoked, the pain was much less bearable and produced a stronger reaction.

The only lesion, discovered at the autopsy, to which these symptoms could have been due was a softening of the lateral zone of the optic thalamus.[1]

We have observed twenty-four more or less similar cases, with sufficient symptoms and signs to justify us in diagnosing a lesion in the optic thalamus such as Roussy has described. In some the loss of sensation was less than that in Case 5 and in others it was even more profound than in Case 6.

The loss of sensation differs in no way from that produced by interference with sensory impulses, either as they enter the optic thalamus or as they pass to the cortex by way of the internal capsule. But to these familiar defects another factor may be added when the lesion destroys certain parts of the optic thalamus. This fresh factor, which alone can be attributed to the disturbed activity of this organ, is a tendency to react excessively to unpleasant stimuli. The prick of a pin, painful pressure, excessive heat or cold, all produce more distress than on the normal half of the body, and this is the essential feature in all the cases with which we shall deal in this chapter. There are other cases, where the optic thalamus is destroyed, in which the spontaneous pains and the characteristic over-response are absent; but with these we are not concerned at present.

[1] For a fuller account of this case see Holmes & Head, *Brain*, 1911–12, vol. xxxiv, p. 255.

§ 2.—The Excessive Response to Affective Stimuli, and the Behaviour in States of Emotion, of the Abnormal Half of the Body

(A) *The Response to Unpleasant Stimuli.*

(*a*) *Prick.*

We have cited Mrs. H. (Case 5) as a characteristic instance of the "syndrome thalamique" described by Roussy, and we shall now proceed to investigate her behaviour to measured painful stimuli.

If a pin is lightly dragged across the face or trunk from the right to the left half she exhibits intense discomfort when it passes the middle line; she not only calls out that it hurts her more, but her face becomes contorted with pain. But she insists that, although the stimulus is more painful, it is "less plain" and "less sharp" than over normal parts; the prick is less distinct but it hurts her more.

This "hyperalgesia," or over-reaction, would seem to point to a lowered threshold to the prick of a pin. But measured stimulation with the spring algesimeter shows that, if anything, the threshold is a little raised; she never responds with certainty over the abnormal (left) half of the body to a stimulus which can evoke a sensation of pricking on similar normal parts to the right of the middle line. And yet, if a measured stimulus of the same strength is applied to similar parts, more pain is evoked over the affected than over the normal half of the body; the same stimulus, provided it is sufficiently strong to cause pain, produces a more uncomfortable sensation on the abnormal side.

This remarkable over-response to prick was present in twenty out of twenty-two patients in whom the strength of the stimulus was carefully measured. But in no instance was the threshold lower on the affected half of the body; in thirteen cases it was identical on the two sides, and in nine a decidedly stronger stimulus was necessary to produce a sensation of prick, in spite of the greater discomfort experienced by the patient when pain had once been evoked.

(*b*) *Painful Pressure.*

Throughout our work we have attempted in every case to measure the amount of pressure which evoked pain. Cattell's algometer was applied to similar parts on the two halves of the body, and the point was registered at which the pressure became uncomfortable.

Now in the class of case with which we are concerned in this chapter, pressure is peculiarly liable to produce greater distress and an increased reaction on the affected side. Out of twenty-four patients every one responded more violently to painful pressure, and all complained that the same pressure, if it evoked discomfort, was more disagreeable on the abnormal than on the normal half of the body.

Moreover, this pain did not develop gradually out of the painless sensation of pressure as on the normal side, but seemed, over the affected parts, to develop explosively. Up to a certain point the patient remained unconcerned, but suddenly, as the pressure increased, he would cry out and withdraw the limb to which the instrument was applied; from the expression of his face, he had obviously been more hurt than by the same pressure on the equivalent normal part.

This increased reaction is frequently, though not necessarily, associated with a lowering of the threshold; the same pressure may be required on both sides to evoke pain, although the response on the affected half of the body is excessive (six cases). In three cases, including the patient who came to post-mortem examination, the threshold was actually higher on the side of the greater reaction; the following readings were obtained, amongst others, from the palm and sole, in this case :—

		Right (affected).				*Left (normal).*		
Palm of hand	.. ..	15	12	11	..	8	8	8
Sole of foot	.. ..	9	9	10	..	5	4	4½

Thus, although more pressure was required to elicit pain from the right than from the left half of the body, the discomfort produced was manifestly greater on the abnormal side.

Although this increased reaction may occur with a normal and even with a raised threshold, we found that in fifteen out of our twenty-four cases the pressure necessary to cause discomfort was less on the affected side. This was particularly the case on the palm and sole of the foot. But in spite of this lowering of the threshold to painful pressure, not one of these cases showed a lower threshold when the stimulus was a prick. Obviously, the pain produced by excessive pressure contains some sensory factor to which the abnormal half of the body is peculiarly susceptible.

Now, if any one will apply the algometer to his own hand or foot, he will find that the pressure causes discomfort rather than pain. There is something terrifying about the crushing sensation, especially when a bone is pressed upon. The condition evoked is less a pain than an unbearable and distressing sensation, and in this way differs profoundly from the prick of a sharp point. Both stimuli produce pain and discomfort: but, whereas a prick produces a sensation of pain associated with more or less discomfort, pressure upon bones and other deep structures evokes more discomfort than formal pain.

In these cases of over-reaction on the affected half of the body, it is susceptibility to the uncomfortable element of a stimulus which is increased, rather than sensibility to pain. Not uncommonly, the threshold may be actually raised to prick but lowered to pressure-pain, although both stimuli produce greatly increased discomfort over abnormal parts.

Any loss of sensibility to pain delays the appearance of this over-reaction; but as soon as the stimulus is strong enough to cause pain, the discomfort will greatly exceed that produced by the same stimulus over normal parts.

(*c*) *Extremes of Heat and Cold.*

Wherever this over-reaction to painful stimuli exists, the response to the more extreme degrees of heat and cold is usually changed. Thermal appreciation may be unaltered, may be diminished, or may be actually lost, and yet the discomfort produced by cold and hot water will be greater on the affected than on the normal half of the body.

In the case we have cited above (Case 5), thermal sensibility was diminished, but the response was more intense on the affected side. All temperatures between about 27° C. and 46° C. were less cold or less hot over the affected parts. But everything above about 47° C. and below about 26° C. was thought to be hotter or colder than on the normal side. The more the temperature of the stimulus sank below or rose above these limits, the more uncomfortable it became on the affected half of the body, compared with normal parts. We shall show later that there is in all probability no actual increase in sensibility to heat and cold at these temperatures; the patient translated the increased discomfort into terms of greater cold and heat.

All sensibility to heat and cold may be lost, and yet this over-reaction may still occur on the affected side. But in such cases the stimulus must be intense; the heat applied must be above 50° C., and the cold required will usually lie below 15° C., and sometimes even melting ice is necessary to evoke this over-reaction. But when once a stimulus has been found capable of producing a response, the discomfort is excessive on the affected half of the body.

In these extreme cases the discomfort may not be expressed in terms of heat and cold. For instance, in Case 6, ice and temperatures above 55° C. produced an intense reaction. The patient's face was contorted as if in pain, and he cried out: "Oh, something has caught me"; "something is forcing its way through me, it has got hold of me, it is pinching me."

To the most interesting group, however, belong those cases where an excessive response was evoked on the affected side, in spite of a thermal sensibility otherwise perfect. In Case 8, for instance, the threshold for the appreciation of heat and cold was identical on the two halves of the body, but whenever a stimulus produced any but the mildest sensation of cold, it seemed "colder" and more unpleasant over the affected than over the normal palm. A stimulus recognised as warm did not become "hotter" on the affected hand, until it was raised to between 40° and 45° C.

Thus, in conclusion, whenever a thermal stimulus can produce discomfort, this will be greater on the affected than on the normal side. Should the appreciation of heat and cold be sufficiently preserved, this discomfort will be thought to imply a higher or a lower grade of temperature in the stimulating object; it will seem "hotter" or "colder" than the same temperature on the normal side. If thermal sensibility is equally perfect on the two halves of the body, the excessive response will begin as soon as the stimulus seems definitely cold. But it will not seem "hotter" on the affected side, until the temperature of the stimulus reaches about 45° C. or above.

(*d*) *Visceral Stimulation.*

Discomfort in its purest form is produced by stimulation of the viscera, and we therefore compared the condition of testicular sensibility on the two sides in patients who showed this over-response to painful stimuli.

If care is taken not to pinch the scrotum, the characteristic testicular sensation, a sickening discomfort, can be evoked with no other accompaniment than a sensation of not unpleasant pressure. Many patients complained that the discomfort was more intense in the testicle of the affected side. Pressure, sufficient to produce "a slight feeling" only on the normal side, caused a widespread expression of discomfort and brisk cremasteric movements of the testicle on the affected half of the body.

The glans penis is endowed with a peculiar form of sensibility which differs normally from that of the skin in the absence of the more discriminative faculties (Rivers and Head p. 274). Heat and cold can be distinguished, but the finer grades of temperature are not appreciated. A prick causes a more widely spread sensation and is more unpleasant than over the rest of the normal skin. In fact, the glans penis is an organ endowed chiefly with the more affective elements of cutaneous sensibility, and it is therefore a peculiarly appropriate field for examination in cases which exhibit the over-reaction on the abnormal side.

When the glans is pricked with such an instrument as the algesimeter, the same strength of stimulus may be necessary to evoke pain on the two halves of the organ; but the discomfort described by the patient and obvious from his expression is greater on the abnormal than on the normal portion.

(*e*) *Scraping, Roughness, Vibration.*

All the stimuli, considered so far, contain for the normal person some obvious element of pain or discomfort. But, in these cases of over-reaction on the affected side, scraping the palm or the sole of the foot, moving a rough object over the skin, or even rubbing the hairs, may evoke an unpleasant sensation, unlike that from the normal half of the body.

The difference between the two sides is, as a rule, most evident when the observer gently scrapes with his fingers the patient's palm. Under normal conditions this is not unpleasant; but on the affected side the patient may cry out and attempt to withdraw his hand. His face is contorted with discomfort. One patient complained: "It is a horrid sensation, as if my hand were covered with spikes and you were running them in; it is not painful but very unpleasant." Frequently this sensation spreads widely, running up the arm or the leg, and is often started with peculiar ease from the sole of the foot (Roussy [100], Case 1).

This excessive response to scraping is frequently a striking feature during examination with the Graham-Brown æsthesiometer. This instrument serves to estimate the appreciation of roughness by measuring the extent to which a tooth must be protruded from a spherical surface in order that it may seem "not smooth." We not uncommonly found that the "raking" sensation produced by this instrument was greatly exaggerated on the affected half of the body. But in no case was the threshold lowered. In some it was equal on the two sides, and in others a greater protrusion was required to evoke a sensation; but in the large majority the discomfort produced was greater on the affected side. Occasionally, even the rubbing of the smooth surface over the affected parts caused an uncomfortable tingling, which confused the patient and rendered measurement impossible. In one case the instrument produced no sensation of roughness, but the tingling and discomfort were intense.

Many of these patients complained that they could not be shaved on the affected cheek because it seemed as if the razor was "passing over a raw surface." Some objected to having the hair cut on the affected half of the head, because of the discomfort, and others complained of the pain caused by the attempt to cut their nails.

Occasionally even the vibration of the tuning-fork may give rise to an unpleasant sensation, which spreads widely over the affected half of the body (Roussy [99], Case 1).

Thus, in cases where the affected parts react more strongly to painful stimuli, it may happen that even scraping with the fingers, the application of rough objects to the skin, shaving, cutting the hair or nails, or even the vibration of a tuning fork may cause discomfort or produce a more unpleasant sensation than on the normal side.

(*f*) *Tickling.*

When the tips of the fingers are gently moved over the palm or the sole, or when the ears and other hair-clad parts are stimulated with cotton wool, a tickling sensation can be produced in most normal persons. This is not unpleasant, and in some people the movements of withdrawal which result are accompanied by smiles of amusement. But in those cases characterised by an over-response to painful stimuli tickling is usually unpleasant. Several patients insisted that the sensation produced on the normal side was not disagreeable, whilst that from the abnormal parts was quite different and unpleasant. In all such cases the reaction was greater on the affected half of the body.

(B) *The Response to Pleasurable Stimuli.*

So far we have considered over-reaction of the affected half of the body to stimuli which are in themselves unpleasant, or are capable under certain conditions of evoking an unpleasant sensation. We were anxious to discover if sensations, normally accompanied by a pleasurable feeling-tone, also produced a similar over-reaction.

Unfortunately, the greater number of the methods applicable for the measurement of sensibility either produce discomfort or, like the tests for weight and for posture, evoke an entirely indifferent sensation. But in the milder degrees of heat we possess a measurable stimulus endowed with a pleasant feeling-tone. In the majority of cases, however, which showed an over-reaction to the uncomfortable aspect of a stimulus, sensation was at the same time more or less gravely lost; and this loss was particularly liable to fall upon that portion of the thermal scale which normally yields a sensation of pleasant warmth: in such cases this test is usually inapplicable.

On the other hand, in a few cases when thermal sensibility was abolished, warmth applied over a sufficiently large surface evoked a feeling of pleasure. Thus, one of our patients found a hot-water bottle pleasant and soothing to the affected foot, but did not recognise that it was warm until he touched it with some normal part. In the same way, many patients found the warm hand of the observer unusually pleasant on the abnormal side, although no such manifestations of pleasure were produced when it was applied to normal parts of the body. In one case, we were able to show that the patient could not recognise any thermal stimulus as such, and yet over the affected half of the chest large tubes containing water at from 38° C. to 48° C. evoked intense pleasure. This was shown not only by the expression of her face, but by her exclamations, "Oh! that's lovely, it's so soothing, so very pleasant." Temperatures of 50° C. and above, or of 18° C. and below, caused great discomfort exactly as in most of these thalamic cases (*vide* p. 619).

Several of our patients, however, were able to appreciate heat as low as 34° C. on the affected half of the body. Here, whenever the sensation evoked was one of pleasant warmth, the pleasure was obviously greater on the affected side. In one case, a tube containing water at 38° C. applied to the normal palm was said to be warm; but the patient cried out with pleasure when it was placed in the affected hand. His face broke into smiles and he said: "Oh! that's exquisite," or "That's real pleasant." Another patient said: "It seems warm on both hands, but it is more soothing, more pleasant on the affected palm."

The following observations were made on an intelligent and highly educated man. We determined the threshold for the appreciation of heat on the two hands. It was found to be the same, although both the pleasure given by the lower degrees of heat and the discomfort produced by the higher degrees were exaggerated on the affected palm. We then attempted to discover at what point unpleasant heat became converted into pleasant warmth. On the affected hand a temperature of 50° C. was "too hot," "very unpleasant," whilst it was "not so hot" on the normal palm; 48° C. was still "too hot," but 45° C. became "real pleasant," although it was "simply warm" on the other side. Thus in this case excessive pleasure was converted into excessive discomfort at about 46° C. This is the temperature at which, on introspection, we are conscious that hot water gains a "sting" absent from the lower degrees.

Cold has no pleasurable element, at any rate during the greater part of the year in this country. As soon as a sensation of cold is produced it is said to be "colder" and "more uncomfortable" on the affected half of the body. The threshold, or point at which a stimulus is said to become cold, generally lies somewhere between 24° C. and 27° C., and, as soon as the sensation of coldness is well developed, this discomfort begins. So far we have been unable to find any temperature which produces a sensation of pleasurable cold.

Thus, in conclusion, we find that in cases where the pleasurable aspect of heat can be appreciated, the pleasure is accentuated on the affected side; yet the threshold for the appreciation of heat is never lowered and may even be raised on the side of the excessive reaction.

(C) *The Behaviour of the Affected Half of the Body in States of Emotion.*

In the preceding sections we have seen that the two halves of the body respond differently to affective stimuli. But no one seems to have recognised that states of emotion may evoke different manifestations on the two sides; not only can pleasant and painful stimuli produce a stronger reaction when applied to the affected parts, but the two halves of the body may behave differently to mental states of pleasure and discomfort.

Music is peculiarly liable to evoke a different reaction on the two halves of the body. One of our patients was unable to go to his place of worship, because he "could not stand the hymns on his affected side," and his son noticed that during the singing his father constantly rubbed the affected hand.

Another patient (Case 11, p. 620) went to a memorial service on the death of King Edward VII. As soon as the choir began to sing, a "horrid feeling came on in the affected side, and the leg was screwed up and started to shake." The characteristic, so-called choreiform, movements were a prominent feature in this case, and whenever the unpleasant sensation was evoked in the affected side these movements were accentuated. The singing of a so-called comic song left her entirely cold, but "A che la morte" produced so violent an effect upon the abnormal half of the body that she was obliged to leave the room. In this case indifferent sounds, such as the note of a tuning-fork or sound of a bell, produced no abnormal effect, and closing the ear of the affected side made no difference to the character or intensity of the response.[1]

[1] Occasionally, however, auditory stimuli produce an increased reaction on the affected side exactly in the same way as pain and extremes of temperature. Such a case was described by Merle [80], and we have seen an instance of this condition (Case 12, p. 622). This patient complained that any continuous sound and all noises upset him. When a tuning fork was held before either ear it evoked obvious discomfort and gradually became intolerable. At the same time the spontaneous movements became extremely violent. It was difficult to be sure that the fork placed before one ear was a more potent cause of discomfort and exaggerated movement in the affected arm than when it was placed before the ear of the opposite side; but after testing him on many occasions, we came to the conclusion that the effect was greater if the sound affected the ear on the abnormal side of the body. There was, however, no doubt that he disliked the sound more in this ear than in the normal one.

A highly educated patient confessed that he had become more amorous since the attack, which had rendered the right half of his body more responsive to pleasant and unpleasant stimuli. "I crave to place my right hand on the soft skin of a woman. It's my right hand that wants the consolation. I seem to crave for sympathy on my right side." Finally he added, "My right hand seems to be more artistic."

Thus, not only does the abnormal half of the body respond more vigorously to the affective element of a stimulus, but an over-reaction can also be evoked by purely mental states. The manifestations of this increased susceptibility to states of pleasure and pain are strictly unilateral and may lead to many curious complications.

§ 3.—The Loss of Sensation which may be associated with Lesions of the Optic Thalamus

Associated with this over-reaction to painful stimuli, some loss of sensation will always be manifest on the affected half of the body. In some cases, the amount of this loss is so insignificant that, as it can be discovered by measurement only, we can imagine the existence of the over-reaction without it. But up to the present time we have not seen a patient in whom this excessive response was not accompanied by some sensory loss. It may vary in amount from a diminution so slight that it is scarcely recognisable, up to a destruction of all forms of sensibility so severe that only the grossest stimuli can be perceived.

The vehemence of the excessive response bears no relation to the extent of the accompanying loss of sensation. Sometimes, severe discomfort may be evoked by affective stimuli in cases where sensibility is grossly diminished; but many patients with but slight loss suffer great discomfort, for the existence of a sensibility of approximately normal acuteness opens the way to the reception of more impulses that can evoke an excessive response.

(*a*) *The Appreciation of Posture and Passive Movement.*

With lesions of the optic thalamus and neighbouring parts, the appreciation of posture and passive movement suffers more frequently than any other sensory quality. Sometimes, the ordinary rough tests reveal no obvious defect, although measurement shows that the recognition of the position of the hand, or the power of appreciating passive movement, is less accurate on the affected side. Thus in one case passive movements of the normal index were appreciated within a range of from 3° to 3·5° (flexion, average 3·5°; extension, average 3°), whilst on the affected side, movement was not recognised under from 7° to 8° (flexion, average 8°; extension, average 7°). At the opposite pole stand such cases as No. 6, a patient in whom the lesion was determined post-mortem. This man was totally ignorant of the position of his right arm and leg, and could not recognise passive movement as such in the limbs of the affected side.

Between these two extremes all grades of diminished appreciation of posture and of passive movement could be discovered. These two functions were always found to be affected together, except in two cases, where the defect in the appreciation of passive movement was slight and lay close to the limits of experimental error.

(*b*) *Tactile Sensibility.*

Here again we find the same extraordinary divergence in the amount of the sensory loss. In five cases the tactile threshold, measured with von Frey's hairs, was identical on the two hands; but, in the majority, some more or less grave deviation from the normal was discovered on the affected side. Sometimes, the affected parts are entirely insensitive to the tactile hairs and even considerable pressure may not be appreciated.

But frequently the loss of tactile sensibility is much less extreme and is manifested simply by a raised threshold. Sometimes, the normal hand responded with certainty to a hair of 21 grm./mm.^{2}, whereas from 70 to 100 grm./mm.^{2} was required on a similar part of the affected side to evoke a perfect series of answers. The following records illustrate this condition.

	Left (normal)	Right (affected)
21 *grm./mm*^{2}	IIIIIIIIIIIIIIII	
21 *grm./mm*^{2}.		IOOOIOOOIOOOIOOO
23 *grm./mm*^{2}.		IOIOIOIOIOIOIOIO
35 *grm./mm*^{2}..		IIIIIIIOIIOIIOII
70 *grm./mm*^{2}		IIIIIIIIIIIIIIII
23 *grm./mm*^{2}.		IIIOIIIOIIIOIIIO
21 *grm./mm*^{2}.		IOOOIOIOIOOOIOOO
21 *grm./mm*^{2}	IIIIIIIIIIIIIIII	

	Left (normal).	*Right (affected).*
21 grm./mm.^{2}	16 out of 16 . .	—
21 ,, ...	— . .	4 out of 16
23 ,, ...	— . .	8 ,, 16
35 ,, ...	— . .	13 ,, 16
70 ,, ...	— . .	16 ,, 16
23 ,, ...	— . .	12 ,, 16
21 ,, ...	— . .	5 ,, 16
21 ,, ...	16 out of 16 . .	—

Occasionally, the consecutive contacts necessary for this test caused the widespread tingling to which these patients are prone. This may make it impossible to demonstrate the threshold conclusively. Increasing the strength of the stimulus increases the number of correct answers, but the persistent tingling confuses the patient and he frequently replies when he has not been touched.

Another difficulty that may prevent the demonstration of a tactile threshold, by means of von Frey's hairs or with graduated pressure, is the occurrence of involuntary movements. Many of these patients show curious irregular movements which may not always be present, but are liable to start again when the affected side is stimulated. Movements arising involuntarily may be mistaken under these conditions for touches. The longer the testing is continued the more accentuated these movements become, and demonstration of a threshold is then impossible.

To sum up, the tactile threshold may be normal on both sides in the cases with which we are dealing in this chapter; or it may be raised to a greater or less extent, even up to complete abolition of sensibility to measured tactile stimuli. Accessory sensations or the misinterpretation of involuntary movements may confuse the records, but the loss of threshold and the irregular response, so characteristic a consequence of cortical lesions, is not found as the result of destruction at this level of the nervous system.

(c) Localisation.

The power of recognising the position of a stimulated spot was more or less grossly affected in twelve out of twenty-four cases. This faculty may be so profoundly disturbed that a touch on the hand is referred to the same half of the face or trunk. More commonly, the patient complains that he has no idea where he has been touched. "I feel you touch me, but I can't tell where it is; the touch oozes all through my hand." Although the method we have generally used forces him to recognise that he has been touched somewhere on the hand, the patient frequently gives up all attempts to determine the spot, saying, "I have no idea where you touched me."

In cases of graver loss of sensation, tactile sensibility is not infrequently much diminished, but the inability to localise the stimulated spot is equally great, even with a prick or with painful pressure, to which the patient is acutely sensitive.

When all power of localisation is abolished and the posture of the limb cannot be recognised, sensations may be no longer referred to something outside the body; they are thought to be due to some change within the part rather than to an external stimulus. When the hand was scraped one of our patients said, "It is as if something inside the arm were moved, not like anything touching me." Sometimes the sensation was said to be "a cramp inside my arm."

Wherever localisation is affected, the unpleasant sensation evoked by painful stimuli may spread widely over affected parts. When, for instance, the sole has been pressed with the algometer, the pain may occupy the whole of the leg below the knee, and the patient does not recognise that the instrument was applied to his foot. No matter what stimulus may have evoked the unpleasant sensation, it spreads widely if the faculty of localisation is destroyed. The power of recognising the position of the stimulated spot seems to exert an inhibitory influence on the distribution of this uncomfortable sensation. Appreciation of the locality of the site from which the sensation has been evoked tends to confine it to the neighbourhood of that spot, and around this it radiates to a limited extent.

(*d*) *Heat and Cold.*

Twenty-two out of twenty-four patients who showed signs of a thalamic lesion responded excessively to the unpleasant aspect of heat and cold. In nine of these cases the threshold for thermal stimuli was the same on the two sides, and but for the over-response sensibility to heat and cold appeared to be normal; the range of discrimination was identical on the two halves of the body. This class is peculiarly interesting, for in them may appear the remarkable over-response to pleasurable heat we have described on p. 559.

But, not infrequently, all appreciation of heat and cold is abolished and ice and water at over 50° C. evoke nothing but discomfort. This sensation is the same, whichever of the two extremes is used; the patient cannot tell the difference and may not recognise the cause of the unpleasant sensation.

Occasionally, the insensibility is less profound and temperatures below 26° C. and above about 40° C. may evoke a response from the affected half of the body. But this response may be the same for heat and cold; water above 40° C. and below 26° C. produces the same sensation and may therefore be called indiscriminately hot or cold. For, if the patient knows from the experience on his normal side that thermal sensibility is under examination, he concludes that this vivid sensation is caused by "something hot" or "something cold." No such confusion between the extreme degrees of heat and cold ever occurs when the patient is able to distinguish intermediate degrees.

We have seen no reason so far to think that at this situation in the nervous system the power of appreciating either heat or cold can be lost alone. The few apparent exceptions were due to the adoption by the patient of the same thermal nomenclature for the unpleasant reaction produced by certain temperatures towards the two ends of the scale, a confusion rendered possible by the absence of thermal appreciation.

Sometimes the disturbance of sensibility to heat and cold is less severe; temperatures above 38° to 40° C. are recognised as warm and those below about 26° to 28° C. as cold. Under such conditions any temperature that can be appreciated is thought to be respectively "hotter" or "colder" on the affected side, and yet there is no evidence that the supposed greater heat or cold is due to anything but the increased affective reaction.

Throughout all these cases, where the loss of thermal sensibility was not absolute, a threshold could always be determined. It might be the same on the two sides, or it might be more or less raised on that half of the body which showed an excessive response. But never did we find that remarkable loss of threshold and inability to discriminate between two temperatures, both of which were recognised to be hot or to be cold, so characteristic a feature with cortical lesions.

(e) The Compass Test.

In order that this test may be applied, the patient must of necessity be able to recognise that he is being touched; tactile sensibility must not be gravely diminished. But many of the patients, who reacted excessively to painful stimuli on the abnormal side, were so insensitive to touch and pressure that the contact of two points produced no sensation and the compass test could not be employed.

Another disturbing element in these cases is the widespread unpleasant tingling frequently evoked by a firm touch; this tingling is liable to distract the patient's attention and confuse the records greatly.

Excluding these sources of error, a considerable number of cases still remain in which the power of recognising the "two-ness" of the compass points was disturbed although each touch evoked a sensation of contact. But, by widening the compasses, a distance could usually be found at which a perfect series of answers could be obtained, and the records improved each time the distance of the two points from one another was increased. Thus in such cases it is possible to obtain a true threshold.

In most of these cases, it is true, tactile sensibility, as measured by von Frey's hairs, showed a somewhat raised threshold. But the discrimination of the compass points is not directly dependent on tactile sensibility, although at this level of the nervous system they may rise and fall together. For, if two sharp points are substituted for the blunt ends of the compasses, the difficulty in recognising them is just as great, although each prick produces a more profound effect over the abnormal half of the body.

Thus, in conclusion, we have found that the compass test could not be applied in many of these patients, owing to the gross loss of tactile sensibility or to the confusion produced by the abnormal tingling. But whenever the measured tactile threshold was the same on the two halves of the body the power of discriminating two points was unaffected; and yet the two faculties are not directly dependent, for two pricks cannot be discriminated more easily than the contact of two blunt points.

(f) The Appreciation of Weight.

Throughout this research we have adopted three methods of testing the appreciation of weight. A weight is placed in each palm and the patient by moving them up and down "weighs" them and estimates which is the heavier. Secondly, a weight is placed on some part of the fully supported hand, removed, replaced rapidly by another weight of the same size, and the patient chooses the heavier. Lastly, a weight is placed upon the hand and further weights are added or subtracted. The patient replies whenever he recognises that the weight has become heavier or lighter.

Now it is obvious that the last two methods depend mainly upon an appreciation of relative pressure, whereas the first demands a power of estimating movement and the force employed in lifting the weight.

At that part of the nervous system with which we are now engaged this difference comes out in a remarkable manner. In some cases the only discoverable loss of sensation consisted in a diminished recognition of posture and passive movement, and correlated with this loss was an inability to distinguish weights placed simultaneously on the unsupported hands; and yet the patient may be able to recognise the relation between two weights, placed one after the other on the affected hand when fully supported.

Conversely, any diminution of tactile sensibility at once affects the power of appreciating relative pressures, and so interferes first with the estimation of weights applied consecutively, and later even with the ability to recognise whether an object resting on the palm has become heavier or lighter. In one case the tactile threshold was slightly raised, but all forms of postural recognition were perfect: here estimation of consecutive weights and recognition of the increase or diminution of a weight resting on the supported hand were both somewhat affected. But appreciation of the relative heaviness of two weights placed one in each unsupported palm was not disturbed.

Thus, at this situation in the nervous system the power of estimating the relation between two weights depends on the integrity of both tactile and postural impulses. The faculty of estimating the relative weight of two objects placed one in each unsupported hand demands a correct appreciation of posture and movement. But appreciation of two weights placed consecutively on the supported hand, and the power of recognising addition to, or removal from, the weight of an object lying in the palm, require a normal tactile sensibility.

(g) The Appreciation of Size, Shape and Form in Three Dimensions.

No tests for the recognition of size, shape, or form can be applied unless the patient is able to appreciate the contact of objects placed in his palm. In five of our cases this was impossible, owing to gross loss of tactile sensibility, whereas, on the contrary, in six cases the lesions which produced an over-response to painful stimuli had in no way affected the power of recognising size, shape or form.

Between these two extremes lies a group in which all three forms of recognition were more or less gravely defective. Although the defective recognition of size, shape and form in three dimensions, which may accompany the over-response to painful stimuli, appears at first sight to resemble that due to cortical lesions, more careful examination shows that they may differ fundamentally from one another. Ordinary clinical tests, employed in the usual rough manner, are incapable of demonstrating this difference. But, when a series of tests are carefully carried out, the patient is able, in most cases, to recognise a difference in size, provided it is sufficiently large; a true difference threshold can be obtained. He does not give up all attempts to estimate the relative size of the test-objects, saying, as in the case of a cortical lesion, "I have no idea." He may make mistakes in their relative size or may believe that the two objects are equal, but retains an impression that they possess a size to be compared. Ultimately, if the difference between them is made sufficiently great, his answers grow increasingly more accurate.

For instance, in the following set of observations (Case 5), it will be seen that the patient could appreciate a difference in two circular test-objects, when the diameter differed by 2 cm., but not when the one exceeded the other by 1 cm. only. She could recognise a difference of 1·5 cm. when the diameters were 3·5 cm. and 2 cm., but not when they were 4 cm. and 2·5 cm.

	Normal palm.	*Affected palm.*
2 cm. and 3 cm.	Four right	Four wrong.
3 ,, ,, 4 ,,	,,	Two right, two wrong.
4 ,, ,, 2·5 ,,	,,	One right, three wrong.
4 ,, ,, 2 ,,	,,	Four right.
3·5 ,, ,, 2 ,,	,,	,,
5 ,, ,, 2 ,,	,,	,,

Here it is obvious that increasing the difference improved the accuracy of the answers, and a true difference threshold could be worked out approximately, even with so small a number as twenty observations.

Unfortunately, we have no method of reducing the tests for shape and form in three dimensions to measure in the same way. For increasing the size of objects used for testing shape beyond certain limits prevents their uniform application to the palm, and any considerable reduction makes it impossible to recognise them on the normal hand. Even the size of the objects used as tests for form in three dimensions cannot be varied greatly, since it is necessary that the patient should be able to roll them between his fingers and palm.

In spite of these difficulties the patient usually attempted to give some name to the object, provided tactile sensibility was not greatly impaired, and he could move it to and fro in his hand. Not uncommonly he said: "I have an idea of the shape, but it seems numb." Moreover, in the majority of instances a certain number of right answers were given, especially to the easier tests, such as the circle or the sphere, and the familiar objects commonly used in clinical examination were frequently recognised.

Thus, in conclusion, we find that in these cases the recognition of size, shape and form in three dimensions may be intact, or more or less gravely affected. In some instances, this loss of recognition is due to gross defects in tactile sensibility. But in a considerable group of cases the difference threshold is raised: here all idea of size, shape and form is not abolished, as in the cortical cases, but a greater difference than normal is necessary before they can be appreciated. In the same way, the patient retains an idea that the objects have a shape and form, but finds difficulty in recognising what it may be.

(*h*) *Vibration.*

The loss of sensation must be unusually gross before the vibrations of a tuning fork cease to be appreciated. In three cases only was the affected half of the body insensitive to this stimulus, and in all of them most other forms of sensation were gravely affected.

Usually the vibrations of the tuning fork are appreciated on both halves of the body, but the stimulus appears to last a shorter time on the abnormal side. If the tuning fork is placed upon some point of the affected side and, as soon as it can no longer be appreciated, is rapidly transferred to a corresponding part on the normal half of the body, the patient continues to recognise the vibration for a further period, which may even extend to fifteen seconds. This shortened appreciation of the tuning fork is one of the most characteristic features of the loss of sensation associated with the over-response to painful stimuli. It occurred in fifteen of our cases, and was independent of that unpleasant feeling-tone evoked by vibration, of which we have already spoken.

At the same time the patient complains that the vibrations are "not so plain" on the abnormal half of the body and in certain cases the fork seems to be vibrating less rapidly on the affected side.

(*i*) *Roughness.*

In three cases only was the loss of sensation sufficiently gross to prevent the appreciation of roughness produced by Graham-Brown's æsthesiometer. This instrument with its graduated projection is peculiarly liable to cause an unpleasant sensation. and occasionally confusion is produced because even the smooth surface of the instrument may evoke a widespread tingling. But in most cases it is easy to show that the threshold for the appreciation of roughness as measured with this instrument is the same on the two halves of the body.

(*k*) *Summary of the Loss of Sensation.*

We can now sum up the forms assumed by the loss of sensation which may be found in these cases.

No sensory functions are so frequently affected as the appreciation of posture and the recognition of passive movement. The amount of this loss varies greatly from a scarcely measurable defect to complete want of recognition of the posture of the limbs on the abnormal half of the body.

Tactile sensibility is frequently diminished; but, excepting in a few cases where all appreciation of contact was destroyed, a threshold could be obtained. It was always possible to show that increasing the strength of the stimulus improved the proportion of right answers, unless the observations were confused by the disagreeable tingling or other accessory sensations.

Localisation of the spot touched was defective in half the cases where sensation was sufficiently preserved to carry out accurate tests. This inability to recognise the site of stimulation was equally great, whether the patient was pricked or touched. In cases where localisation was gravely affected, the disagreeable sensation, so easily evoked, tended to spread widely on the abnormal half of the body. A prick on the hand may cause an extremely painful sensation in the cheek or side, and sometimes the patient simply recognised the stimulus as a change within himself, and did not refer the discomfort from which he suffered to the action of any external agent.

Sensibility to heat and cold may show all degrees of change from total loss to a slight increase of the neutral zone. Heat and cold are not dissociated; and if one form of sensation is lost, the other will be gravely disturbed. The apparent exceptions arise from a misinterpretation of the sensation evoked by high or low temperatures on the affected half of the body.

Not infrequently the compass test cannot be carried out because of the gross loss of sensation and inability to recognise contact; but whenever this method can be applied a threshold can be worked out, and widening the distance between the points increases the accuracy of the answers.

The power of estimating the relation between two weights is frequently disturbed on the abnormal half of the body. If the appreciation of posture and movement is affected, the patient can no longer recognise the identity or the difference of two weights placed in the unsupported hands. But so long as tactile sensibility is not diminished, he can still estimate the relation between weights applied one after the other to the same spot, and can recognise the increase or diminution in weight of an object already resting on the hand.

The appreciation of relative size is often disturbed in these cases, but with care it is usually possible to demonstrate a difference threshold. Shape and form in three dimensions are frequently not recognisable on the affected hand. But, if tactile sensibility is not grossly affected, the patient usually retains an idea that the object possesses a form, and may obtain a considerable percentage of right answers.

Vibration of the tuning fork was recognised by all but three of our patients. In almost every case, however, the length of time during which it was appreciated was shorter, and sometimes the rate of vibration was thought to be slower on the affected half of the body.

Roughness, as tested with Graham-Brown's æsthesiometer, was always recognised, except in three cases where the loss of all forms of sensation was extremely severe. Usually the threshold was the same on the two sides, but it was occasionally raised on the affected hand.

CHAPTER III

SENSORY DISTURBANCES PRODUCED BY LESIONS OF THE CEREBRAL CORTEX

In describing the effect of a cortical lesion upon sensibility, we shall proceed exactly as with lesions of other parts of the nervous system. Each stimulus will be considered in order and the nature of the response described. Thus, for instance, we shall not speak of "deep sensibility" as preserved or lost, but shall give the exact stimuli used and the form of response they evoked. All such expressions as "cutaneous sensation" and "light touch" will be strictly avoided, and we shall deal as far as possible with measured stimuli only.

§ 1.—Graduated Tactile Stimuli

(*Von Frey's Hairs and Pressure-æsthesiometer.*)

Lesions at lower levels of the nervous system produce, on the whole, forms of altered sensibility which react with remarkable constancy to graduated stimuli. A touch of definite intensity, if sufficiently strong to evoke a sensation, will do so in a large proportion of instances; while some less intense stimulus will cause no sensation of any kind. Somewhere between these two we are justified in placing the threshold for tactile sensibility.

But the characteristic change produced by a cortical lesion consists essentially in a want of constancy and uniformity of response to the same tactile stimulus. Increasing the stimulus does not necessarily improve the patient's answers and in many cases no threshold can be obtained.[1]

On attempting to obtain a maximum threshold on the affected hand, we meet with the same curious irregularity of response that has hampered all who have attempted to use graduated stimuli in such cases; the patient seems to be untrustworthy. At one time he responds to a hair of 21 grm./mm.^{2}, at another even 100 grm./mm.^{2} produces no effect. Not only are his answers apparently incalculable, but not infrequently he responds, when he has not been touched.

This irregularity has led most observers to reject all graduated stimuli and to adopt some other form of tactile stimulation, such as rubbing with the finger or with cotton wool, to which the answers are more uniform. But in this irregular response to graduated tactile stimuli lies the key to the sensory disturbance produced by lesions of the cerebral cortex.

We have modified the method of examination in the following manner so as to bring out the true nature of this phenomenon : A hair is selected pro-

[1] Throughout the work we obtain a threshold by finding a stimulus of a strength just sufficient to produce an overwhelming majority of right answers when applied in series. This may be called the maximum threshold. We do not attempt to determine the smallest stimulus which can be perceived.

ducing a stimulus just above the maximum threshold, to which the normal hand reacts with constancy when it is applied sixteen times in the minute. If the same hair is used in the same manner to a corresponding part of the affected hand, the response is irregular and wanting in uniformity. Then more powerful hairs are used, up to those exerting many times the pressure. Still the response remains irregular; in fact, the answers may be less accurate with the more powerful stimulus than with the finer hairs. But further stimulation with the hairs of lower grade does not of necessity materially reduce the proportion of correct answers. The irregular response to the more powerful hairs cannot therefore have been due to fatigue alone.

The following series illustrates the nature of this response. The observations began on the normal hand with sixteen touches from a hair of 21 grm./mm.^{2}, to which the patient responded promptly in every case. Then the affected hand was touched sixteen times with the same hair, and five of these touches were appreciated. A stronger hair was chosen, and eight out of sixteen contacts were appreciated. Step by step the strength of the stimulus was increased, but even with 100 grm./mm.^{2}, which exerts a pressure of 3·5 grm., we obtained six responses only. We then decreased the strength of the stimulus again and at the end of the series we obtained a better set of answers to the weakest hair than to the strongest hair previously employed. Finally, on the normal hand all the touches with the lightest hair were promptly recognised, showing that general fatigue played no part in the peculiar form assumed by the response from the affected hand.

	Normal hand (Right).	Affected hand (Left).
21 *grm./mm*^{2}	IIIIIIIIIIIIIIII	
21 *grm./mm*^{2}		IIIOOOOOOOOOIOIO
23 *grm./mm*^{2}		IOIOIOIIOOIOOIOI
35 *grm./mm*^{2}		OIIOIOOIOOIOOIOO
100 *grm./mm*^{2}		IIOIOOOOIOOOIOIO
23 *grm./mm*^{2}		OIOOIOOOOOIOOIOO
21 *grm./mm*^{2}		OOOIOOIOIOIIOIIO
21 *grm./mm*^{2}	IIIIIIIIIIIIIIII	

To show the record obtained when von Frey's hairs of various bending strains were applied sixteen times in the minute to similar parts of the normal and affected hands. A stroke represents a correct answer, a nought that the patient did not respond.

This record can be translated into the following numbers:—

	Normal hand (Right).	*Affected hand (Left).*
21 grm./mm.^{2}	16 out of 16 ..	—
21 ,, ...	— ..	5 out of 16
23 ,, ...	— ..	8 ,, 16
35 ,, ...	— ..	6 ,, 16
100 ,, ...	— ..	6 ,, 16
23 ,, ...	— ..	4 ,, 16
21 ,, ...	— ..	7 ,, 16
21 ,, ...	16 out of 16 ..	—

It is obvious from these figures that in such a case we can no longer talk of a threshold to von Frey's hairs on the affected hand. For although the hand reacted to 21 grm./mm.^{2} (0·36 grm.) it failed to react in a considerable proportion of instances to 100 grm./mm.^{2} (3·5 grm.). Further stimulation with 21 grm./mm.^{2} produced a larger proportion of right answers compared with those evoked immediately before by 100 grm./mm.^{2}

Such a result only permits us to say that the range between the minimum stimulus to which the patient responds and the maximum threshold extends between 21 grm./mm.^{2} and something above 100 grm./mm.^{2} We cannot so far say that no threshold exists to measured tactile stimuli. Unfortunately hairs above 100 grm./mm.^{2} are liable to evoke a sensation of pricking on many parts of the normal hand, and it is therefore impossible to employ them without running the risk of introducing a disturbing sensation of pain.

But if a series of graduated pressures are allowed to act upon a stout bristle, which does not bend, it is possible to produce greater tactile stimuli which evoke no sensation of pricking. When this test was applied to the patient who yielded the record on p. 571, we obtained the following results :—

	Normal hand (Right).	Affected hand (Left).
0·2 *grm.*	IIIIIIIOIIIIIII	
0·2 *grm.*		OIIIOIOOIOO⁞IOOOO
0·3 *grm.*		OIOOOOOOIIIOOIOO
0·4 *grm.*		OOIO⁞OOOIIOIOOIOO
0·5 *grm.*		OIIOOIOOOOIOOOOO
0·75 *grm.*		IOOOIOOOOOOOOIIO
1·0 *grm.*		IIOOIOIOIOIOOOOO
1·5 *grm.*		IOIOOIOIIIO⁞O⁞⁞OIOO
2·0 *grm.*		OIOOOOOIOIOOIOOO
4·0 *grm.*		I⁞IOOIIOOOI⁞OIIOI
5·0 *grm.*		I⁞OOOIOOIOOII⁞OI
1·0 *grm.*		OOIOOOOOIOOOOOIO
0·2 *grm.*	IIIIIIIIIIIIIIII	

The figures in the first column represent the weight in grammes acting on a constant surface of 0·19 mm.^{2} As before, a stroke represents a correct answer, a nought signifies that the patient did not reply. A dotted stroke represents a hallucination.

This record can be translated into the following numbers :—

	Normal hand (Right).	*Affected hand (Left).*
0·2 grm.	15 out of 16	—
0·2		6 out of 16
0·3		5 ,, 16
0·4		5 ,, 16
0·5		4 ,, 16
0·75		4 ,, 16
1·0		6 ,, 16
1·5		7 ,, 16
2·0		4 ,, 16
4·0		9 ,, 16
5·0		3 ,, 16
1·0		3 ,, 16
0·2	16 out of 16	—

These observations show that, in this patient, a stronger tactile stimulus did not of necessity lead to a corresponding increase in the proportion of right answers.

Even more striking evidence of the absence of a tactile threshold was obtained in Case 15 with the pressure æsthesiometer, an instrument by which measured weights may be brought to bear on a surface of 3 mm. in diameter.

	Normal hand (Right).	Affected hand (Left).
2 *grm.*	IIIIIIIIIIIIIIII	
2 *grm.*	....	OIOOIOOOOOOOOOOO
5 *grm.*	....	OOOOOOOOOOOOOOOO
12 *grm.*	....	OIIOIOOOOIOOOOOO
32 *grm.*	....	OOOOOIIIOIOOOOII
2 *grm.*	....	OOOOOOOOOOOOOOOO
7 *grm.*	....	OOOIOOIOOOOOOOOO
12 *grm.*	....	OOOIOIOOOOOOOOOO
22 *grm.*	....	OIOOOOOOOOOOOOOO
32 *grm.*	....	OOOOOIOOOOOOOOOO
2 *grm.*	....	OOOIOIOOIOIOIIOO
2 *grm.*	IIIIIIIIIIIIIIII	

A set of observations obtained in Case 15 to contacts with the pressure æsthesiometer. In the first column is given the weight acting on a surface 3 mm. in diameter for each series of sixteen tactile stimuli. The symbols used to record the answers are the same as in previous figures. They can be translated as follows:—

PRESSURE-ÆSTHESIOMETER

	Normal hand.	*Affected hand.*
2 grm.	16 out of 16	—
2 „	..	2 out of 16
5 „	..	0 „ 16
12 „	..	4 „ 16
32 „	..	6 „ 16
2 „	..	0 „ 16
7 „	..	2 „ 16
12 „	..	2 „ 16
22 „	..	1 „ 16
32 „	..	1 „ 16
2 „	..	6 „ 16
2 „	16 out of 16	—

To contact with this apparatus the normal hand responded constantly. But on the abnormal hand the answers showed the same remarkable tendency to irregularity that was present when it was stimulated with graduated hairs. No pressure between 2 grm.—the minimum weight of the instrument—and 32 grm. seemed to make any constant difference in the number of right answers. In the above series the best set of answers occurred with 32 grm., but this was equalled by the final series obtained with 2 grm. And yet at the same time the part was not insensitive to tactile stimuli, for with a hair which exerted a pressure of 0·36 grm. (21 grm./mm.^{2}) nine out of sixteen touches were appreciated.

Here, then, it is impossible to say that any tactile threshold can be obtained in the sense usually given to the term. A part that was sensitive to a hair exerting a pressure of 0·36 grm. was not constantly sensitive to a pressure of 32 grm.

This uncertainty of response is not the only peculiarity met with in examining the affected part with measured tactile stimuli. Fatigue is induced with unusual facility, and a part that has responded in the characteristic manner to one of the less powerful hairs may cease altogether to respond to 100 grm./mm.^{2}. This is, however, an extreme reaction seldom, if ever, seen in uncomplicated cortical cases.

Another disturbing factor in the response to graduated tactile stimuli is the occurrence of hallucinations, or replies that are not the direct sequel to a stimulus. We believe that this tendency to hallucinate is not due to any general untrustworthiness on the part of the patient, but is another aspect of the irregular response characteristic of cortical loss. On one occasion Hn. (Case 14) gave so many hallucinatory answers to graduated hair-stimulation of the affected hand that all testing became impossible. But in spite of this "untrustworthiness" the answers obtained from the normal hand and from the soles of both feet were excellent, and on all these parts a perfect threshold could be worked out.

Many of our patients are highly intelligent; if they are asked to describe their sensations at the time they are hallucinating, introspection leads them to remarkably similar conclusions. They start by saying that a sensation from the affected part differs from that evoked by the same stimulus on the normal hand or foot. The hair seems to remain in contact with the skin, and after a series of touches a continuous sensation is produced. Upon this continuous sensation each consecutive touch may or may not produce that additional change recognised as a fresh contact. But at times the sensation interpreted as another contact may arise without actual stimulation and sometimes it may even recur several times.

These hallucinations are in fact the direct consequence of that persistence of sensation, so frequently a feature of the changes produced by a cortical lesion.

Frequently, however, tactile sensibility is less grossly affected by a cortical lesion. The response may still be irregular and the sensation of contact may persist; but with stronger stimuli the proportion of replies increases until, perhaps, every contact may evoke an answer. Under such circumstances, the affected part may exhibit unusual signs of fatigue, although general attention, shown by the response on the normal side, has undergone no diminution (Case 14, p. 627). Moreover, the sensations of contact tend to persist and hallucinations may break an otherwise perfect series of replies.

Whenever a tactile threshold can be obtained, sensibility as a whole is comparatively slightly affected. No form of sensory appreciation is completely lost and some approximation to a threshold can be discovered with other graduated tests, such as the compasses.

The defects revealed by graduated tactile stimuli are less evident on testing with a camel's-hair brush or by moving a wisp of cotton wool backwards and forwards over the affected part.[1] If it happens to be endowed with hairs, there may be no difference between the constancy of the patient's answers from the two sides, but over hairless parts or after removal of the hairs the replies to cotton wool stimulation are usually less certain and more irregular than over similar normal areas. Moreover, the patient sometimes complains that the touch of the cotton wool is "less plain" over the affected limb; but not infrequently he says he can appreciate no difference. Changes that are evident to tests with graduated hairs may be less manifest on stimulation with cotton wool. This is due in part to the fact that movement of cotton wool over hair-clad parts evokes a tickling sensation different in nature and origin from the single contact of a measured tactile stimulus.

We can sum up the conclusions to which we have arrived as follows :—

(1) A cortical lesion may reduce the accuracy of response, from the affected part, to graduated tactile stimuli.

The form assumed by this defective sensibility differs from that produced by lesions at other levels of the nervous system. For the affected part may respond to the same graduated hair as the normal hand; but this response is irregular and uncertain. Increasing the stimulus may lead to no corresponding improvement, and even the strongest tactile hair may occasionally evoke less certain answers than a hair of much smaller bending strain. Moreover, a touch with the unweighted æsthesiometer may be as effective at one moment as the same instrument weighted with 30 grm. at another. In such cases no tactile threshold can be any longer obtained.

(2) This irregularity of response is associated with persistence of the tactile sensation and a tendency to hallucinations of touch.

Where the sensory defect is not sufficiently gross to abolish the threshold, persistence, irregularity of response and a tendency to hallucinate may still disturb the records.

(3) In all cases where tactile sensibility is affected, whether a threshold can be obtained or not, fatigue is induced with unusual facility. Although the patient may cease to respond to tactile stimuli over the affected part in consequence of fatigue, his answers may remain as good as before from the normal parts. The fatigue is local and not general.

[1] Movement over the surface greatly increases the effect of any stimulus such as cotton wool. For, firstly, the area affected is greater than if the cotton wool were simply brought into contact with the skin. Secondly, the leverage of the hairs set in motion by dragging a wisp of cotton wool or a brush across the part greatly increases the stimulating effect. Finally, movement across the surface is in itself a powerful stimulus, and, as we have shown when discussing the results of lesions of the optic thalamus, may evoke a sensation although simple contact is not appreciated.

(4) With stationary cortical lesions, uncomplicated by states of shock or by "diaschisis," sensibility to touches with cotton wool is never lost over hair-clad parts. Over hairless parts stimulation with cotton wool may produce a sensation which seems "less plain" to the patient, and his answers may show the same inconstancy so evident when he is tested with graduated tactile stimuli.

§ 2.—Measured Painful Stimuli

In all lesions of the sensory path below the optic thalamus, some loss of sensation to painful stimuli is of common occurrence. But we have not so far discovered any disturbance of this form of sensibility as the consequence of a stationary cortical lesion, except when the disease was of recent origin or unless the patient had suffered shortly before from convulsions, or had been subjected to other causes of shock.[1]

A prick is the only effective means of applying a measurable painful stimulus to the skin. But all mechanical means for measuring the force needed to evoke a sensation of pain, when a sharp point is thrust into the skin, labour under the same disadvantage. Any sharp object, such as a needle, produces first of all the recognition that the stimulus is pointed : further pressure adds to this a sensation of pain. Now, it is almost impossible to prevent the ordinary patient from saying that he is pricked whenever he appreciates that the stimulus is a sharp point, and if he is told to wait until he obtains a sensation of pain we run the risk of placing the threshold too high.

Usually the patient can discover no difference between two pricks of the same force applied to similar portions on the two sides of the body, but occasionally he states that the stimulus is "plainer" or "sharper" on the normal than on the abnormal part.

This difference in sensation is accompanied by no raising of the threshold either to prick or to painful pressure. The readings obtained with the prick algesimeter, or with the pressure algometer, are the same on the two sides. Moreover, the patient shows no more signs of discomfort from the one side than from the other, with the same stimulus.

We therefore believe that this want of "plainness" or "sharpness," of which the patient may complain, is usually due to a want of distinct appreciation of the pointed nature of the stimulus; that is to say, the want of "plainness" or "sharpness" is not due to a diminished sensibility to the painful aspect of the prick, but is a discriminative loss equivalent to the want of recognition of size and shape (cf. Case 15, p. 629).

The pressure algometer gives a measure of discomfort rather than pain. To this coarse stimulus the affected part responds as readily as the normal, and we have found none of that over-reaction so prominent a feature with lesions of the optic thalamus.

Thus, pure cortical lesions usually cause no increase or decrease of sensibility

[1] For a more complete statement on the question see p. 708.

to measured painful stimuli. But, if the cortical destruction is recent or progressive, or if it produces convulsions, however slight, remarkable defects may appear in painful sensibility. The threshold, not only to prick but to painful pressure, may be considerably raised, and sometimes even coarse pricking may fail to evoke a sensation with any certainty. In fact, we may be face to face with a truly diminished sensibility to painful stimuli closely resembling the loss produced by interference with sensory impulses at a lower level. These changes are due to shock, exhaustion, and to the state called by Monakow "diaschisis." They are due to a profound disturbance of function, extending back beyond the level of the sensory cortex and affecting even the receptive mechanism in the optic thalamus.

In conclusion, a pure cortical lesion usually leads to no change in the threshold to measurable painful or uncomfortable stimuli. Nor does the patient express greater dislike to these stimuli on one side than on the other. A prick may be said to be "plainer" or "sharper" on the normal than on the affected side; but this is due to a defective appreciation of the pointed nature of the stimulus and bears no direct relation to the painfulness of the sensation evoked.

§ 3.—Temperature

Many cortical lesions produce no change in the response to thermal stimuli, provided those periods of shock, which follow an operation or an epileptiform seizure, are strictly avoided.

In other cases, however, we found definite changes in the sensibility of the affected parts to heat and cold, although the lesion had remained quiescent for many years (Case 15 and Case 16). In every case the nature of the disturbance of sensation was similar and consisted essentially in an increase of the range within which a thermal stimulus was thought to be neither hot nor cold.

Normally this neutral zone varies greatly under different conditions and in different persons. It usually occupies from 2° to 5° C., but its position on the scale shifts with the external temperature. At any moment it can be raised or lowered by warming or cooling the hand; but, although the position on the scale may be shifted by adaptation, the interval in which a thermal stimulus is thought to be neither hot nor cold is not materially altered.

Fortunately, in all our cases we were able to compare the behaviour of the normal and the affected sides of the body under the same conditions and with equal care. Now, wherever the appreciation of thermal stimuli was affected by a cortical lesion, this neutral zone extended over a greater number of degrees than on the normal hand. In one instance (Case 15) it lay between 29° C. and 31° C. for the normal hand, whilst on the affected hand all temperatures between 27° C. and 36° C. seemed to be neither hot nor cold. In another patient this neutral zone extended from 23° C. to 38° C. on the affected side.

Not only is the range of the neutral zone increased, but the responses from the affected hand are slow and irregular compared with those obtained from normal parts under similar conditions. The patients complained that heat and cold, which they could recognise correctly, seemed "less plain" over the abnormal than over similar normal parts: they were conscious that even temperatures which they could appreciate produced a different effect upon the two sides.

Moreover, the power of comparing two thermal stimuli, applied either together or in sequence, may be diminished. Temperatures of 40° C. and 48° C. may be correctly appreciated throughout a long series of tests; yet the patient may be unable to say with any certainty which is the hotter. He is puzzled by the inconstant intensity of the sensation evoked by the same temperature at different times. He may have no doubt that tubes containing melting ice and water at 20° C. are both cold, but he cannot tell, with any approach to certainty, which of the two is the colder.

Here, as with the defects in tactile sensibility, it is the power of discrimination, the faculty of comparing two stimuli with one another, which is disturbed by a cortical lesion. The only actual loss of sensation, therefore, falls upon that part of the scale where thermal recognition habitually depends on some previously existing standard. In a normal person anything which alters this standard, such as warming or cooling the hand, may even change the name given to a particular temperature in the neighbourhood of this neutral zone; 30° C. can seem at one time warm, at another cold, and on the third occasion neutral. Cortical lesions therefore enlarge this neutral zone and all thermal sensibility is abolished over that part of the scale where the appreciation of heat and cold depends upon the relation to some pre-existent standard.

Shock or convulsive attacks may produce profound loss of sensibility, corresponding more nearly with the changes which follow lesions at lower levels of the nervous system; but such gross sensory defects never result from quiescent lesions confined to the cerebral cortex.

In conclusion, we find that the appreciation of heat and cold was not affected in a considerable number of cases of cortical lesions. But whenever thermal sensibility was disturbed the following changes were found :—

(1) The neutral zone, within which the stimulus was said to be neither hot nor cold, was considerably enlarged in comparison with that observed on similar normal parts of the same patient.

(2) The patient complained that, although he recognised correctly the nature of the stimulus, it seemed "less plain" than over normal parts. His answers were less constant and less certain; a temperature recognised without difficulty at one time seemed doubtful at another.

(3) The power of discriminating the relative coolness of two cold stimuli, or the relative warmth of two hot tubes may be diminished. Thus 20° C. may be said to be the same as ice, although both are uniformly called cold, and 40° C. may seem as warm as, or even warmer than 48° C. The faculty

of appreciating the relation to one another of two temperatures on the same side of the scale is disturbed.

§ 4.—The Appreciation of Posture and of Passive Movement

Inability to recognise the position of the affected part in space is the most frequent sensory defect produced by lesions of the cerebral cortex. In some cases, this and the allied faculty of recognising passive movement may be the only discoverable abnormalities. Whenever sensation is disturbed at all, these two forms of spacial recognition will be certainly affected.

Since some disturbance of the power of recognising passive movement always accompanies defective postural recognition, these two kindred faculties will be dealt with together in this section.

(*a*) *Recognition of Posture.*

In most cases of cortical disease, the usual rough method of testing is amply sufficient to demonstrate defective appreciation of posture. The patient's eyes are closed and the affected limb is placed in some position different from that in which it lay at first. He is then told to touch some part of it, such as the index finger, with his normal hand. At first he usually fails to find the limb: when at last he strikes some part of it, he moves his indicating hand down to find the finger he was asked to touch. Should the power of localisation remain intact, he can ultimately grope his way to the exact spot; but, if localisation is also affected, although he may reach the hand, he will probably be unable to find the finger.

So gross is the defective recognition of posture in most cases that this method amply suffices to demonstrate it in an unequivocal manner. Horsley [16] has, however, introduced a useful means of measuring this deviation from the normal.

The finger to be tested is applied to the one surface of a glass plate divided by lines into measured squares, and with the free hand the patient seeks to indicate on the other surface of the plate the position of the finger he is seeking. The results of his attempts can be read off on the measured plate. Instead of this glass plate we have used a piece of stiff cardboard. In the centre of the one surface of this cardboard is a slight depression to receive the tip of the index finger, and on the other a sheet of white paper can be fixed. With the normal hand the patient seeks to indicate the position of the affected finger, which remains at rest in the depression, and the point upon which he ultimately settles is marked on the paper. His indicating hand is then withdrawn and he is asked to make another attempt. Each record of a series of observations made in this way can be measured and collated at leisure.

In every case where sensation was disturbed in any way, however slightly, as the result of a cortical lesion, the records with Horsley's plate showed some loss of postural appreciation in the affected hand. This method therefore forms a delicate means of detecting sensory changes of cortical origin.

Thus in Case 14 we obtained the following results with the plate horizontal at the umbilical level: Four attempts only out of ten came within 7 cm. of the affected index. When the plate was held in the sagittal plane, two attempts to find the index of the affected hand fell within 4 cm. of its position and a circle with a radius of 8 cm. was required to cover the remaining eight points.

The deviations discovered by Horsley's method, even in normal individuals, are so considerable that it is necessary to have some standard in each patient with which to compare the records obtained from the affected parts. It might be objected that most cortical lesions produce so much paralysis that the affected hand cannot be used to point out the position of the normal forefinger. But, in spite of its paresis and defective sense of posture, the records obtained when the affected hand sought the normal forefinger were uniformly better than when the patient attempted to point to the affected forefinger with his normal hand. That is to say, defective appreciation of the position of the hand to be sought for has a more disturbing effect upon the records than weakness and loss of postural sense in the indicating hand.

This is particularly well shown by the records from a patient in whom the left hand was gravely paretic, and the sense of posture defective: and yet all ten attempts with this hand to find the normal forefinger fell within 3 cm. of its position, and five lay within a distance of 1 cm. But when he attempted to point to the affected index with the normal hand he came once only within a distance of 1 cm. and three attempts lay outside a radius of 3 cm. Thus the normal hand seeking the affected forefinger made a worse record than the abnormal hand attempting to find the normal index, whose position was known.[1]

All these tests depend on knowledge of the position in space of the extremity as a whole. To what extent its separate segments are affected can only be discovered by asking the patient to imitate, as exactly as possible with his normal limb, the posture of the affected part. His eyes are closed and, whilst his attention is diverted by conversation, some part such as the index finger is moved into the desired position. After an interval he is asked to place his normal index in the same position as the index of the opposite hand. By this means we have been able to confirm the statements of most recent writers that the gravest loss produced by a cortical lesion is usually found in the extremity of the limb (Bergmark [6]).

(b) *Recognition of Passive Movement.*

The inability to recognise posture is always associated with diminished appreciation of passive movements, in some cases so great that even complete

[1] The most important postural impulses for the act of pointing are those from the shoulder joint and, in these limited lesions of the cortex, the shoulder is usually less affected than the distal segments of the upper extremity. Thus, even a gravely paralysed limb can often be guided more correctly in the desired direction than the normal limb attempting to point to a spot of which the position is imperfectly known.

flexion and extension of a joint cannot be recognised. Here no measurement is required; the loss of appreciation is absolute. But whenever the loss is less gross we agree with Petrén and his fellow-workers that the smallest movement which can be appreciated by the patient must be measured: such measurement alone can demonstrate whether this faculty is or is not affected.

Measurements alone can furnish us with the materials for determining the relative extent to which the appreciation of passive movement is disturbed at the various joints of the affected limb, and in cases where the condition of the patient is changing, they may form a useful record of the progress of the disease.

But when we attempt to measure the extent of the smallest appreciable movement, two different phases of recognition must be distinguished. The patient may say at once when he thinks a movement has occurred; this gives the measure of the least perceptible movement. Or he may wait until he is able to indicate its direction. As a rule in the normal limb, most patients wait until they can recognise the direction of the movement before they say that the joint has been moved; but the difference between the point at which the movement is appreciated and that at which its direction is recognised is normally small.

In the abnormal limb, however, this distance is greatly exaggerated and movements may be perceived long before their direction can be recognised. It is, therefore, important to record both the extent of the smallest movement perceived and the range necessary to evoke recognition of its direction.

All these points are well shown in the records from a case where the lesion produced slight sensory changes only: here the power of recognising passive movements might have been said to be unaffected, had it not been for the measurements. On the normal side the patient waited until he could recognise the direction of the movement, and yet when the little finger was flexed or extended was invariably correct with movements within 5°. On the abnormal side he was never certain of the direction of the movement until it had exceeded 10°, although he frequently appreciated the occurrence of a movement of 5°.

All cortical lesions, which produce any change in sensibility, lessen the power of appreciating passive movements and the knowledge of their direction. In every case this loss was associated with a concomitant disturbance of the recognition of posture. Whenever sensibility was changed, however slightly, these two allied functions were always affected. Diminished power of appreciating the posture of some part of the limb, and of recognising passive movements, are the most constant and most easily demonstrable defects of sensation produced by cortical lesions.

In all our cases the loss was greatest towards the distal portions of the limb; in this it corresponds exactly with the disturbance of the sense of posture. Here we can only confirm the work of almost every previous observer.

When attempting to measure the smallest appreciable movement we have been struck with the tendency to inconstant answers when testing the affected limbs. On the normal side most patients are remarkably constant and the values obtained often do not vary by one degree. Thus when the normal elbow was flexed or extended in one case all the answers lay between 1·5° and 2·5°. But with movements at the affected elbow the answers ranged between 10° and 22°.

Another striking phenomenon in these cases is the occurrence of hallucinations of movement. Even though the limb remains at rest the patient may describe sensations of movement which seem to him as clear as those evoked by our manipulations.

In conclusion, we find, like most of our predecessors, that—

(1) Cortical lesions most frequently disturb the recognition of posture and of passive movements. Whenever sensation is in any way affected in consequence of a cortical lesion these two functions generally suffer.

(2) In all our cases the disturbance in the faculty of recognising posture and passive movements was greater towards the peripheral parts of the affected limb.

(3) When a patient with unilateral disturbance of these faculties attempts to point to some part of his body, defective knowledge of its position causes greater error than want of recognition of posture and movement in the hand with which he points.

(4) When testing the patient's power of appreciating passive movement, the answers are frequently uncertain and hallucinations of movement may occur. And yet the patient may be remarkably consistent and accurate when normal parts are tested.

§ 5.—Localisation

By localisation we understand the power of recognising correctly the spot that has been stimulated, and it would seem, at first sight, that little difficulty could arise in discovering whether this faculty was affected or not; but a good deal of confusion exists owing to technical difficulties inherent in the methods usually employed to investigate the power of localisation.

Of all the methods at present in use that of Henri is probably the most suitable. Excellent and simple as we found this method, it labours under one serious defect for clinical purposes. Some of our patients were liable to become confused when asked to point out the spot stimulated on a diagram, picture, or even on a photograph of the hand. We therefore adopted the following modification, which we found to be a great improvement on the original Henri method.

The hand to be tested, for example the left, is hidden from the patient's sight with a screen. One of us standing behind places his own left hand in a similar position in full view of the patient, who indicates on this living model the situation of the place where he believes he has been touched. A second observer marks on a life-sized diagram the position of the stimulated spot and the point indicated by the patient. This method we have employed throughout this work. It avoids both the technical difficulties of spot-naming and the fallacies of the groping method, and is peculiarly useful in clinical investigations.

The uncertainty and irregularity of response to tactile and pressure stimuli, so common a consequence of cortical lesions, is liable to lead to fallacious results when testing the power of localisation. We usually, therefore, touch the spot with some blunt instrument of neutral temperature, and continue the touches until the patient says he appreciates the contact. He then indicates on the hand of one of the observers the situation of the stimulated spot.

Were we concerned with a cutaneous sensory loss consequent on a lesion of peripheral nerves this method would be fallacious, for such touches stimulate the afferent mechanism of deep sensibility. But tactile impulses evoked from the skin and those which pass by way of the deep afferent system have united into a single tactile group long before they reach the optic thalamus. We are, therefore, justified in using any form of tactile stimulus which the patient can appreciate, in order to test his power of localisation.

The power of recognising the position of a spot stimulated is comparatively seldom affected as a consequence of pure cortical lesions, provided all periods of shock are avoided. Most seizures, and all operations on the brain, are followed by temporary loss of this function, grossly in excess of anything found with stationary lesions of the cortex.

The methods we have employed enable us to discover whether the power of localisation is intact or not, although the patient is entirely ignorant of the position of the affected limb; it may be, even under these conditions, that every part of the affected hand can be touched in succession without a single mistaken answer. But, should localisation be affected, scarcely a single stimulus is referred to its correct position and the patient frequently complains that he has "no idea" where he has been touched.

Some observers (Russel and Horsley [101]) have stated that, when localisation is disturbed by lesions of the cortex, the position of the indicated spot lies in some constant relation to that of the point stimulated. Our failure to discover any uniform tendency to erroneous localisation in one direction is probably due to the method we have adopted, and particularly to the avoidance of groping.[1] The dual and composite nature of the groping method is well shown by the effect produced by moving the hand: movements of which the patient is unconscious may cause a fundamental change in the direction towards which he tends to localise, if he is allowed to grope for the spot touched. Thus proximal can be converted into distal localisation by drawing the hand

[1] If the power of localisation is tested in this way, the patient will usually tend to place his finger on a point proximal to the stimulated spot. But this is due to defective recognition of the position of the limb in space and to the consequent tendency for its distal segments to seem closer to the trunk than is in reality the case. The same "shortening" is present in many cases of phantom limbs following amputation.

nearer the body, and a preponderating tendency to localise in a postaxial direction can be converted into a pre-axial direction by turning over the hand. Suppose that, when testing the dorsum, the majority of the points indicated lie towards the ulnar side of the stimulated spots; reverse the hand and the larger number will now lie to the radial side. These apparently inconsequent results depend upon the dual nature of the groping test and disappear entirely with the methods we have used.

Moreover, by our methods we obtain records which can be studied at leisure, and the number of observations permanently recorded is sufficient to indicate whether the errors in any direction are due to chance or to a constant displacement of locality.

We cannot insist too strongly that, when localisation is defective from lesions of the cortex, the stimulus is not usually localised in some false direction, but the patient has a vague and uncertain idea amounting in some cases to complete ignorance of its position.[1]

In one case localisation was disturbed in the left hand in consequence of removal of a portion of the cortex five years ago (Case 15). On the normal hand, every touch was correctly localised, but on the abnormal hand, out of thirty-three tactile stimuli six only were correctly placed. Eleven were thought to be proximal and eight distal to the spot touched; six were localised falsely over parts of the same level, and in two cases he said he had no idea of the situation of the touch.

Thus the following records were recently obtained from a man in whom a portion of the cortex had been removed from the left hemisphere in 1904 (Case 17). The localisation of fifty-six tactile stimuli on each hand could be classified as follows :—

	Correct.	*Proximal.*	*Distal.*	*Same level.*	*"Don't know."*
Normal hand (L.) ..	43	4	2	7	0
Affected hand (R.) ..	14	5	13	14	10

Erroneous localisation is not due to the uncertainty in tactile appreciation so commonly produced by a cortical lesion; for it is equally manifest when the stimulus that the patient is asked to localise is a prick about which he is never in doubt. The following observations were made by asking one of our patients with defective localisation to indicate the position of a series of pricks :—

	Correct.	*Proximal.*	*Distal.*	*Same level.*	*"Don't know."*
Normal hand (R.) ..	20	0	0	0	0
Abnormal hand (L.) ..	5	6	6	3	0

Defective localisation is not a necessary concomitant of the defective recognition of posture so commonly produced by cortical lesions. In several cases where the appreciation of position and passive movement was gravely

[1] For a further discussion of this question see p. 698.

affected localisation was demonstrated to be perfect by every method except that of groping for the stimulated spot.

For instance, in the case where a small portion of the cortex was removed in 1908 the appreciation of position and passive movement was gravely affected (Case 14). But from observations made on many occasions during the last three years we were unable to find any difference between the power of localisation on the two hands, provided the groping method was avoided. He was equally correct whether we used the original or the modified Henri method. He preferred, however, the latter; it seemed to him easier and his answers were more quick and certain.

Moreover, in these cases where the sense of position is gravely defective but localisation is good, changing the position of the limb passively does not diminish the accuracy with which the point of stimulation is indicated, provided the groping method is avoided. If a series of readings are taken in the usual way, and, whilst the affected hand still remains screened from sight, its position is changed, subsequent readings are no less accurate than the first series. We can therefore state definitely that the power of recognising the position of the limbs can be gravely affected as a consequence of cortical lesions without disturbing the accuracy of localisation.

The faculty of localising the stimulated spot as determined by all methods except groping is less often affected by a cortical lesion than the power of appreciating posture. In fact, we have not yet seen a case in which localisation was disturbed without a coincident loss in postural recognition.

The conclusions to which we have arrived in this section may be summed up as follows :—

(1) The power of localising the stimulated spot is not infrequently preserved, although sensation may be otherwise disturbed as a consequence of cortical lesions.

(2) This faculty is independent of the power of recognising the position of the affected limb; appreciation of posture may be lost, although localisation is not in any way diminished.

(3) If the power of localisation is lost, the patient will be unable to recognise not only the position of a spot touched, but also the position of a prick.

(4) When localisation is defective in consequence of cerebral lesions, the patient does not habitually localise in any particular direction, but ceases to be certain where he has been touched or pricked.

§ 6.—The Compass Test

Loss of the power to distinguish two points applied to the skin simultaneously is one of the most striking changes produced by cortical lesions. It is not present in every case; the patient may have difficulty in recognising the posture of the affected limb, and the appreciation of passive movements may be diminished, yet the compass test may yield equally good results on the two sides.

But with the larger number of cortical lesions the discrimination of two points will be affected. It may be, in the milder cases, that the threshold is raised; to these we shall return later. More commonly no threshold can be obtained even by separating the limbs of the compasses to the widest extent possible within the limits of the principal segments of the affected limb. If a bad record is obtained when the points are 5 cm. apart, widening the distance to 20 cm. may cause no material improvement. Decreasing the difficulty of the problem does not of necessity improve the accuracy of response; determination of a threshold has become impossible.

Any defect in tactile sensibility is liable to disturb the compass records. When, therefore, we consider the peculiar changes described in the first section of this chapter, the loss in discrimination of two points might appear at first sight to be due to diminished tactile acuity. This cannot, however, be the cause of the defective compass records; for the inability to distinguish two points applied simultaneously is equally definite if each limb of the compasses is armed with a needle and two pricks replace the two tactile stimuli.

We have already seen that the recognition of a prick is never destroyed in consequence of a cortical lesion, and sensibility to pain undergoes no changes analogous to those of tactile sensibility. It is therefore obvious that the power of recognising "two-ness" is a separate function of sensation which may be destroyed by a cortical lesion. This loss is not dependent on the changes in tactile sensibility, though the two defects are strictly analogous phenomena.

The response to graduated tactile stimuli is irregular and uncertain. The patient responds intermittently to a stimulus of low intensity, but increasing the stimulus does not necessarily increase the proportion of right answers. An exactly similar change is revealed by the compass test. All recognition of the double nature of the stimulus may be lost, and it does not matter whether the two points are sharp or blunt. All estimation of a threshold has become impossible, not because the patient is insensitive to the contact of the two points but because the faculty of distinguishing them has been destroyed by the cortical lesion. This is exactly analogous to the impossibility of obtaining a tactile threshold, and the two phenomena co-exist in most cases.

Not every cortical lesion produces so severe a loss of compass discrimination. Although the recognition of posture is disturbed, the compass records may remain equally good on the two sides; but as soon as tactile sensibility shows any of the changes produced by a lesion of the cortex the power of distinguishing two points will also suffer.

Sometimes, in cases where sensation is little disturbed, it is possible by widening the distance between the compass points to obtain a perfect record over the affected part; a true threshold can then be discovered. But the records tend to be confused by the same irregularity and uncertainty of response so characteristic of the disturbed tactile sensibility in these cases of cortical disease.

Weber's test consists in applying the two points strictly at the same moment. We have already seen that, when this test is affected by lesions at lower levels of the nervous system, the patient can still recognise the double nature of the stimulus if one point is applied to the skin even a fraction of a second after the other. From their origin at the periphery, the impulses which underlie the appreciation of two points applied successively, run separately from those by which we are able to recognise the simultaneous application of the compasses.

But, in a certain proportion of cortical cases, it does not matter whether the compasses are applied simultaneously, or whether an interval is allowed to elapse before the second point touches the skin. The power of recognising the double nature of the stimulus is lost, and no increase of the distance between the two points makes a constant or material difference to the accuracy of the answers. If the interval is greatly prolonged between the moments at which the first point and the second point touch the surface, the patient generally answers "one" to each application. That is to say, he fails to recognise with any certainty that two points are in contact with his skin, although he perceives each touch separately. Evidently he has lost that faculty by which "two-ness" is recognised, and it does not matter whether the points are applied simultaneously or successively.

Now, whenever successive application of the two points is recognised localisation will be found to be intact. The power of appreciating two points applied successively is in reality the faculty of localising two spots that have been stimulated one after the other. It is independent of the power of discriminating two stimuli which act upon the surface at the same moment.

This difference was clearly shown in a series of observations made in Case 14. We found that the patient could not recognise two points separated by 3 cm. applied transversely across the back of the hand or fingers. Localisation was, however, perfect and he never failed to name correctly the finger that had been touched. The compass points were then separated to a distance of 2·25 cm., and so applied that each point fell over the basal phalanx of a separate finger. So long as the compasses were applied strictly simultaneously he never said he had been touched on two fingers, but always selected one or the other: he thought he had been stimulated with one point only. But as soon as even a fraction of a second was allowed to elapse between the two contacts he invariably recognised that he had been touched with two points and named the two fingers correctly. The faculty of localisation was intact, and he was thereby enabled to appreciate the double contact, provided that the two points did not touch the surface at the same moment.

We may conclude from the observations described in this section that—

(1) A cortical lesion may destroy the power of discriminating two compass points, both when applied simultaneously and successively.

If this is the case, no threshold can be obtained for either form of the test; increasing the distance between the points does not constantly improve the accuracy of the answers.

(2) This disturbance is not caused by changes in tactile appreciation; for it can be demonstrated equally well with two painful as with two tactile stimuli.

(3) The condition of tactile sensibility and the accuracy of the simultaneous compass test are closely associated; a disturbance of the tactile threshold is usually accompanied by a raised threshold for the appreciation of two points applied simultaneously.

(4) Should the power be preserved of recognising two points when the compasses are applied consecutively, localisation will be found to be intact. The patient's appreciation of the two points when they are separated by an interval of time is due to the recognition of the separate locality of the two spots touched.

§ 7.—The Appreciation of Weight

This test has been too frequently neglected in clinical work, probably because it demands considerable care on the part of the observer, and goodwill in the patient. When carefully carried out no test is more satisfactory; for the results can be expressed in a numerical relationship, and when the faculty of recognising differences in weight is disturbed, the errors, compared with those of the normal hand, are enormous.

There are several ways of conducting this test which are fully described in the chapter on methods. But at the highest sensory level, the appreciation of difference in weight depends mainly upon two faculties. When a weight, placed upon the fully supported hand, is either increased or diminished, the recognition of the change is based mainly on the power of appreciating differences in pressure. To estimate the relation between two weights placed upon the hand one after the other requires not only an appreciation of pressure, but the power of relating some consequence of the first weight with the immediate effect of the second weight. Lastly, when a weight is placed at the same moment in each palm, and the patient is allowed to "weigh" the two objects against one another, he relies mainly upon his power of estimating movement and posture.

Cortical lesions usually diminish the accuracy of the answers to all three tests, and, if sensation is severely affected, all power of estimating weight may be lost. Although the patient may still appreciate the contact of the weights that are placed upon his hand, he may be totally unable to recognise their relation to one another, however the test may be applied.

Occasionally, the sensation of something in contact with the hand persists for many seconds after the removal of the weight. But although the patient believes that something still lies in his hand, he cannot estimate its weight in relation to an object on the opposite palm. He says, "It is still there, but it does not seem to have any weight."

Conversely, the following condition can be frequently observed. A weight is placed in each hand and allowed to remain there. From time to time the patient is asked to estimate the relation between the two weights. He will almost certainly say that the one in the normal hand is heavier; but gradually he begins to think that there is no weight in the abnormal hand, and the sensations produced by its removal may even be mistaken for the re-application of the weight to the hand. He says, "You have put the weight on again."

In conclusion, we have found that—

(1) The power of estimating the relative weight of two objects of the same size and shape is readily disturbed by cortical lesions.

(2) Though the patient may retain sensations of contact when the weight is placed in his hand, all power of recognising the relative heaviness of the object has disappeared.

(3) This faculty is equally disturbed in most cases, whether the weights are placed on the supported or unsupported hand.

§ 8.—Appreciation of Size, Shape and Form in Three Dimensions

To recognise size, shape and form demands that the relation between two percepts should be correctly appreciated. In the case of the tests for size, we frankly ask our patients for the difference between two objects of the same shape. When testing for shape and form, a relation is always implied between the test-object and something which the patient has experienced before.

In most cases, when sensation is affected, appreciation of size, shape and form in three dimensions is lost; the patient usually complains that he has "not the least idea" of the shape or relative size of the test-objects. Although he insists that he "can feel them quite well," they convey no indication that they possess size, shape or form. One of our patients recognised that the cone had a point because in his manipulations he pressed it into his hand; but he had no idea that it possessed any shape.

This total abolition of the power to recognise size, shape and form makes the defect peculiarly easy to discover even by the crudest tests. Thus it is universally acknowledged that cortical lesions tend to destroy the power of recognising common objects, such as a knife, scissors, or coin placed in the hand, and our more accurately graded tests simply serve to confirm this general consensus of opinion.

This defective recognition is not in any way due to the paralysis produced by the cortical destruction; for, in two cases where the movement of the hand was gravely affected, size, shape and form were perfectly recognised. When a test-object is placed in the patient's hand it is of advantage if he can roll it between his fingers; but where the faculty of recognising these tests is maintained, even objects in three dimensions will be named correctly if the patient's fingers are closed over them passively.

The correct appreciation of size, shape and form does not depend to any great extent on the recognition of posture; for it was perfectly retained in two cases, although postural recognition and the appreciation of passive movement were gravely affected.

But in most cases where the sense of posture was affected and we were unable at the same time to obtain a tactile threshold, all recognition of size, shape and form in three dimensions was abolished. Not that such recognition depends directly upon the state of tactile sensibility. The combined affection of the sense of posture and loss of the tactile threshold indicate simply that the defect produced by the lesion has reached a sufficient grade to destroy the power of recognising similarity and difference. The appreciation of size, shape and form, therefore, suffers like all tests which imply a relation.

§ 9.—Roughness and Texture

The power of appreciating roughness can be compared on the two halves of the body by means of the Graham-Brown æsthesiometer. In this instrument one or more cylinders are projected to a measurable extent from a smooth metal surface; and the patient says whether the instrument is smooth or rough when it is moved across some part, such as the hand.

In no case of quiescent cortical lesion was there any appreciable difference between the affected and normal parts. Not only could the patient experience no difference, but the extent to which the cylinder must be protruded to evoke a sensation of roughness was the same for the two sides. This stimulus is one which can be appreciated, notwithstanding grave loss of sensibility produced by a cortical lesion.

But, in spite of this power to recognise the roughness or smoothness of the surface of the æsthesiometer, all appreciation of texture may be lost. This test demands not only the immediate recognition that the object is rough or smooth, but the relation of that sensation to other percepts. Thus, although he may know that one surface is rough and another is smooth, he may be unable to name the substance by its texture. Cotton, silk and stamped velvet are all one to the affected hand, although readily distinguished on the normal side. When once this test has been applied the patients often complain that they have lost all idea of texture, saying, "I can feel it, but I have not the least idea what it is."

These two tests, both depending on the same sensory impulses, clearly illustrate the nature of the loss of sensibility produced by cortical lesions.

The one depends upon the immediate appreciation of a smooth or rough stimulus. The other demands the correct relation of one group of percepts to another. The first is therefore maintained, whilst the second is destroyed by any cortical lesion which produces a measurable disturbance of sensibility.

§ 10.—Vibration

At lower levels of the nervous system, a lesion frequently destroys all power of appreciating the vibrations of a tuning fork. But we believe this never occurs from a stationary cortical lesion.

Usually the patient can discover no difference in the sensations produced by the fork on the two halves of his body. Occasionally, however, he says it seems "plainer," or "stronger," on the normal than on the affected limb. If this is the case the vibration will be appreciated for a shorter period over the affected parts. The fork is set in motion and the patient is asked to say when he can no longer appreciate the vibration. It is then rapidly transferred to a similar spot on the normal limb, and vibration may still be recognised for as much as twenty seconds longer. If this defect were greatly increased it is obvious that the power of recognising vibration would be abolished; but this never occurs from a pure cortical lesion. The vibration of a tuning fork seems to contain some sensory element which insures that it is appreciated, even though the cortex is gravely affected. But the cortical lesion diminishes the "plainness" of the sensation and shortens its duration.

In some cases, the vibration of the tuning fork not only seems "plainer," but is said to beat "faster" on the normal than on the affected limb. As this depends entirely on introspection a few patients only have noticed it, and we have avoided questions which might suggest a difference in apparent rapidity on the two sides.

CHAPTER IV

ANALYSIS OF THE LOSS OF SENSATION PRODUCED BY LESIONS OF THE OPTIC THALAMUS AND NEIGHBOURING PARTS

In a previous chapter we have described the various forms of sensation which may be disturbed by lesions of the optic thalamus and of the parts in its neighbourhood. Test by test we followed the loss of sensation, and showed that it varied in different cases within extreme limits. We shall now attempt to discover by analysis of these disturbances of sensation whether the impulses which pass away from the optic thalamus differ in their grouping from those which enter this organ from the mid-brain.

Since the optic thalamus is the terminal station for all secondary sensory paths, a lesion situated within its limits might destroy the receptive structures in which their impulses end; in such a case the loss of sensation would correspond to that produced by an equivalent lesion of the tracts of the mid-brain by which these impulses are conducted to the optic thalamus.

On the other hand, the lesion might leave this receptive mechanism intact but interfere with the paths that are streaming away to the cortex. In this case the sensory defect would reveal what elements of sensation pass to the cortex after they have been regrouped in the thalamus.

In so complex a structure as the thalamus, containing a multitude of incoming and outgoing paths, no lesion could destroy completely one set of impulses only. But, although most cases show evidence of a diffuse disturbance of sensory functions, some point more to partial interference with the receptive mechanism, and some to destruction of the paths which run from the thalamus to the cortex. We shall analyse these two groups separately in order to discover, if possible, the nature of the rearrangement which takes place in the thalamus, and to determine the grouping of the sensory impulses which pass away from this junction to the cortex.

As our object in these chapters is to study the nature of the loss of sensation, and not to erect clinical categories for diagnostic purposes, we shall not deal with those cases where a widespread lesion of the optic thalamus abolishes all sensation on one half of the body, and consequently no over-response to affective stimuli is possible.

§ 1.—Disturbance of the Afferent Receptive Mechanism in the Optic Thalamus

In certain cases, which show the over-reaction to affective stimuli and other signs indicative of a lesion of the optic thalamus, the loss of sensation is extremely gross. Not only is sensibility for touch and temperature abolished, but even the threshold for painful stimuli may be raised. Pain, once appreciated, produces more discomfort on the affected half of the body; but in order that this appreciation may occur, the stimulus must be more intense than on the normal side. The strength of a prick, and the amount of pressure required to produce pain, are greater over the affected parts, although as

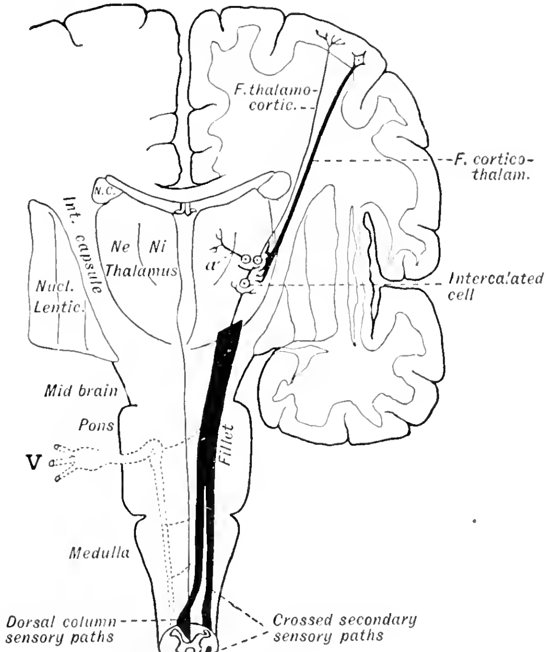

Fig. 159.

To represent diagrammatically the anatomical arrangement of the paths and centres concerned in sensation. Two distinct paths exist in the spinal cord; a crossed secondary path in the ventrolateral column which conveys impressions of pain, temperature and touch, and a second uncrossed path in the dorsal column which also carries touch, and in which run impulses that underlie the sense of position, the appreciation of movement, the discrimination of two points, and the recognition of vibration, size, shape, form, weight and consistence. This second path decussates in the lower part of the medulla oblongata, but runs separate from the first path at least as high as the pons. All these secondary sensory fibres, now crossed, terminate in the ventrolateral region of the optic thalamus. The impressions they carry are regrouped here and, through intercalated neurones, are distributed along two distinct paths; the one carries impressions to the cerebral cortex, the other, we assume, towards the more mesial parts of the optic thalamus. The cortico-thalamic fibres, which terminate in the lateral nucleus of the optic thalamus, are also shown.

soon as pain is produced the reaction is excessive. This loss of sensibility is probably due to interference with painful impulses either in the receptive portion of the optic thalamus, or as they still run in the secondary sensory paths which end in this junction.

This conclusion is supported by the extreme loss of other forms of sensation which is found in cases where the pain-threshold is distinctly raised. Moreover, instances have been recorded in the literature where the loss of sensation was of the grossest kind and, although no attempt was made to determine the threshold for various forms of painful stimuli, we have little doubt, from their likeness to cases under our observation, that the threshold must have been raised. This was the condition in a case described by Roussy, where autopsy revealed a lesion in the neighbourhood of the termination of the fillet.

In one of the cases (Case 6) we have cited in Chapter II sensibility to prick was gravely diminished, and the algometer readings were uniformly higher on the affected half of the body in spite of the profound over-reaction to both stimuli. The patient was entirely insensitive to the thermal element of heat and cold, and showed no discomfort until ice, or water at 60° C., was used: then, however, the response was excessive on the affected half of the body. Even sensibility to the tactile elements of pressure was gravely affected.

Autopsy showed that the caudal portion of the lateral nucleus of the optic thalamus close to the ending of the fillet was the seat of a lesion of vascular origin. In this case a few impulses evoked by stimuli of high intensity could pass the receptive junction of the optic thalamus and excite sensations of pain and discomfort. Had the lesion caused a slightly graver interference with these impulses the loss of sensation would have been absolute, and the characteristic over-response to affective stimuli could not have made its appearance. Roussy ([100], Case 2) has observed an instance of this condition where the patient was insensitive to all stimuli, and the upper end of the fillet within the optic thalamus was found to be involved in the lesion. In such cases the forms assumed by the loss of sensation resemble those produced by a mid-brain lesion: the threshold for touch, for pain, for heat and for cold are much raised, and sensibility to one or more of these stimuli may be abolished entirely.

We believe that in all cases which present the "syndrome thalamique," accompanied by loss of sensation so gross that the threshold is raised to affective stimuli, the receptive mechanism is affected; this seems to be situated mainly in the caudal portion of the lateral nucleus of the optic thalamus.

§ 2.—Disturbance of Sensory Impulses as they pass from the Optic Thalamus to the Cortex

In certain cases which show characteristic signs of a lesion of the optic thalamus, the threshold to prick is identical on the two halves of the body and the readings of the pressure algometer may be actually lower on the affected side. The loss of appreciation of posture and passive movement may be severe, and the power of comparing two weights may be diminished, but the remaining forms of sensibility are less grossly affected than in that group of cases we have just considered in § 1 of this chapter.

Here we believe that the receptive mechanism is not affected to any material extent. The complete retention of painful sensibility shows that the impulses upon which it is based have been allowed to exert their full influence on the central organ where they are transformed into sensation. Moreover, the sensory elements are dissociated in ways which are unknown, until this level is reached; both the nature of the loss of sensation and the character of the sensibility which remains show that the afferent impulses must have been interrupted after they have undergone a fresh regrouping at the thalamic junction. An analysis of these forms of dissociated sensation will therefore show the grouping of the impulses which pass away from the optic thalamus to act upon the sensory cortex.

The first remarkable fact revealed by a study of these cases is that, whenever a stimulus can be appreciated, a threshold can be obtained. The tactile threshold may be raised, but increasing the strength of the measured stimulus improves the accuracy of the answers. In the same way it may be necessary to employ a colder or a warmer tube to evoke a thermal sensation, but, as a rule, a threshold can be obtained without difficulty. Sensibility to any one stimulus tends to be diminished rather than to be abolished completely.

When we turn to the forms assumed by the loss of sensation we find that in every case the recognition of posture and passive movement was more or less gravely disturbed. Sometimes the loss was so slight that it could be discovered by measurement only; but in every case a difference was demonstrable between the two sides. Whenever this loss of appreciation of posture and passive movement exceeded a scarcely perceptible amount, it was accompanied by a diminished power of estimating the difference in weights placed on the unsupported hands.

Tactile sensibility was frequently diminished in these cases, but was never abolished completely. Stronger hairs might be necessary to evoke an answer, but ultimately a threshold could usually be obtained, and increasing the stimulus led to an increase in the accuracy of the responses.

Any material raising of the tactile threshold was accompanied by inability to appreciate the relation of weights placed on the fully supported hand one after the other. Moreover, the patient could no longer recognise with certainty increase or decrease of a weight resting on the affected hand.

Not uncommonly, the simultaneous compass test was also affected and a threshold could not be obtained until the points had been separated to many times the distance necessary on the normal side. Wherever this test was defective, the power of recognising size and shape was diminished, showing the probable association at this level of the nervous system of the impulses upon which these various functions depend.

Localisation was less often disturbed in the cases at present under consideration; but occasionally the patient had lost the power of indicating correctly the position of the stimulated spot. Whenever localisation was disturbed, the power of recognising two compass points applied consecutively was also affected.

Thermal sensibility was frequently intact in this group of cases. The impulses underlying heat and cold seem to run together in a distinct path, which not uncommonly escapes when the sensory loss is of the type at present under consideration. But if thermal sensibility is disturbed, heat and cold are affected together, after passing the thalamic junction.

Vibration of a tuning fork could always be appreciated, but in the majority of cases in this group its duration appeared to be shortened; if the vibration of the fork seemed to have ceased on the affected half of the body, it could still be appreciated for from five to twenty seconds longer on a similar normal part.

Thus it would seem that sensory impulses travel from the optic thalamus to the cortex in five groups.

(1) Those concerned with the recognition of posture and passive movement. If these impulses are affected the power of discriminating weights on the unsupported hand may also be diminished.

(2) Certain tactile elements: integrity of this group is necessary for the discrimination of weights placed on the fully supported hand.

(3) Those impulses which underlie the appreciation of two points applied simultaneously (the compass test): on this group also depends the recognition of size and shape.

(4) Those which underlie the power of localising the situation of a stimulated spot. Recognition of the double nature of two points applied consecutively also depends on this group of impulses.

(5) All thermal impulses are grouped together to underlie a scale of sensations with heat at the one end and cold at the other. At the level with which we are now dealing these impulses have already excited the affective centre and are passing away to the cortex.

CHAPTER V

THEORETICAL CONCLUSIONS

So far we have described in detail the effects which may follow lesions situated in different parts of the brain. In the present chapter we shall attempt, by analysis of these results, to present a coherent account of the mechanism of sensation.

We believe there are two masses of grey matter, or sensory centres, in which afferent impulses end to evoke that psychical state called a sensation. One of these is situated in the optic thalamus, whilst the other consists of a considerable area of the cerebral cortex.

The anatomical structure known as the optic thalamus is an extremely complex portion of the brain, and contains not only the terminal centre for certain aspects of sensation, but plays a threefold part in the fate of sensory impulses:—

(1) Firstly, it contains the termination of all secondary paths; here sensory impulses are grouped afresh and redistributed in two directions, on the one hand to the cortex cerebri, and on the other to the grey matter of the optic thalamus itself (*vide* Chapter IV).

(2) Secondly, it contains a mass of grey matter, the essential organ of the thalamus, which forms the centre for certain fundamental elements of sensation. It is complementary to the sensory cortex and exercises different functions in the production of sensation.

(3) Lastly, the lateral part of the optic thalamus is the organ through which the cortex can influence the essential thalamic centre, controlling and checking its activity. The excessive response to affective stimuli, so prominent a feature of lesions in this situation, is not due to irritation but to removal of cortical control.

Next, we shall consider the nature of the activity of the sensory cortex. We shall show that it is concerned more particularly with discrimination and with the relation between two sensations, or between a sensation and its representation. It is essentially the organ by which attention can be concentrated on any part of the body.

Finally, we shall deal with the interaction of the cerebral cortex and the centre in the optic thalamus during the production of sensation.

§ 1.—The Essential Activity of the Thalamic Centre

The most remarkable feature in that group of thalamic cases with which we have dealt in this work is not loss of sensation, but an excessive response to affective stimuli. This positive effect, an actual overloading of sensation with feeling-tone, was present in all our twenty-four cases of this class; and, though emphasis has not been laid upon it as a characteristic feature, it has been observed by others in cases where the existence of a lesion in the lateral zone of the optic thalamus was confirmed by autopsy (Roussy [99, 100], Edinger [28]).

This excessive response may be accompanied by much or by little loss of sensation, but the extent of this loss bears no relation to the amount of the over-reaction to painful stimuli. It is only necessary that sufficient sensory impulses, capable of exciting discomfort, should still be able to reach consciousness. If this is possible, the affected half of the body will respond more profoundly than normal parts to all painful stimuli, in spite of the gross loss of sensation.

But the characteristic thalamic response does not consist in an excessive reaction to painful stimuli only. In suitable cases we have shown that the response to pleasurable stimuli, such as warmth, is also greater on the affected side. Moreover, the manifestations of general mental states of pleasure and of discomfort may be more pronounced on the abnormal half of the body.

The pains and uncomfortable "paræsthesiæ" which occur in these cases have been explained by some observers as due to irritation. The lesion is supposed to irritate some part of the sensory path in the region of the optic thalamus and thus to produce pains and "hyperalgesia." But this conventional hypothesis is insufficient to explain the observed facts in the clinical course of these cases. In the large majority of instances the lesion has proved to be a hæmorrhage or a softening. Now all vascular lesions of the nervous system notoriously tend to produce the greatest disturbance of function at the time when they occur: the subsequent progress of the case always shows a certain amount of recovery. But in this group of thalamic cases the pains and over-reaction come on, as a rule, during the stage of recovery of function, frequently at a considerable period after the "stroke" has occurred, and they usually last unaltered for years.

Moreover, we have pointed out that the response to pleasurable stimuli is also increased in some of these cases, a condition incompatible with the constant existence of an irritative lesion which evokes pain.

Further, we have not found this peculiar over-response from lesions of other parts of the sensory path,[1] and the extreme rarity of such cases in the

[1] Spontaneous pains associated with over-sensitiveness to prick or other stimuli have been described as a consequence of lesions of the central nervous system at other parts of the sensory path, but few of these cases will stand criticism. For example, in the case published by Raymond and Rose [95] as a lesion of the pons varolii the authors themselves admit the possibility of multiple lesions, and the presence of choreic and athetoid movements points in all probability to affection of the optic thalamus. Raymond and Français [94] recorded a pontine case in which pains and "hyperæsthesia" to prick were present, but the position of the lesion was not determined by autopsy. In Mann's case [75] there was merely persistent unilateral pain, and Mann himself recognised that this was accompanied by "hypæsthesia" and not by "hyperæsthesia," as in Edinger's case of thalamic disease, with which he contrasted it.

literature compared with the overwhelming frequency of this over-response with the lesions of the optic thalamus, compels us to adopt some other explanation for its occurrence at this level of the nervous system.

It is obvious, therefore, that the attempt to explain this condition by a hypothetical irritation fails entirely, and we must consider whether the clue is not to be discovered in the removal of some control normally exerted by one sensory centre upon another.[1]

Let us turn for a moment to the motor side of the nervous system, where the effects produced by removal of control are more fully understood. It is well known that a lesion of the motor region of the cerebral cortex, or of the tracts which run from it to the spinal cord, produces not only loss of voluntary movement, but also a positive effect in the increased tone and rigidity of the affected limbs. This increase of tone, as Hughlings Jackson [57] pointed out in the Croonian Lectures, is not the direct effect of the destructive lesion, but is produced by the activity of subcortical centres released from control. He laid down the law that no destructive lesion can produce a positive effect directly. The activity of the cortex cerebri normally inhibits and controls subcortical motor centres and the destructive lesion sets these centres free to display their powers unchecked. Loss of voluntary power is consequently associated with tonic over-action and an increased reflex discharge in response to afferent impulses.

We believe that an exactly similar condition is revealed on the sensory side of the nervous system by cases of thalamic disease accompanied by an excessive response to peripheral stimuli. We know that paths run, not only from the optic thalamus to the cortex, but from the cortex to the thalamus, and they have been shown to terminate in its lateral zone, the very region affected in cases that have exhibited the "syndrome thalamique." But, since these paths come from all parts of the cortex to impinge upon the optic thalamus, the functions they exercise cannot be removed by partial destruction of the cerebral hemispheres; cortical lesions produce no thalamic over-response to affective stimuli. The only certain method of releasing the optic thalamus from the influence exerted by the cortex is to destroy the lateral nucleus in which the majority of these cortico-thalamic paths seem to end. It is probable that a subcortical lesion so situated that it destroyed all these paths just before they entered the thalamus might produce the "syndrome thalamique," although the substance of this organ remained intact; but such lesions are rare compared with those which produce this effect by destruction of part of the thalamus itself.

The only function which can be ascribed to these cortico-thalamic paths is that through them the cortex controls, in some way, the activity of the

[1] The condition known as protopathic sensibility, arising from lesions of peripheral nerves, is also characterised by an over-response to painful and to thermal cutaneous stimuli. This over-response is due to the uncontrolled action, on normal sensory centres, of impulses capable of exciting sensations heavily charged with feeling-tone.

thalamus. If this view is correct, lesions which interrupt these paths, but leave intact the main substance of the optic thalamus, must lead to a permanent over-activity of functions exercised by that organ. Any afferent impulses, which are capable of exciting this part of the brain, will act on an uncontrolled centre and must, consequently, evoke an excessive effect.

All stimuli which produce an excessive effect, when the thalamus is freed from cortical control, contain elements which can excite the essential centre of this organ. Analysis of the over-response in these thalamic cases will, therefore, reveal what sensory qualities are due to the activity of the optic thalamus. Now we have shown that the nearer a sensation approaches pure discomfort, the more certainly will the response be exaggerated on the affected half of the body. States of pleasure and stimuli, such as warmth, capable of exciting pleasurable sensations, may also evoke excessive manifestations on the abnormal side. Since, therefore, affective states can be increased when the thalamus is freed from cortical control, we may conclude that the activity of the essential thalamic centre is mainly occupied with the affective side of sensation.

This conclusion is strengthened by the fact that stationary cortical lesions, however extensive, which cause no convulsions or other signs of irritation and shock, produce little or no effect on sensibility to pain. Destruction of the cortex alone does not usually disturb the threshold for the painful or uncomfortable aspects of sensation.

Some stimuli, not commonly included amongst those which evoke pleasure and discomfort, may produce an exaggerated response when the grey matter of the optic thalamus is free to react unimpeded. Thus, cotton wool moving over a hair-clad part may produce a "stronger" sensation on the abnormal half of the body. Roughness is another stimulus which appeals to the essential thalamic centre and not uncommonly produces an exaggerated response over affected parts. The vibration of a tuning fork, applied to the surface of the body, also contains an element which may produce an excessive effect and, in most cases, although the length of time during which the vibrations are appreciated is materially shortened, the patient asserts that the sensation is "stronger" on the abnormal side.

But all these stimuli evoke sensations more or less allied to tickling and scraping, and it is not surprising that the affective element should be exaggerated. We believe, however, that an appeal can be made to the essential thalamic centre by stimuli which produce changes of internal state other than those of pleasure and discomfort. A cortical lesion never abolishes sensibility to contact; the response may be intermittent, irregular, and grossly defective, but is never completely absent. A weight resting on the hand may not be recognised, but at the moment it is placed on the skin and, not infrequently, when it is removed, or even gently touched, the patient says that "something has happened." When the loss of sensation is extremely severe, and all sensory impulses passing to the cortex have been cut off, the patient may be unable to recognise that the effect he experiences is produced by an external object and may simply reply that something is happening to him. These contact stimuli, which may produce this vague sensation of "something happening" within the body, evoke precise recognition that an object is acting on its surface when the cortical paths are intact. Under normal circumstances the thalamic element in contact sensibility rarely, if ever, reaches consciousness, which is dominated by discriminative sensations of touch, and it only becomes a conscious factor in sensation when the influence of the cortex is removed.

Thus, we believe that the essential organ of the optic thalamus is the centre of consciousness for certain elements of sensation. It responds to all stimuli capable of evoking either pleasure and discomfort, or consciousness of a change in state. The feeling-tone of somatic or visceral sensation is the product of thalamic activity, and the fact that a sensation is devoid of feeling-tone shows that the impulses which underlie its production make no thalamic appeal.

The functions of this organ are influenced by the coincident activity of the cortical centres, and this control is effected by means of paths from the cortex to the thalamus which probably end in its lateral nucleus. Injury in this region sets free the thalamic centre from control and it can therefore react without restraint to all stimuli capable of arousing affective states. Since, however, most stimuli which act upon the body in daily life are noxious and so contain a disagreeable element, most sensations experienced by the patient with a lesion of the optic thalamus are painful. This is particularly the case when sensation is so gravely diminished that stimuli of great intensity only can reach consciousness. The occurrence of spontaneous pains and the painful paræsthesiæ of the affected half of the body, so constant a feature of these cases, are due to the uncontrolled activity of this centre through which painful stimuli evoke a disagreeable sensation.

§ 2.—The Nature of the Sensory Activity of the Cortex

In a previous chapter we have described the results produced by a cortical lesion upon a series of measured sensory tests. Let us now analyse these defects in the hope that thereby we may learn the part played by the cortex in that response to an external stimulus we call a sensation.

We are not concerned here with the limits of the area on the surface of the brain which are associated with a disturbance of sensibility; before it is possible to talk of "cortical localisation" we must know what sensory qualities are due to the activity of the cortex. Much of the doubt that still hangs round the topography of "sensory centres" arises from this ignorance. Most observers start with the assumption that impulses originate in peripheral end-organs and pass unaltered to the cortex, there to underlie that psychical state we call a sensation. But we have already seen that the impulses upon which depend the "primary sensations" of touch, pain, heat and cold, are highly complex and undergo much regrouping before they arrive at the final sensory centres.

Afferent impulses on their way from the periphery to the cortex pay toll first of all to the unconscious co-ordinating mechanisms of the spinal cord and the cerebellum. Then, after being regrouped at the thalamic junction, they act upon two terminal centres. One of these, the essential organ of the optic thalamus, responds to all those elements which can evoke consciousness of an internal change in state, more particularly pleasure and discomfort. Sensory impulses then pass by way of the internal capsule to act upon the cortex, and these are the afferent materials out of which the cortex manufactures the forms of sensation with which it is concerned.

We know the nature of these impulses as they travel through the capsule to the cortex: it is revealed by those cases of thalamic and capsular disease in which the loss of sensation is due to interference with paths which pass from the optic thalamus to the sensory cortex.

The dissociations of sensibility which can occur under such conditions show that, after exciting the essential centre of the optic thalamus, sensory impulses pass on in five main groups to be distributed to the cortex :—

(1) Those which underlie postural recognition and the appreciation of passive movement. Upon this group depends the secondary faculty of judging the difference or identity of two weights placed on the unsupported hands.

(2) Impulses which underlie the recognition of tactile differences or the power of appreciating those qualities of touch other than contact and roughness. To this group we owe the faculty of recognising the increase or diminution in weight of a test-object, and of distinguishing the difference between two weights placed on the supported hand.

(3) Those upon which depend spacial discrimination (compass points applied simultaneously) and its allied faculty, the recognition of size and shape.

(4) Those impulses which enable the patient to recognise the spot stimulated (localisation). They carry with them the power of appreciating the double nature of two points applied to the surface one after the other.

(5) Thermal impulses. On this group depends the possibility of recognising those degrees of temperature which necessitate a comparison with the consequences of some previous thermal sensation.

Such are the afferent materials out of which the cortex manufactures those forms of sensation for which it is responsible. We have already studied the nature of this activity, as revealed by the effects of a cortical lesion. Such a lesion tends, as we have seen, to produce peculiarities in the response to sensory stimuli unknown at any other situation in the nervous system. The larger the area affected between the precentral fissure and the occipital lobe, the more certainly will sensibility show these characteristic changes.

The accuracy of response to measured tactile stimuli, whether von Frey's hairs or graduated pressure, is greatly reduced. The answers are irregular and uncertain, and increasing the stimulus does not of necessity lead to an equivalent improvement in the proportion of accurate replies. Contact sensibility is not lost, and cotton wool may still be appreciated, although it may seem "less plain" than on the normal side. Tactile sensations tend to persist and hallucinations may be present to an abnormal degree. Fatigue is induced with unusual facility; this is not general but affects solely the sensibility of the affected part, for the answers from the normal side may remain as good at the end as at the beginning of a series of observations.

The power of estimating the relative warmth or coldness of two stimuli suffers when thermal sensibility is affected by a cortical lesion. That portion of the scale can no longer be appreciated where the sensation evoked by a given temperature normally depends on that to which the part of the body has been previously adapted. This zone of relative heat and cold is abolished over the affected parts, and temperatures that fall within it are said to be neutral. Even when the warmth or coldness of the stimulus can be correctly appreciated, the sensation seems "less plain" over the affected limbs; the replies of the patient are less constant and less certain, and a temperature recognised without difficulty at one time seems doubtful at another. The power of discriminating the relative coolness of two cold stimuli and the relative warmth of two hot tubes is diminished, provided two temperatures are chosen which do not appeal differently to the thalamic sensory centre. Thus even the faculty of appreciating the relative intensity of two temperatures on the same side of the scale is disturbed, although both may be named correctly.

But all these stimuli contain elements capable of rousing the activity of the essential thalamic centre. The tests for the recognition of posture, of passive movement, spacial discrimination (compasses) and the locality of the stimulated spot contain no such elements, and it is these aspects of sensation that suffer most profoundly in consequence of a lesion of the sensory cortex. Postural recognition and the appreciation of passive movements are usually grossly affected. The power of localising the stimulated spot is less frequently disturbed, but may be abolished. These two faculties are independent of one another and may be affected separately. Moreover, a disturbance of localisation caused by a lesion of the cortex is not due to coincident uncertainty of tactile sensibility, for it is equally demonstrable when the stimulus is a prick to which the patient responds on every occasion.

A cortical lesion can destroy the power of appreciating the double nature of the compass points applied simultaneously to the skin; increasing the distance between them may not, under such circumstances, improve the accuracy of the replies. This loss is in no way due to defects of tactile sensibility, for it can be demonstrated when the compasses are armed with two sharp points.

When dealing with the arrangement of the sensory impulses which pass through the internal capsule to be distributed to the cortex, we showed that the power of estimating weight, size, shape and form in three dimensions depends on the integrity of several separate groups. Thus the appreciation of difference between two weights placed in the unsupported hand demands perfect postural recognition. The faculty of estimating weights placed consecutively on the supported hand depends on the integrity of tactile sensibility. Such dissociation is impossible with lesions of the cortex, for we are no longer dealing with a disturbance of sensory impulses, but with the difficulty of recognising the relation between two percepts. The patient generally gives up all attempts at appreciation, saying he has "no idea" of the shape, form, or relative size and weight of the test-object.

The tests for the appreciation of roughness and of texture demonstrate clearly the part played by the cortex in sensation. With Graham-Brown's aesthesiometer the threshold is identical on both hands; in every case the amount of protrusion necessary to make the flat surface of the instrument seem rough is the same on the two sides. In this test the patient has to determine solely whether the sensation is one of roughness or smoothness. But, as soon as he is asked to correlate these sensations and combine them with those of touch, as in the tests for the appreciation of texture, he fails entirely. He complains that from the affected hand he can gain no idea of the relation between the various stuffs passing under his fingers. One may seem rough, another smooth, but the sensations do not enable him to recognise the material he is handling.

Evidently, one of the faculties which we owe to cortical activity is the power of relating one sensation to another, whether they arise simultaneously or consecutively. Recognition of weight, size, shape, form and texture depends entirely on this faculty. Such tests consequently reveal the grossest defects whenever a cortical lesion produces any considerable influence upon sensibility.

A little consideration shows that loss of this faculty of relation is at the bottom of the diminished appreciation of posture and passive movement, which constantly forms one of the gravest defects produced by lesions of the cortex. For it would be impossible to discover the position of any part of the body, unless the immediate postural sensations were related to something that had preceded them. A direct perception of posture, analogous to that of roughness, is impossible; in every case the new position of the limb is relative to some previous posture.

At any moment we can become conscious of the position of any part of our bodies, and although such postural recognition is not constantly in the central field of attention, it always forms the measure against which we judge subsequent change. This is peculiarly the case with the appreciation of passive movement. Not uncommonly a patient with a cortical lesion can recognise that some movement has occurred, but is entirely unable to discover its direction or amplitude; complete appreciation of passive movement is the recognition of serial changes in a certain direction.

Munk [86] and all those who have recognised the relative nature of the appreciation of posture and passive movement have spoken of the cortex as the repository of images of movement. This is, however, an unsatisfactory term when we consider the actual effects produced by a cortical lesion; for, when we speak of a visual or of an auditory image, we mean something that can be recalled into consciousness. If we compare the colour of one ribbon with that of another seen a few moments before, many of us can recall the image of the first and compare it with that of the second. Both may be in the central field of consciousness together.

When we sit immobile and imagine our fingers touching some object on the table, many of us see, at once, the picture of an outstretched arm; the only image in consciousness is a visual one. Now, in cases where all power of recognising posture is lost this visual image remains unchanged, and it cannot therefore be the standard to which we refer alterations in posture. Place the patient's affected arm in front of him on the bed, allowing him to see the position in which it lies; close his eyes, and in most cases he will see a mental picture of his hand. Then change its position whilst his eyes remain closed and he will continue to see a picture of the hand in its old position. Moreover, if localisation is not affected, he will name correctly the spot stimulated but will refer it to the position in which he visualises the hand. The visual image of the limb remains intact, although the power of appreciating changes in position is abolished.

It is evident, therefore, that the standard resulting from previous postures and movements, to which immediate reference is made when a fresh position is recognised, cannot be a visual image. The existence of a group of human beings whose conscious life by day is devoid of all visual images would be sufficient evidence of this fact apart even from the direct results of experiment. Some such persons may possess true movement images. That is to say, the assumption of an imagined posture may be accompanied by re-presentations of movement equivalent to the pictures of those who visualise strongly.

But in both cases the image, whether it be visual or motor, is not the fundamental standard against which all postural changes are measured. Every recognisable change enters into consciousness already charged with its relation to something that has gone before, just as on a taximeter the distance is presented to us already transformed into shillings and pence. So the final product of the tests for the appreciation of posture or passive movement rises into consciousness as a measured postural change.

For this combined standard, against which all subsequent changes of posture are measured before they enter consciousness, we propose the word "schema." By means of perpetual alterations in position we are always building up a postural model of ourselves which constantly changes. Every new posture of movement is recorded on this plastic schema, and the activity of the cortex brings every fresh group of sensations evoked by altered posture into relation with it. Immediate postural recognition follows as soon as the relation is complete.

One of our patients had lost his left leg some time before the appearance of the cerebral lesion which destroyed the power of recognising posture. After the amputation, as in so many similar cases, he experienced movements in a phantom foot and leg. But these ceased immediately on the occurrence of the cerebral lesion; the stroke which abolished all recognition of posture destroyed at the same time the phantom limb.

In the same way, recognition of the locality of the stimulated spot demands the reference to another "schema." For a patient may be able to name correctly, and indicate on a diagram or on another person's hand, the exact position of the spot touched or pricked, and yet be ignorant of the position in space of the limb upon which it lies. This is well shown in Hn. (Case 14), who never failed to localise the stimulated spot correctly, although he could not tell the position of his hand. This faculty of localisation is evidently associated with the existence of another schema or model of the surface of our bodies which also can be destroyed by a cortical lesion. The patient then complains that he has no idea where he has been touched. He knows that a contact has occurred, but he cannot tell where it has taken place on the surface of the affected part.

It is to the existence of these "schemata" that we owe the power of projecting our recognition of posture, movement and locality beyond the limits of our own bodies to the end of some instrument held in the hand. Without them we could not probe with a stick, nor use a spoon unless our eyes were fixed upon the plate. Anything which participates in the conscious movement of our bodies is added to the model of ourselves and becomes part of these schemata; a woman's power of localisation may extend to the feather in her hat.

Thus, it is evident that among the various functions of cortical activity which imply a relation, the act of comparison may be of different grades in the hierarchy of consciousness. The appreciation of two weights placed at the same time one in each hand is an example of the faculty of relating two groups of presentations simultaneously in the focus of consciousness.

Recognition of posture and passive movement implies the combination of every fresh group of sensations with postural schemata outside the central field of attention. The change in consciousness which corresponds to this combination is immediate recognition of an altered position.

But such disturbance of the power of recognising similarity and difference will not account for all the abnormalities of sensation produced by a cortical lesion. When the affected part is under examination, the patient's replies are uncertain and variable; hallucinations and persistence of sensation tend to disturb the records. They show in an exaggerated form the errors that may appear in a normal person who is inattentive. And yet, as soon as we examine any unaffected part, the patient may come through the same series of tests without a mistake. On the left hand in Case 14, the records were on one occasion so bad that we took a similar series of readings, not only from the other hand, but also from both feet; those from the affected hand alone showed the features which might have been attributed to inattention.

Moreover, in many cases increasing the strength of the tactile stimulus does not of necessity produce a corresponding improvement in the answers. As good a record may be obtained with a hair exerting a pressure of 0·36 grm. as with one of ten times the strength. In the same way as many correct answers may be given to the contact of an instrument weighing 2 grm. as when it exerts a pressure of 32 grm. on the same area.

Evidently a lesion of the cortex produces an effect upon sensation of a different order from that found at any lower level of the nervous system. All those defects, which may occur when a normal person is under examination with psychophysical tests, are present in a grossly exaggerated form. Those defects, which we ordinarily attribute to want of attention, are raised to a degree unknown in the normal human being. But the patient's power of general attention has not been lowered in such cases as those we have cited in these chapters. Records from the limbs of the sound side show that the phenomena of defective attention are confined to the abnormal parts. A portion only of the patient has, as it were, become untrustworthy.

We believe that the functional integrity of the cortex enables attention to be concentrated upon those changes which are produced by the arrival of afferent impulses. When this is disturbed, some impulses evoke a sensation, but others, from lack of attention, do not affect consciousness. Attention no longer moves freely over the sensory field to be focused successively on fresh groups of sensory impressions. Sensations, once evoked, are not cut short by the moving away of the focus of attention as when cortical activity is perfect. Hence arise persistent sensations and hallucinations which are so prominent a feature after lesions of the cortex.

To sum up, we believe that the cerebral cortex is the organ by which we are able to focus attention upon the changes evoked by sensory impulses. A pure cortical lesion, which is not advancing or causing periodic discharges, will change the sensibility of the affected parts in such a way that the patient's answers appear to be untrustworthy. Such diminished power of attention makes the estimation of a threshold in many cases impossible. Uncertainty of response destroys all power of comparing one set of impressions with another and so prevents discrimination.

But, in addition to its function as an organ of local attention, the sensory cortex is also the storehouse of past impressions. These may rise into consciousness as images, but more often, as in the case of spacial impressions, remain outside central consciousness. Here they form organised models of ourselves which may be termed "schemata." Such schemata modify the impressions produced by incoming sensory impulses in such a way that the final sensations of position, or of locality, rise into consciousness charged with a relation to something that has happened before. Destruction of such "schemata" by a lesion of the cortex renders impossible all recognition of posture or of the locality of a stimulated spot in the affected part of the body.

§ 3.—The Interrelation of the Optic Thalamus and the Cortex in the Production of Sensation

In daily life all stimuli excite more or less both thalamic and cortical centres, for most unselected sensations contain both affective and discriminative elements. But, amongst the tests we have employed in sensory analysis, some appeal almost entirely to the one or other centre. The test for recognition of posture, as carried out by us, is purely discriminative; whilst the pain produced by squeezing the testicle, or to a less degree by the pressure algometer, appeals almost exclusively to the more affective centre.

Sensory impulses arriving at the optic thalamus are regrouped in such a way that they can act upon both its essential centre and the sensory cortex. The essential organ of the thalamus is excited to affective activity by certain impulses, and refuses to react to those which underlie the purely discriminative aspects of sensation. These pass on to influence the cortical centres, where they are readily accepted. In a similar way, the primary centres of the cortex cannot receive those components which underlie feeling-tone; in this direction they are completely blocked.

It has long been recognised that sensations are endowed with feeling-tone to different degrees. In those which underlie postural appreciation this quality is entirely absent, whilst visceral sensations are, in some instances, little more than a change in a general feeling-tone: one set of impulses appeals almost exclusively to the cortical centre, the other to that of the optic thalamus. All thermal stimuli, however, make a double appeal. Every sensation of heat or cold is either comfortable or uncomfortable; the only entirely indifferent temperature is one that is neither hot nor cold.

In the same way, most unselected tactile stimuli appeal both to the sensory cortex and to the optic thalamus. For not only is a touch always related to, and distinguished from, something that has gone before it, but we have shown that contact, especially of an object moving over hair-clad parts, is capable of exciting thalamic activity. Vibrations of the tuning fork also make a double appeal, for when the cortical paths are cut the amplitude of the vibration must be greater in order that it may be appreciated; on the other hand the vibratory effect may be stronger on the abnormal side in those thalamic cases where the affective response is excessive.

But these two centres of consciousness are not co-equal and independent. Under normal conditions the activity of the thalamic centre, though of a different nature, is dominated by that of the cortex. When we examine the sensation normally produced by a prick, we recognise that the pain develops slowly and lasts a considerable time after the stimulus has ceased. Moreover, the same intensity of stimulation will produce a different effect on the same spot on different occasions. A long latent period, persistence, and want of uniformity are characteristic of all painful sensations. This is seen in an exaggerated form in cases where the thalamic centre has been freed from control. The response to prick is slow, but persists long after the stimulus has ceased. Moreover, the reaction, when it occurs, tends to be explosive; it is as if a spark had fired a magazine and the consequences were not commensurate with the cause.

On the contrary, the sensations normally produced by moderate tactile stimuli are characterised by a short latent period, and disappear almost immediately on the cessation of the stimulus. A lesion of the sensory cortex disturbs both these characters. Tactile sensations became uncertain and incalculable, and no threshold can be obtained; persistence and hallucinations mar the uniformity of the records.

Now we have shown that the sensory cortex is the organ by which attention can be concentrated on any part of the body that is stimulated. The focus of attention is arrested by the changes produced by cortical activity at any one spot. These are sorted out and brought into relation with other sensory processes, past or present. Then the focus of attention sweeps on, attracted by some other object.

All stimuli which appeal to the thalamic centre have a high threshold. They must reach a high intensity before they can enter consciousness, but once they have risen above the threshold they tend to produce a change of excessive amount and duration, and this it is the business of the cortical mechanism to control. The low intensity of the stimuli that can arouse the sensory cortex, and its quick reaction period, enable it to control the activity of the cumbersome mechanism of the thalamic centre.

Our view of the sensory mechanism explains many of the facts already recognised both by psychologists and clinicians. It enables us to understand how integration can occur at all afferent levels of the nervous system, and makes development possible even in the individual. The aim of human evolution is the domination of feeling and instinct by discriminative mental activities. This struggle on the highest plane of mental life is begun at the lowest afferent level, and the issue becomes more clearly defined the nearer sensory impulses approach the field of consciousness.

SHORT ACCOUNTS OF SOME ILLUSTRATIVE CASES

Case 1.—*Brown-Séquard paralysis* (vide p. 537).

Case 2.—*The consequences of a lesion of the brain-stem* (vide p. 541).

Case 3.—*Occlusion of the posterior inferior cerebellar artery* (vide p. 544).

Case 4.—*Tumour of the mid-brain and optic thalamus* (vide p. 547).

Case 5.—*Disease of the optic thalamus* (vide p. 552).

Case 6.—*Disease of the optic thalamus with autopsy* (vide p. 553).

Case 7.—*An instance of the thalamic syndrome with scarcely any loss of sensation.*

Rachel F., aged 60, was admitted into the National Hospital under the care of one of us (G. H.) in February, 1910. She was a married woman and had enjoyed good health till September, 1908, when the stroke occurred that produced her symptoms. While engaged in her housework, she suddenly experienced a "peculiar drawn feeling" in her left shoulder and the left side of her neck, and then fell to the floor, but did not lose consciousness. She immediately lost the power of moving her left limbs and felt as if these limbs had disappeared, "as if I had lost them." She soon discovered that she "could not feel" on these limbs or on this side of her body.

After a period of about five or six weeks she began to move the left limbs again; three months after the stroke she was able to walk alone, and a little later she could bring the left hand to her mouth. Since then the affected limbs have become gradually stronger. About six months after the attack she first noticed the irregular spontaneous movements of the left hand, which, though very variable in intensity, have on the whole increased. A little later similar movements of the left toes became noticeable.

The "peculiar drawn feeling" that ushered in the attack probably persisted for a few weeks; on this point her memory is indefinite, but as sensation returned she began to complain of an "unpleasant numb feeling" and of tingling and "pins and needles" in the left hand and arm, and of numbness in the left foot. About six months after the onset she began to have a sensation as if "something were crawling under the skin" of the affected side, especially on her face, and a "scalding sensation in the left cheek, which is worse when the cheek is cold than when it's warm." For about the same length of time she has suffered with dull aching pains in her left arm, and a "crampy pain" in the left leg.

Vision, hearing, smell and taste were, as far as she knows, unaffected by the attack, but the left side of her mouth and tongue "have always felt dry," and food always seems rough and cold on this side; even a cup of hot tea is unpleasantly cold to the left cheek.

Speech and swallowing were never affected; during the first few days of her illness she had slight difficulty in holding her urine, but this soon passed off.

CONDITION IN FEBRUARY, 1910.

She is a healthy-looking woman who appears much younger than her age. Her heart is slightly hypertrophied, her arteries rigid, and her pulse-tension high.

She is fairly educated and intelligent; her memory is excellent and her attention good.

Special senses.—Smell, taste, and hearing are unaffected and equally acute on the two sides. The visual fields are unrestricted and the optic discs are normal, but the retinal arteries appear sclerosed.

Cranial nerves.—The functions of all the cranial nerves are unaffected; the pupils are equal and react well to light and on accommodation. The corneal reflex is brisk on the right side, but very much reduced or almost absent on the left.

Motor system.—The right limbs are normal in every respect. The size and tone of the muscles are equal in the two arms and the range of movement of the left is unrestricted, though this limb is distinctly weaker than the right; the grasp of the right hand, measured with the dynamometer, was 41 (an average of five readings), while on the left it was 23 only. She uses this limb readily in coarse general movements, as in pointing, but owing to the spontaneous movements and ataxia it is useless to her for finer actions. There are almost constantly irregular involuntary movements of the left fingers and frequently, too, of the wrist; they often constitute a rhythmical tremor, but are more usually irregular or even choreiform. The most common movement is flexion and extension of the fingers at the basal joints, but flexion and extension of the wrist and adduction and abduction of the fingers are also of frequent occurrence. These movements increase on any attempt to use the limb, on strong volitional movements of the normal arm and even on walking. They persist during the movement of the limb itself as a sort of intention-tremor, but differ from an ordinary intention-tremor in that the amplitude of the oscillations is greatest when the movement is begun and decreases towards its completion. She has very little power of restraining the movements. In addition to the tremor there is considerable ataxia of the limb.

The movements of the trunk and head are unaffected.

There is no wasting or alteration in the tone of the muscles of the left lower extremity, and its movements are slightly weaker only than the corresponding ones of the right. Spontaneous movements, more or less similar to those described in the arm, occur in the left toes and at the ankle, and the volitional movements of this limb are poorly co-ordinated and tremulous. She walks with short shuffling steps, occasionally dragging the left toes along the ground. Her gait is more affected than might be expected from the relatively slight weakness of the leg.

Reflexes.—All the tendon-jerks are brisker on the left than on the right side. The abdominal reflexes cannot be obtained on either side. The right plantar reflex gives a flexor, but the right an extensor response.

Spontaneous sensations.—She complains chiefly of a "scalding sensation" and of burning pain in her left cheek. The left side of her mouth and this side of her tongue are dry, rough and sore, and it seems to her as if this side of her palate were "covered with ulcers." All food, no matter what its temperature may be, is unpleasantly cold to this side of her mouth. She also complains of "aching pains" in the left shoulder and the left arm (there are no arthritic changes) which are often so severe as to keep her awake, and of "crampy pain" in her left leg, especially behind the knee. The left hand and foot are usually numb and the hand often tingles.

Tactile sensibility.—She appreciates light cotton wool contacts equally well on the two sides, on both hairless and hair-clad parts, and can recognise no difference in the sensations evoked. On testing with von Frey's hairs the same threshold is obtained on both hands and on the cheeks. It was noticed, however, that after the left cheek had been tested she rubbed the spot on which the contacts with the hairs had been made, and when asked why she did so said, "You made it itch and tingle"; this tingling persisted for some time after stimulation.

Roughness.—With Graham-Brown's instrument the same threshold for roughness was obtained on the two sides; but when a stimulus above the threshold is employed it appears rougher on the affected than the on sound side, and especially on the sole produces a more violent movement of withdrawal.

Tickling.—This can be evoked satisfactorily from the soles only. The left sole is very much more ticklish than the right, and stimulation by drawing the fingers across it produces a strong vigorous reaction and rapid withdrawal of the limb, while on the right side this evokes scarcely any emotional reaction. The tickling of the left side is not, however, actually painful or unpleasant.

Vibration.—There is a shortening of the period during which vibration can be appreciated on the left hand compared with the right, and the vibrations of the fork appear "plainer" on the normal side.

Sensibility to pain.—No diminution of sensibility to pricking can be detected on any part of the left side, and with the spring algesimeter the threshold is found to be identical on corresponding parts. Pricks that evoke pain, however, are invariably "sharper," more unpleasant and "sting more" on the affected than on the normal side, and in many places, especially on the palm and sole, produce a much greater reaction with an apparently uncontrollable tendency to withdraw the part. On testing with the algesimeter this is found to occur with any stimulus above the threshold. There is no evidence that the pain persists abnormally, or that it radiates from the spot stimulated.

Pressure pain.—As measured with the algometer the threshold is approximately the same on the two sides, or in places, as on the sole, actually lower over affected parts.

	Right (normal).			*Left (affected).*		
Palm	5½	6	7	5½	6	7
Tibia	3	2	2½	2½	2	2
Sole	5	5½	5	3½	2½	2½

But painful pressure on the affected side evokes a much greater reaction and appears to the patient "very much sorer" and more painful. When such pain is produced in the right sole for instance, only a slight jerk of the leg occurs, while on the left side the foot is dorsiflexed violently and the leg is drawn up and her general response denotes intolerable discomfort.

Thermal sensibility.—All degrees of temperature can be normally appreciated on both sides and the thresholds are equal; but extreme temperatures, as ice and tubes above 55° C., appear to her colder or hotter on the left side, and evoke stronger reactions.

Sense of position.—There is slight loss in the left arm, especially at the distal joints, but none can be demonstrated with certainty in the leg.

Appreciation of passive movements.—By ordinary methods of testing there seems to be very little alteration in the affected arm, but by measuring the angle of movement necessary for its appreciation and the recognition of its direction a definite defect is revealed. The following records were obtained on moving the index-finger at its basal joint :

R. Index-finger ..	Flexion			2½	2			2	2		2
	Extension	2	2			1½	1½			2	
L. Index-finger ..	Flexion			10	12	12				15	12
	Extension	7½	10				6	7	8		

Localisation tested on the hands is found to be equally accurate on the two sides.

Compasses.—The threshold is approximately the same on the two sides, and she is equally quick and decisive in her replies. A perfect series of readings can be obtained with 1·5 cm. on the palms and with 2 cm. on the soles.

Appreciation of weight, tested by the different methods we employ, seems almost as accurate on one side as on the other. She is less able to recognise alterations in weights lying on the left than on the right hand, but the constant involuntary movements of the affected hand make this test difficult.

Appreciation of size.—The same difference threshold is obtained for the two hands.

Appreciation of shape and form.—There is no material difference between the two hands to these tests, though she is a little slower and less certain in recognising differences in shape on the left than on the right.

Recognition of relative consistence.—She frequently fails to recognise the relative hardness of two test-objects placed in the left hand, which she can easily distinguish in the right hand.

Recognition of texture.—With the left hand she fails to recognise the texture of many of the test-stuffs we placed in it. Silk, for instance, is called cotton, velvet is described as woolly or something rough, and cotton as a woollen material.

She has remained under observation as an out-patient at the National Hospital since these notes were taken in an unchanged state, excepting that she complains more of the pains in the left side. The observations recorded above have been repeated and verified on many subsequent occasions.

Case 8.—An instance of the thalamic syndrome where cutaneous sensibility was not diminished. All pleasant or disagreeable stimuli, more particularly heat and cold, produced a profoundly greater response on the affected half of the body.

George S., aged 64, was admitted into the National Hospital under the care of one of us (G. H.) in September, 1910. He was well till the attack, that produced his symptoms, occurred in February, 1909. While walking he noticed a numbness in his left cheek and his left hand, and a few hours later a tingling, "like pins and needles," spread over his left arm and from his shoulder into his face: it was particularly severe in the left side of his tongue. Later in the day the tingling extended throughout his left side and into his left leg; then he had some difficulty in walking. He was kept awake that night by a soreness and painful tingling in his left arm, which next morning was present over his whole left side. He never lost the power of moving the affected limbs, in fact their movements were scarcely limited, and there was not much diminution of sensation on this side: "I was able to feel everything, in fact too much so"; but objects he touches have not felt natural since the attack. The pains and uncomfortable sensations have persisted more or less unaltered from their onset, but they have always been worse in either very hot or very cold weather.

Hearing and vision were unaffected, but he has found that he cannot taste so well since his illness; he noticed this loss of taste the day after the onset. He complains, too, that his mouth has become very dry. During the past year he has occasionally had a slight tingling pain in his right hand and a "tingling numbness" in the right leg, but, unlike the paræsthesiæ on the left side, these sensations are not constant.

Condition in September, 1910.

He is a thin, spare man, but fairly well preserved for his age. His arteries are rigid and the pulse tension high, but there is no other sign of visceral disease. He had been an engineer and is fairly well educated; his memory and attention are excellent.

Special senses.—Smell is unaffected. He cannot taste sugar or salt on either side of his tongue, but quinine can be appreciated equally on both sides. There has been for years considerable middle-ear deafness on the left side, but there is no other demonstrable affection of hearing. Vision is poor owing to commencing cataract, but the visual fields are unrestricted.

Cranial nerves.—The functions of all are unaffected, except that the left corneal reflex is very much diminished.

Motor system.—The right limbs are unaffected. There is a slight general wasting of the small muscles of the left hand, but otherwise the right and left limbs are equally developed. The tone of the two sides is about equal, and there are no contractures. The left arm is slightly weaker than the right, but this is largely due to the fact that strong muscular contractions give pain. Its movements are also slower and more awkward. Involuntary movements do not occur.

Reflexes.—The tendon-jerks and the abdominal reflexes are equal on the two sides, and both plantar reflexes give definite flexor responses.

Spontaneous sensations.—He complains of a constant "soreness" of his left hand and his left foot, and of similar pain in the left half of his tongue. The whole of the left side also "feels cold," and anything that touches it seems unpleasantly cold to him. He always wears a glove on this hand. The whole of this side is also tender; when he places his foot on the ground, for instance, "it feels as if there were tintacks under the foot." He also complains of "a painful tingling" throughout this side, of a "gnawing pain" in the left temple, and occasionally "sharp pains" shoot through the left limbs.

Tactile sensibility.—Light cotton wool contacts are equally well appreciated on the right and the left sides, and there is no obvious difference in reaction to this stimulus. The same threshold can be obtained on the two sides with von Frey's hairs.

Roughness.—The same threshold is obtained with Graham-Brown's instrument on the two sides, and no over-reaction or expression of discomfort is evoked from either palm or sole.

Tickling and scraping.—There is no over-reaction to tickling, and he says there is very little difference between the sensations evoked on the two sides. The left side of the body is, however, more "tender" to scraping than the right.

Vibration is equally well appreciated on the two sides, and the fork evokes no unpleasant sensations on either side.

Sensibility to pain.—The left limbs and the whole of the left half of the body, including this side of the face and tongue, are "more sensitive" to pricks than similar parts of the right side, and the reaction thereto and the emotional expression are considerably greater. When a pin is drawn across his chest from the right to the left side he immediately complains that it is more painful to the left of the middle line. As measured with the algesimeter there is no difference in the threshold on the two sides.

Pressure-pain.—The algometer produces intolerable pain on the left side, and a sudden and violent reaction. As soon as pain is evoked he writhes and jumps; moreover, its effects persist longer than on the right side. The threshold values, too, are distinctly lower on the affected side.

	Right (normal).				*Left (affected).*		
Palm	7	7	7	..	$5\frac{1}{2}$	5	$4\frac{1}{2}$
Second metacarpal ..	5	4	4	..	$2\frac{1}{2}$	2	2
Sole	3	$2\frac{1}{2}$	$2\frac{1}{2}$	..	$1\frac{1}{2}$	2	$1\frac{1}{2}$

Thermal sensibility. There is no diminished appreciation of temperature over the affected half of the body, and the same thresholds for heat and cold were obtained on the two sides. But any temperature that is definitely cold to the left side causes an expression of discomfort and an excessive reaction; a tube a few degrees below the threshold is "just cold" to the right hand, but "very cold, very unpleasant" to the left. Similarly, even 45° C., which was described as warm on the right hand, was "too hot and uncomfortable" on the left. When, however, milder degrees of warmth, as 38° C., are employed, or if the hands are placed on a vessel containing water at this temperature, he describes the sensation evoked in the affected hand as "delightful," or "more soothing and more pleasant than on the right." Further, he states that this gives him not merely local pleasure, but "makes him feel happy all over," and this is clearly indicated by his general reaction and expression.

The thresholds were afterwards carefully determined for the two hands; 28° C. was neutral to both, while 30° C. was "warm" to the right and "nice and warm" to the left. The hands were then adapted to warmth, by being placed in a warm bath at 42° to 43° C. for two and a half minutes, and were tested again to the same temperatures immediately on removal. Now 28° C., which was previously neutral, was "very cold, very unpleasant" to the left hand, and 30° C., which had been "nice and warm," was either neutral or "just cold." Thus, by adaptation, the thresholds for heat and cold were easily shifted, and 28° C., which had been neutral, received a feeling-tone of discomfort, while 30° C. lost its feeling-tone of pleasure and became neutral.

Sense of position and the appreciation of passive movement.—There is considerable loss of the power of recognising the position of his left limbs, which is greater at the distal joints; he is, for instance, unable to describe or to imitate with his right hand the positions into which his left hand or fingers may be placed. The appreciation of passive movement is also affected; in order that a movement of the left fingers can be recognised it is necessary that its range should be about four times as great as that required on the right hand, and at the elbow the range of movement must be three to four times as large as on the right side.

The power of *localisation, the compass test,* and the recognition of *size, shape, form* and *consistence* are equal on both sides, and remarkably accurate.

Appreciation of weight.—When the hands are supported the appreciation of weight is little different on the two sides; two weights placed consecutively on the same hand can be discriminated within about the same limits on the two sides. When, however, the hands are unsupported, he fails to recognise the difference between 50 grm. in the right hand and 200 grm. in the left. These observations are rendered difficult by the tendency for the sensation of weight to die out when the test-object is allowed to lie for any time in the affected hand.

Thus it would seem that, in this case, the power of estimating weight on the unsupported hand was dissociated from the faculty of estimating relative pressures when the hands are fully supported.

Case 9.—An instance of the thalamic syndrome where the thresholds to painful stimuli were identical on the two sides, and heat produced excessive pleasure on the affected half of the body.

Peter C., aged 59, was admitted to the Seamen's Hospital under the care of one of us (G. H.) in June, 1911. In December, 1909, he noticed he was unusually thirsty and that the amount of urine he passed was greatly increased; his doctor told him it contained sugar, and put him on a restricted diet.

On March 20, 1910, he went to bed well, but woke in the early morning to find that his left limbs were paralysed. He remained several weeks in bed, but was able to walk again in about three months. Shortly before the stroke he found that his sight was affected and he could "scarcely see anything on the left side." There was no diplopia.

At first the left limbs were paralysed, but, as power returned, he noticed that he had difficulty in controlling their movements; he cannot say exactly when the involuntary movements of the left hand began. He thinks that the numbness, tingling and pains, from which he now suffers on the left side, came on immediately after the attack, but the pain was certainly less in the earlier stages than it is now.

Condition in June, 1910.

He is a somewhat old-looking man for his years, with degenerated arteries and a high-tension pulse. His urine is of high specific gravity, greatly increased in amount, and contains much sugar but no albumen. He is an intelligent, well-educated man, and had been an overseer in his work. His memory is fair and attention good.

Special senses.—Smell, taste and hearing are unaffected, but there is complete left hemianopsia, the blindness reaching up to within three degrees of the fixation point.

Cranial nerves.—The functions of the cranial nerves are unaffected, except that the corneal reflex of the left side cannot be obtained.

Motor system.—The right limbs are entirely unaffected. There is no rigidity of the left arm and leg, and no loss of voluntary power, but all their movements are gravely ataxic. In addition there are almost constant involuntary movements of the arm, which generally take the form of a tremor, but at times are more irregular or choreiform.

Reflexes.—The tendon-jerks are present and equal on the two sides, ankle clonus cannot be obtained, and the plantar reflexes are of the flexor type.

Spontaneous sensations.—He complains of pain, tingling and numbness in the left half of the body. The pain has the character of a dull aching, "as if bruised from a blow." The tingling is mainly in the left hand and foot and is constantly present. He describes the numbness as "a sort of dead pain," which occupies the whole of the left half of his body, except the face, and is much worse in cold weather.

Tactile sensibility.—He fails to appreciate many contacts of cotton wool when it is rubbed over the hairless parts of the affected side, such as the palm and the sole, but he almost always succeeds in recognising this stimulus on hair-clad parts of the body. When asked to compare the sensations evoked on the two sides, he says that the cotton wool is more distinct over the normal palm and sole, but on hair-clad parts the sensations are "sharper and heavier" on the affected side. On testing with von Frey's hairs the threshold was found to be slightly raised on the affected side; on the normal hand a hair of 21 grm./mm.^{2} was appreciated perfectly, while on the opposite hand 35 grm./mm.^{2} was required to produce a sensation.

Roughness.—It is impossible to measure the power of appreciating roughness, for even the smooth surface of Graham-Brown's instrument produces a sensation on the left side which he cannot distinguish from that of roughness; but, when the instrument, set at the same degree of roughness, is rubbed over the two hands, he says it seems rougher on the normal, but more unpleasant on the affected side.

Tickling and scraping.—Gentle stimulation of the normal sole with the pulps of the fingers produces a tickling which is not unpleasant, but on the affected sole this stimulation is disagreeable and evokes an excessive reaction. This difference is still greater when the soles are scraped.

Vibration.—The vibration of a tuning fork can be appreciated on the left side, but it is distinctly shortened as compared with the right side. It evokes no excessive reaction.

Pain.—There is no evidence of diminished sensibility to prick on the affected side, and the algesimeter gives identical threshold-values on the two halves of the body. But when two pricks of equal value are compared on corresponding parts of the two sides he invariably says that on the affected part "it hurts more and is three times as sore"; moreover the reaction evoked is much greater than that from the normal side. He says, "I can't stand it so well on the left side: the pricks seem to stay there, they don't go away when you take away the pin."

Pressure-pain.—As tested with the algometer the threshold-values are approximately the same on the two halves of the body, but the reaction to this stimulus is everywhere greater on the left side than on the right.

Thermal sensibility.—There is a slight reduction of sensibility to temperature on the left half of the body. Thus temperatures between about 25° C. and 40° C. are not appreciated, whilst the neutral zone on the normal side extends from 28° C. to 33° C.; the extremes of temperature produce more disagreeable sensations and a greater emotional reaction on the affected side. But when large tubes containing water at 40° C., or slightly above, are applied to the affected parts of the body he says, "That's nice, it's much more pleasant than on the other side." Even when warm hands are placed on his hands or on his feet, he says that the sensation is different on the two sides; on the affected half of the body "it is more comfortable; it is a real pleasure; it soothes me; it gives me the feeling that it must do me good." At the same time his face lights up with a definite expression of pleasure.

Sense of position.—The knowledge of the position of the distal joints of the left arm and leg is defective, but there is less loss at the proximal joints.

Appreciation of passive movement is defective in the left hand as compared with the right; the fingers must be moved through nearly ten times as great an angle as is necessary on the right side before the movement can be appreciated. At the elbow the loss on the left side is considerably less in proportion: he can appreciate a movement that is not more than three times as great as that necessary on the normal side.

Compasses.—The compass test is gravely affected on the abnormal half of the body: good readings are not obtained even when the points are separated to 5 cm. on the palm, or to 15 cm. on the forearm. He has no difficulty, however, in recognising the two points when applied successively.

Localisation is perfect on both sides.

Appreciation of size is somewhat defective in the left hand: thus he failed in every case to recognise the difference between objects with diameters of 3·5 and 4 cm., and of 2 and 2·5 cm., although he was uniformly correct on the normal side; but as soon as the difference was increased to that between diameters of 3 and 4 cm., or 2 and 3 cm., his answers from the affected hand were uniformly correct. It is therefore possible to obtain a definite difference-threshold for the appreciation of size.

Shape, form, texture and *consistence* are all badly appreciated when the tests are applied to the left hand.

Case 10.—*An instance of the thalamic syndrome associated with complete loss of thermal sensibility, although hot and cold stimuli produced pleasure and discomfort.*

Margaret B., aged 65, was seen at the West End Hospital for Nervous Diseases in July, 1911; through the kindness of Dr. Harry Campbell, to whom we are much indebted for the privilege of making the following observations. Her past health had been good; she married at 28 years of age, but has had no children.

In October, 1910, she suddenly found she was unable to hold anything in the left hand, and almost immediately fell to the floor unconscious. When she regained consciousness some hours later she was unable to move her left limbs, and they, together with the left side of her trunk and face, seemed numb: at first it seemed to her that she had completely lost her left arm. About six weeks later some power of movement returned in the arm, and in two months she was able to walk with a little assistance. Since then she has improved gradually; walking has been her chief trouble, as owing to its tenderness she cannot place the left foot properly on the ground.

The involuntary movements of the left arm began as the power of movement returned; she is aware of them only when she sees them. About two or three weeks after the stroke the left-sided pains first appeared, as a gnawing pain in the groin; they increased in intensity during the first two or three months of her illness.

Vision, hearing, smell and taste were not affected, and she has not had any sphincter disturbance or affection of speech. Since the attack, however, she has noticed that her mouth is unnaturally dry.

CONDITION IN JULY, 1911.

She is a rather thin, elderly woman who has lost much weight during her illness, which she attributes to the pains that disturb her by day and night. She is intelligent, her memory is fair, and she is attentive when under examination.

Cranial nerves.—The functions of all the cranial nerves are normal: there is no difference between the voluntary or expressional movements of the two sides of the face, and the tongue is protruded straight. The pupils are equal, and react well to light and on accommodation. The right corneal reflex is brisk, but the left is absent.

Special senses.—Smell, taste, hearing and vision are normal, and the visual fields are not restricted.

Motor system.—The right limbs are unaffected.

The muscles of the left forearm and hand are slightly wasted, but the tone of the limb is unaltered and there is no tendency to contracture. Movement is somewhat limited at the shoulder-joint by arthritic changes, but is otherwise unrestricted. Owing to the great loss of sensation it is difficult to estimate the actual strength of the limb, but there seems to be little, if any, weakness; she is slow, however, in exerting power on this side, and her efforts are not well sustained. All its movements are ataxic, and there is in addition considerable intention-tremor. While the arm lies on the bed frequent irregular involuntary movements of its distal segments occur. These generally take the form of a sudden extension of one or more fingers, or an isolated movement at the wrist, but often a short series of oscillations (tremor) may be observed. These involuntary movements can be excited or exaggerated by certain peripheral stimuli, even if they do not reach consciousness.

There is no definite wasting of the left leg, and the tone of its muscles is normal; there is no rigidity or contracture, and the range of movement is normal. The power is almost as good as that of the right limb, but its movements are very ataxic. No involuntary movements have been seen in the leg. She walks with short shuffling steps as though she were afraid to trust her weight to the left limb.

Reflexes.—The arm-jerks are equal and brisk on both sides. The knee- and ankle-jerks are slightly greater on the left side, but clonus could not be obtained. The abdominal reflexes are absent. The right plantar reflex is flexor, but stimulation of the left sole provokes such an extensive and vigorous movement of the whole limb, and such dislike on the part of the patient, that the exact nature of the response cannot be determined; however, no typical slow extension of the great toe can be seen.

Spontaneous sensations.—She gives vivid descriptions of the pain and disagreeable sensations she suffers on the left side. "There is a feeling as if boiling water were being poured down the left arm from the shoulder to the elbow, and as if I had a band on the forearm which some one was pulling so tight as to hurt me." There is also a sensation at the back of the left shoulder "as if a log of wood were hanging from it." The hand is numb and feels "as if little pins were sticking into the fingers."

There is also pain in the left eye, "a tight feeling in the face," and "a feeling of fulness in the left ear." "I can't lie on the left side of my head as it is so sore." Pain is always present in the left side of her body, greatest above the iliac crest: "It feels as if you had your nails dug into my side and you were hanging with your whole weight on it," or "as if rats were always gnawing at my side." Her left thigh from the hip to the knee seems painfully tight, and below the knee there is a constant gnawing pain, greatest in the heel and the sole of the foot. She cannot lie on the left side as it is so tender, and cannot bear anything cold to touch it.

Tactile sensibility.—She fails to appreciate cotton wool contacts on the left hand and fingers, and on the hairless parts of the rest of the limb. If, however, a wisp of wool is rubbed backwards and forwards on the hair-clad parts, as on the back of the forearm, an unpleasant sensation is evoked, "a curious tickling," which is unquestionably painful, or "a burning feeling, as if you touched me with something very hot." Yet, over the same parts, she always fails to appreciate cotton wool when merely pressed on, no matter how firmly. The condition is exactly similar on the left leg, and yet a very intense reaction can be evoked by rubbing wool on the sole. She can recognise most contacts on the left side of the face unless they are slight, and also on this half of her body. Rubbing a wisp of wool on the left chest provokes a strong reaction; she winces and afterwards rubs the part with her own hand, complaining that "you made it itch." When a wisp of wool was rubbed to and fro on the fingers curious involuntary movements began, yet she was conscious neither of the stimulation nor of the movements. This was repeatedly verified.

Pressure-touch was tested with the pulp of a finger that had about the same surface temperature as her own skin. She is unable to recognise firm pressure on the whole of the left arm and leg; even when some part of these limbs is firmly grasped she appreciates nothing, provided the pressure is not sufficiently great to give discomfort. She is also insensitive to moderate pressure on the left side of her face, and even the eyeball can be pressed firmly through the upper lid without arousing her consciousness.

Roughness.—She has lost the ability of appreciating roughness on the left side. On testing the palm with Graham-Brown's instrument it is found that, even when the surface is quite smooth, it produces an unpleasant tingling sensation; but she cannot distinguish this sensation from that evoked by the instrument when the cylinder is projected 10 degrees (0·5 mm.).

Tickling and scraping.—She is naturally extremely ticklish. Drawing the tips of the fingers over the right sole tickles her greatly and evokes a strong reaction, but not an expression of discomfort, while on the left sole the same stimulation is unbearable, and she says: "It's burning; it's as if you were tearing the skin off; it sends pins and needles up the leg as far as the knee." The right palm can be easily tickled, but on the affected hand she cannot bear this stimulation; it evokes a strong reaction, gives a sensation "as if red-hot needles were being plunged into her," and starts a pain that spreads up the arm as high as the elbow. A wisp of cotton wool rubbed over the pinnæ is appreciated more distinctly on the right, but tickles more and evokes a stronger reaction on the left. The same holds for the two sides of the chest. Rubbing a wisp of wool over the left nipple provokes an intense general reaction, but if her eyes are closed she has no idea where she has been stimulated.

She is most intolerant to scraping with the finger-nails on the whole of the left side of her body; it starts a widely spreading and very unpleasant sensation of burning.

Vibration.—She is unable to appreciate even the strongest vibrations of the tuning fork anywhere on the left limbs; there is considerable loss of appreciation even over the left malar bone as compared with the right.

Sensibility to pain.—When the left hand is pricked she replies at once: "Oh, that is ten times worse than on the right; it sends a pain right up to my elbow." "The prick is not at all the same as on the right; on the left it goes all over my hand, while on the other side it stays in the one place." "It is horrible on the left; it is a dreadful burning pain." Every prick on the affected hand provokes an intense reaction and the patient is most reluctant to submit to it. There is apparently little or no persistence of the sensation evoked.

Similarly on the left side of the face, of the chest, and on the leg, pricking produces an intense reaction and more pain and discomfort than on the right side, and the pain spreads widely from the spot stimulated. She has usually little or no idea of the locality of the spot that is pricked.

On testing with the algesimeter it is found that the threshold for pain appears to be slightly raised on the affected side. The following figures represent the lowest values that produced a sensation of pricking with the spring-algesimeter.

	Right (*normal*).	*Left* (*affected*).
First dorsal interspace	3 grm.	5 grm.
Dorsum of middle finger	2 ,,	3 ,,
Dorsum of forearm	3 ,,	3 ,,
Front of chest	2 ,,	2 ,,

Pressure-pain.—The application of the algometer produces a much "sorer" sensation on the left side than on the right, and provokes a much greater reaction. Further, the pain develops explosively on the affected side and spreads widely. The following figures represent the threshold values on corresponding parts of the two sides.

	Right (*normal*).			*Left* (*affected*).		
Palm	5	5½	4½	4	3½	
First metacarpal bone	3½	3½	3½	2½	3	3½
Front of shin	3	3	3	4	5	5
Sole	4	4		3	3½	

Thermal sensibility.—She has lost completely the appreciation of temperature on the right side, excepting perhaps on the face. The mean degrees evoke no sensation, but the extreme degrees produce pain and an excessive response which may be called indiscriminately hot or cold. Thus when a tube at 60° C. was applied to the palm she cried out, "Oh, I have a pain up my arm, it is as if you were pouring boiling water over my arm; it's like a wheel running over my arm." And when a tube containing ice was applied immediately afterwards she reacted similarly and said, "It is just the same, but not so bad; it is as if you had turned a fountain of boiling water on at my shoulder." On the palm, temperature below 25° C. and above 50° C. produced this discomfort; those necessary to do so on other parts of the affected side varied slightly from these degrees. The pain did not usually develop till the tube had remained for some time in contact with the skin.

During these tests it was observed that while high or low temperatures produced pain and discomfort, mild warmth frequently evoked a reaction of pleasure. This aspect of temperature was consequently tested, employing larger tubes in order to cover a greater surface of skin. It was found that though the stimuli could not be recognised as thermal, temperatures between 38° C. and 43° C. were positively pleasant to the affected side, much more so than over normal parts, and that they could evoke a very definite reaction of pleasure. Thus, when she was asked to describe the sensations produced by 40° C. applied successively to the two sides of her chest she said, "Oh, that is very nice on the left; it is comforting, I like it there. It feels warmer on the right side, but it is not nearly so soothing, o so pleasant." 43° C. was "very pleasant" to the left palm, and she seemed reluctant to allow the tube to be taken away; while when 41° C. was placed on the sole she exclaimed, "Oh, that's nice: I would like it there all day." She occasionally called these pleasurable temperatures warm, but careful testing makes it improbable that they evoked any thermal sensation.

Thus, though there is complete abolition of thermal sensibility, high and low degrees of temperature produce on the affected side excessive discomfort and an exaggerated reaction, and mild warmth is more pleasant and evokes pleasurable sensations on this side.

Sense of position.—There is total loss of knowledge of the position of the left arm and leg; she has not the slightest idea where these limbs lie.

Appreciation of passive movement is also completely lost in the left arm and leg; she does not recognise that anything is happening even on maximal movements of the fingers or hand.

Localisation of tactile stimuli cannot be tested owing to the great loss of touch on the affected side, but she seems to have a very imperfect knowledge of the situation of painful stimuli.

Appreciation of weight is also completely lost, whether tested on the supported or unsupported hand. She cannot recognise any difference between an empty case weighing 5 grm. and the same case containing 500 grm.

Recognition of form is completely abolished in the left hand.

Owing to the extreme tactile insensibility the *compass test* could not be carried out, and it was impossible to test *size, shape*, or *texture*.

Case II.—An instance of the thalamic syndrome where states of emotion were manifested on the affected half of the body by increased involuntary movements and disagreeable sensations.

Mrs. A. R., aged 52, has been under the care of one of us (H. H.) for the past four years. In 1902 she began to notice tremor of the right arm and the right leg. Three months later, whilst talking at the telephone, she suddenly fell; she found she could not move the right limbs, but does not think she lost consciousness. She remained in bed a week. The loss of power passed off rapidly, but she then discovered she had lost control of the limbs of the right side, probably in consequence of the loss of sensation; for from that time she found she was not aware of the position of the right limbs when she could not see them, as in the dark or when her leg was underneath the table. For a day or two after the stroke she had no "feeling" in the affected half of the body, but sensation returned rapidly and she then began to suffer from pains throughout this side. The involuntary movements which had existed before the stroke returned more vigorously with the recovery of power. Speech was never affected, there was no diplopia, and the functions of the sphincters were not disturbed.

Condition in 1910.

She is a healthy-looking, unusually cultivated and intelligent woman. The circulatory system is unaffected, the vessels are not thickened, arterial tension is not raised, and the urine does not contain sugar or albumen.

Special senses.—Vision, smell, and taste are unaffected, but hearing is slightly diminished on the right side.

Ordinary sounds, such as the note of a tuning fork or the sound of a bell, produce no abnormal effect, but all music that is capable of stirring her emotions excites the unpleasant sensations in the right half of the body. She has always been musical and, up to the time of the stroke, enjoyed good music intensely; but since the attack all such music excites the uncomfortable sensations in the right half of the body and exaggerates the involuntary movements. The singing of a so-called comic song leaves her cold, but serious music is so intolerable, owing to the sensations it produces throughout the right side of her body, that she is obliged to leave the room.

Cranial nerves.—The functions of all the cranial nerves are unaffected; the pupils are equal and react well to light and on accommodation.

Motor system.—The left limbs are normal. The muscles of the right limbs are equal in size to those of the left. The tone of the leg is slightly greater on the affected side, but there are no contractures. All movements are possible, and their range is good, excepting those of the toes. The strength of movements of the right lower extremity against resistance is somewhat less than of the left, dorsiflexion of the foot being especially feeble. The grasp of the right hand is not quite so strong as that of the left, but there is no paralysis or contracture of the limb. Constant involuntary movements of the different segments of the right limbs are present, due apparently to alternate contractions and relaxations of muscles and their antagonists. This tremor, whilst it affects any one segment of the limb, seems to be fairly regular in rate and amplitude, but it frequently spreads from one part to another, or may affect several segments at the same time. It is greatly increased by voluntary movement or by anything that leaves a segment of the limb unsupported. She is unable to control this tremor voluntarily.

Reflexes.—The tendon-jerks are brisker on the right side than on the left but ankle clonus is not obtained. The plantar reflex on the left foot is of the flexor type; there is little doubt that the reflex from the right sole is also normal, but any attempt to elicit it from this foot produces so violent a movement of withdrawal of the whole of the leg, and evokes so much discomfort, that it is difficult to investigate.

Spontaneous sensations.—She complains of many different abnormal sensations in the right half of the body. The right hand seems swollen and cramped, "as if I had been riding a pulling horse," and the toes of the right foot feel as if they were curled up underneath. "The foot seems round and not flat on the ground." As a rule there is no spontaneous pain in the affected limbs as long as she lies quietly in bed, but directly she is up and about a dull aching pain sets in over the whole of the right half of the body. She also complains of a "cold stinging feeling" in the right hand, and not infrequently in the right foot. She objects intensely to any one sitting to her right side, for she then begins to suffer from the same disagreeable sensations in this half of her body that are evoked by contact. When one of us placed himself to her right without touching her, she complained of a soreness all down the side, "as if you were pulling a dressing from a wound." This ceased entirely when the observer moved to her left. This phenomenon seems to be not uncommon in this class of cases and we have met with it in two other instances.

Tactile sensibility.—She recognises cotton-wool contacts on both hairless and hair-clad parts of both halves of the body, but says there is a considerable difference between the sensations evoked on the two sides: "On the left it is quite distinct, but on the right it is as if you touched me more lightly." A threshold is obtainable on the right hand with a hair of 70 grm. mm.^{2}, whilst on the left she had no difficulty in appreciating every contact with a hair of 14 grm. mm.^{2} On the affected side, however, the records of serial contacts tend to be confused by the persistence of sensation.

Roughness.—As measured by Graham-Brown's instrument, the same amount of protrusion is required to produce a sensation of roughness on the two halves of the body, but when the same stimulus is compared over similar parts she says it is "harder and rougher on the left side, but more uncomfortable and scratching on the right side."

Tickling and scraping.—When a wisp of cotton wool is lightly brushed across the left ear she smiles and says it is "quite pleasant," but when the right ear is treated in the same manner she withdraws and raises her hand to brush the stimulus away, saying it produces a "harsh and very unpleasant feeling which seems to open up the soreness of the side." When the left sole is stroked with the pulp of the fingers she smiles and does not withdraw her foot, but on the right even the slightest touch produces an intense reaction and she complains that the sensation is extremely unpleasant.

Vibration is appreciated on both halves of the body, but is shortened, and the tuning fork appears to be beating more slowly on the affected limbs.

Sensibility to pain.—Pricks are "not so distinct" on the right as on the left half of the body, and the threshold is slightly raised; but a much greater reaction is evoked from the whole of the affected than from the normal side. A measured prick of the same strength "is not so sharp, but is far more unpleasant on the right side than on the left."

Painful pressure.—The reaction to the painful aspect of pressure is so intense on the right side that it is scarcely possible to measure sensibility to this stimulus. Thus, on the normal palm 5 kg. of pressure are necessary to evoke discomfort, whilst on the affected hand even half a kilogramme produces an intolerable sensation.

Thermal sensibility.—There is no defect of sensibility to temperature, and the thresholds for heat and cold are identical on the two sides. Moreover, there is no exaggerated response to extremes of heat and cold on the affected side.

Sense of position is gravely defective in the right limbs; she fails to describe or imitate correctly any position into which the right arm or leg may be placed.

Appreciation of passive movements is equally defective. She can, however, recognise a passive movement and its direction if the range is sufficiently great, but no movement of the upper limb is appreciated until it has reached at least five times that necessary on the normal side.

		Right.	Left.
Index-finger	Flexion	22 25 27	4 5 4
	Extension	20 20 25	3 3 3
Elbow	Flexion	17 16 20	3 2 2
	Extension	12 15 15	2 3 2

Localisation.—Almost as good results were obtained on the right as on the normal half of the body with the usual tests, but she is somewhat slower, and herself recognises that she was less certain on the affected side.

Compasses.—Sensibility to this test is considerably affected on the right half of the body; for instance, on the hand a record with the points 6 cm. apart is defective, while 1·5 cm. gives a perfect reading on the left palm. She is, however, able to appreciate the two points when applied successively. This defect cannot be due to loss of tactile sensibility, for in two long series of observations she made the same number of errors with the blunt-pointed compasses as when sharp points, which pricked her, were employed.

Appreciation of size is seriously defective, but she is able to appreciate the relative size of two objects when they differ by something over twice the amount necessary on the normal side.

Appreciation of shape and form.—Although she made no mistakes with our test-objects on the normal side, she was frequently wrong on the affected hand; she says, "I have an idea of the shape, but I am not certain." She can recognise many common objects, such as a pencil, scissors, a watch, a knife and a key.

Case 12.—An instance of the thalamic syndrome where all loud sounds produced great distress and much increased the involuntary movements on the affected side.

Frederick W., aged 65, was admitted into the London Hospital under the care of one of us (H. H.) in May, 1911. He was an engine-fitter, and was perfectly well until April 15, 1910. On that day, as he knelt down to tie some heavy objects on to his barrow, he became dizzy and lost consciousness. He remained unconscious for two or three days with complete left hemiplegia. Movement of the left arm and leg gradually returned; about a month after the stroke the involuntary movements appeared and from this time increased steadily in violence. Since he regained consciousness he has constantly complained that noises were peculiarly unpleasant to him, and at the same time he found that he could not hear so well with the left ear; this seems to have followed directly on the stroke. Vision was not affected and there was no diplopia at any time. There was no disturbance of smell or taste.

The pains which are now so prominent a feature of his case came on about three or four weeks after the stroke, and have since then increased in severity.

Condition in May, 1911.

He is a worn-looking old man with thickened vessels and somewhat raised arterial tension. Otherwise there is no visceral disease. The urine contains no albumen or sugar. He is fairly intelligent, and as long as he is not exposed to noise is quiet and attentive.

There is no aphasia or apraxia, but when he is excited he shows a curious difficulty in expressing what he wants to say. He stammers and can scarcely utter a word; at the same time the left arm is thrown into violent movement. If he is allowed to remain quiet for a time these movements subside and he can then enunciate all his words perfectly.

Special senses.—Smell, taste and vision are unaffected. On the other hand, hearing shows the following changes: If a tuning fork is held near either ear, whilst he is in an absolutely quiet room, he listens for a few seconds calmly and then becomes more and more agitated; his face shows obvious signs of discomfort and the involuntary movements of the affected arm become greatly increased, or they may be started by the sound of the fork. It is difficult to be certain that the tuning fork is a more potent cause of discomfort and exaggerated movement of the affected arm when placed near the one or the other ear, but our impression after several examinations is that it is easier to produce these effects from the left ear. Moreover, he is certain that he dislikes the fork more when it is approached to the left ear than to the right. Music, of which he used to be unusually fond, is now intensely disagreeable; even favourite tunes "now work me up till I can't bear them," and excite the involuntary movements to great violence and amplitude. On the day he travelled to London the noise of the railway was so intolerable to him that he attempted to throw himself out of the train. No musical sounds are now capable of giving him pleasure.

On examination it is found that whispering and the watch are equally well heard in the two ears, and there is no gross difference between the appreciation of the various tuning forks. The right meatus is narrow and the left more so; the membranes are slightly grey and thickened, but there is otherwise nothing abnormal. Thus, though there was a history of "deafness" after the stroke, no loss of hearing can be now demonstrated in the left ear.

Cranial nerves.—The ocular movements are unaffected and the pupils react well. The right corneal reflex is brisk, but the left is abolished. The masseters contract equally. When the patient is at rest the left half of the face is somewhat more contracted than the right, and the nasolabial fold is deepened; the two sides move, however, equally in strong voluntary movement, but in speech irregular overaction of the whole of the left half of the face occurs, including even the muscles of the forehead. These irregular movements are particularly liable to appear under all conditions that provoke or exaggerate those of the left arm. The movements of the palate and tongue are unaffected, but occasionally spontaneous movements are seen in the left half of the tongue.

Motor System.—The right limbs are unaffected. The muscles of the left limbs are not wasted, their tone is normal and there is no rigidity or contracture. The strength of the arm is excellent; any apparent weakness is due to the gross ataxia. As he lies quietly in bed the left hand and forearm are usually in constant irregular movement; the movements resemble those of a child that is fidgety, or of a man who is ill at ease when speaking. But, when he is excited by noises or emotional causes, they increase and become almost flail-like; the arm swings around, dashes against his bed or his body with astonishing violence, and the leg is similarly agitated, though the amplitude of its movements is less. These movements disappear in sleep, and when he wakes his limbs are at rest. In addition, all voluntary movements of these limbs are extremely ataxic. His gait varies with the vehemence of the involuntary movements of the left leg; when they are slight he can walk without difficulty in spite of the obvious ataxia of the leg, but when the movements are excited they often become so violent as to prevent him walking.

Reflexes.—All deep reflexes are brisk but equal on the two sides. Both plantars give flexor responses, and the abdominal reflexes are equal on the two sides.

Spontaneous sensations.—He complains of constant pains over the whole of the left half of the body, sometimes stationary in the neighbourhood of the great joints, sometimes shooting through a limb or over the whole side. They are liable to be evoked by peripheral stimuli that cause discomfort. He also complains of a "numbness" down the left half of the body, "as if it had been hurt and bandaged up." The left side and this half of the face seem to him to be puffed and swollen, and there is a "cold feeling" round the left eye. If he lies on the left side it seems as if he were "on a hard lump."

Tactile sensibility.—There is complete loss of sensibility to contacts with cotton wool on the left arm, left leg and this half of the trunk, but he occasionally responds to wool rubbed over the left ear and forehead. Pressure-touch is also gravely diminished.

Roughness.—He appreciates roughness, as tested with Graham-Brown's instrument, within normal limits on the right half of the body, but even when the protrusion is five times this amount he fails to recognise the scraping of the instrument on the left side. Under these conditions he merely says, "Something is happening to me, but I don't know if you are doing anything."

Tickling and scraping.—Although cotton wool may not be appreciated over the left lower limb, a wisp repeatedly rubbed over the sole produces a sensation of painful "tingling all up the leg." When the pulps of the fingers are gently drawn over the right sole he smiles but remains still, but when the same stimulus is applied to the left sole his face shows obvious discomfort and he says, "You are tickling me, but it does not seem any place in particular; it is a crawling feeling which affects me all up the side." When the left sole is scraped with the finger-nails he shows signs of distress and says, "I don't know what you are doing, but it affects me all up the side." Both tickling and scraping excite and exaggerate the involuntary movements.

Vibration.—The appreciation of vibration is totally lost on the left limbs and on the left half of the trunk, and no unpleasant sensations are provoked by the application of the strongly vibrating fork.

Sensibility to pain.—He generally fails to appreciate moderate single pricks on the left upper limb, but when pricked more firmly, or several times in succession, he reacts vigorously, describes the sensation as "something burning," or "a sharp, fiery prick," and says it is much more painful than on the opposite side. On the chest he replies more frequently to a single light prick, and there is extreme over-reaction to the point of a pin when, being dragged from right to left, it crosses the middle line. The threshold to prick is evidently raised on the left side of the face and on the left leg, but a series of pricks produce the same uncomfortable burning sensations as on the affected arm. Pricks on the left side are also "more uncomfortable because they affect me all over." He has no idea of the situation of the pricks; whether on the elbow or on the back of the hand, they are equally referred to the palm. He also confuses a series of pricks on the shin with the effect produced by tickling the left sole with the pulp of the fingers; not only does he confuse the locality of the sensation, but he has no idea of the different nature of the stimuli.

Measurements with the algesimeter also show that the threshold is greatly raised on the whole left half of the body, excepting the left sole. Here the same strength of stimulus evokes pain as on the right sole, but the reaction is invariably greater.

Pressure-pain.—The pressure necessary to evoke pain is uniformly higher over the left than on the normal half of the body, but the pain evoked is excessive. Thus, over the normal sole he complained of pain with a pressure of 3 kg., and at 5 kg. the signs of distress were considerable; but on the left sole no pain was produced until the pressure had reached at least 5 kg., and yet he complained that this stimulus was much more uncomfortable on the left than on the right sole.

Thermal sensibility.—All appreciation of temperature is abolished on the left half of the body. Ice produces an uncomfortable sensation over the affected parts, which he describes "as if something pricked me and made me jump," and the reaction is greater than from the normal side. No temperature between 10° C. and 50° C. produces any reaction.

Sense of position and of passive movement.—He is totally unable to recognise the posture or passive movements of the left limbs, and makes no attempt to say in what direction they are moved.

Localisation.—He has lost the power of recognising the locality of all stimuli, including prick and painful pressure. He can generally recognise in which limb pain is evoked, but has no idea what part of the limb the stimulus affects.

Compasses cannot be tested owing to the gross loss of tactile sensibility.

Appreciation of weight.—He is unable to appreciate weight in the left hand and cannot even recognise the difference between 30 and 700 grm., whether the hand is supported or not.

The power of *appreciating form* is also abolished in the left hand.

Visceral sensibility.—There is no doubt that the left testicle is less sensitive to pressure than the right, but when pain is evoked by squeezing it strongly he says, "It feels sharpest on the right, but I would rather you did not squeeze the left."

Case 13.—An instance of the thalamic syndrome where the loss of sensation was extreme and the thresholds for all painful stimuli, including the pressure-algometer, were greatly raised.

Thomas G., aged 43, was admitted to the National Hospital, under the care of Dr. Turner, in August, 1910. On May 4, 1907, whilst at work, "a numbness" appeared in the right foot and gradually spread up the right half of the body. During the next half-hour he found his right arm and leg became weak and his speech was affected. He was taken to a hospital and remained there in bed for nearly seven weeks. Speech returned rapidly, and the loss of power in the limbs gradually passed off. About eight months after this stroke the right limbs began to shake: the involuntary movements have always been worse in the arm. The stroke produced immediate loss of sensation in the right half of the body; but the pains and the tingling did not set in till some months later. The special senses were not affected by the stroke.

Condition in September, 1910

He is thin and prematurely aged; his radial vessels are thickened and tortuous, but the pulse-tension is not raised. Urine is of low specific gravity and contains no albumen or sugar.

He is illiterate, but answers well to direct tests; although he becomes tired easily, his memory is fair. There is now no evidence of affection of speech, or of apraxia.

Special senses.—Smell, taste, hearing and vision are unaffected.

Cranial nerves.—The functions of all the cranial nerves are normal, except that the right corneal reflex is much diminished.

Motor system.—The left limbs are unaffected. There is a general increase of tone in the muscles of the right limbs and slight rigidity, but the range of movement is not restricted and there are no contractures. The strength of all movements is remarkably good, and there is little difference between that of the limbs of the two sides; even isolated movements of the right fingers can be easily performed, but more slowly and awkwardly than on the left side. All movements of the right limbs are, however, very ataxic and accompanied by a definite intention tremor.

But in addition the limbs of the right side are the site of involuntary movements, which usually take the form of a tremor that is irregular in both amplitude and rate. This tremor is most evident in the distal segments of the limbs, but is present even at the shoulder and hip. Occasionally, more irregular movements, which can be described as choreiform, also occur; these are increased on any attempt at voluntary movement. He walks fairly well but holds the right leg rigid, and its movements are poorly directed and co-ordinated.

Reflexes.—All the tendon-jerks are increased on the right side as compared with the left, and ankle clonus can be obtained, but both plantar reflexes give flexor responses. The abdominal and cremasteric reflexes are obtained on the left side but abolished on the right.

Spontaneous sensations.—He complains of pains throughout the whole of the right half of the body, which are not only constant but are subject to intense exacerbations which last from three to four hours. These are particularly severe in the face and at the back of the eye. He also suffers from "pins and needles" in the right hand and the right foot, which arise without obvious cause. The right arm seems "numb" as high as the elbow, and the right leg up to the knee.

Tactile sensibility.—Over the whole of the right half of the body and the right limbs there is considerable diminution of tactile sensibility. Even when cotton wool is rubbed across the part his answers are irregular and he often fails entirely to appreciate the stimulus. Sensibility to pressure-touch is also much diminished.

Tickling and scraping.—On tickling the sole of the left foot a strong reaction is obtained, but the sensation is not unpleasant; but from the right sole the sensation is distinctly unpleasant, "as if your nails were digging into my flesh," and the movements which constitute the reaction are more extensive and violent than those which occur on the normal side. There is a similar difference on gently tickling the two palms. If these parts are scraped the difference is even more pronounced.

Vibration.—He cannot appreciate vibration on the upper limb, and the sensation produced by the tuning fork is greatly diminished on the right half of the chest and the right leg and foot. No unpleasant sensations are evoked by this stimulus.

Sensibility to pain.—Sensibility to prick is greatly diminished on the whole of the right half of the body; on the upper extremity he fails to appreciate many strong pricks. While 2 grm., as measured with the algesimeter, evoked a sensation of pricking on the left hand, 22 grm. was the minimum pressure that could evoke pain on the right. Moreover, he always asserts that a pin pricks him more, and is more painful, on normal than abnormal parts, but at the same time the reaction evoked is considerably greater from the abnormal side. The unpleasant sensations spread widely on the affected parts. On the leg, however, where the loss of sensation is less, the pain and discomfort, as well as the reaction, are greater on the abnormal side.

Pressure-pain.—The readings of the pressure algometer are higher on the right half of the body than on the left, except on the sole of the foot; here half the pressure required on the left side produces pain on the right, and he objects more strongly to it.

Thermal sensibility.—On the whole of the left half of the body, except the face, sensibility to temperature is completely abolished. Ice, and water at 60° C., cannot be distinguished, but both evoke painful or more uncomfortable sensations than on the normal half of the body.

Sense of position and the *appreciation of passive movement* are completely abolished in the right limbs; thus even a movement of 90° at the right elbow fails entirely to produce any sensation.

Localisation, the *compasses* and the *appreciation of size* and *shape* cannot be tested owing to the gross loss of sensibility.

He fails to recognise any of the ordinary test-objects for *form*; and on testing for the appreciation of *weight* it is found that he cannot recognise even 200 grm. placed in the right hand.

Visceral sensibility.—On compressing the testicles gently, not only does he say that it is more painful on the abnormal side (right), but the expression of discomfort and the reaction are excessive compared with that from the left.

Case 14.—To illustrate the consequences of removing a small portion of the cortex in the region corresponding to the motor centre for the arm and hand.

Reginald H. This is the patient from whom Sir Victor Horsley removed a portion of the precentral gyrus in March, 1908, at the age of 14. He formed the basis of the Linacre Lecture [54] in 1909. Owing to the kindness of Sir Victor Horsley, to whom we are much indebted, we have been able to examine this patient from time to time between April, 1908, and the present date (1911). Our most complete observations were made between October, 1909, and October, 1910.

For the nature of the operation and the structure of the tissue removed we must refer to Sir Victor Horsley's account; but, roughly speaking, the part removed contained the foci from which movements of the left upper limb could be excited by electrical stimulation at the time of the operation. It consisted of a portion of the precentral gyrus, 4½ cm. in vertical extent, with its middle point somewhat above the genu of the fissure of Rolando. In this account we shall summarise his condition subsequent to October, 1909, for since that date the signs and symptoms have shown no material change.

He is an extremely intelligent youth, a good witness, and willingly submits to prolonged examination.

Special senses.—Smell, taste, hearing and vision are unaffected.

Cranial nerves.—The functions of all the cranial nerves are carried out normally; the movements of the face are symmetrical and the tongue is protruded straight.

Motor system.—The bulk of the muscles of the left forearm and hand is slightly less than that of the right, and their tone is distinctly increased. The limb is rigid, but there are no organic contractures. Voluntary power is considerably diminished in the left arm, more particularly in the fingers, but at the shoulder and elbow the movements are of fair strength and good range. He walks normally and can even play lawn-tennis; there is no difference between the strength or the tone of the muscles of the lower extremities.

Reflexes.—The arm-jerks are exaggerated on the left side, but the knee- and ankle-jerks are equal, and both plantar reflexes give flexor responses.

Spontaneous sensations.—He complains of no spontaneous sensations, except that when the arm is cold it "feels numb."

	Normal hand (Right).	Affected hand (Left).
21 *grm./mm*²	IIIIIIIIIOIIIIII	
21 *grm./mm*²		OIIIIIIIIIIOIII
23 *grm./mm*²		IIIIIIIIIIIOIIO
35 *grm./mm*²		IIIIIIIIIIIIII::
70 *grm./mm*²		IIIIIIIIIIIIIII
100 *grm./mm*²		IIIIIIIIIIIIIOI
23 *grm./mm*²		OIIIIOIIOIIOOI:I
35 *grm./mm*²		IIIIIIIII::IIIIIO
70 *grm./mm*²		IIIIIIIIIIIIIII
23 *grm./mm*²		OOIIIIIOIIIIOIO
21 *grm./mm*²		IIIIIIIIIIIIIII
21 *grm./mm*²	IIIIIIIIIIIIIII	
23 *grm./mm*²	IIIIIIIIIIIIIIII	
35 *grm./mm*²	IIIIIIIIIIIIIII	
70 *grm./mm*²	IIIIIIIIIIIIIII	
100 *grm./mm*²	IIIIIIIIIIIIIII	

To illustrate a set of records obtained in Case 14 when the hands were stimulated with von Frey's hairs of different strengths. On the affected side a threshold could be obtained, but the records were disturbed by hallucinations and other irregularities. His answers from the normal hand were remarkably constant.

Tactile sensibility.—On the normal hand and on both feet a perfect series of answers can be obtained with a hair of 21 grm./mm.²; but on the affected hand the answers are slower and less constant, the sensation of contact tends to persist after the removal of the stimulus, and hallucinations frequently disturb the records. It is possible, however, with care to obtain evidence of a definite threshold.

Roughness and vibration are appreciated equally on the two sides, and measurement gives the same threshold for both on the two upper extremities.

Tickling and scraping are equally appreciated on the two hands and arms.

Sensibility to pain.—Careful measurements with both the prick-algesimeter and the pressure algometer fail to reveal any difference of threshold for pain on the two upper limbs, or elsewhere on the body. Further, the reaction of the two sides to painful stimuli is identical.

Thermal sensibility.—There is no demonstrable alteration of sensibility to temperature, and the thresholds for heat and cold are identical on the two hands; thus, on one occasion the neutral zone lay between 28° C. and 30° C. on both palms and the palmar aspects of the fingers. There is no abnormal reaction on either side to the extreme degrees of temperature.

Sense of position.—The power of recognising the position in space of the left arm, and especially of its distal segments, is gravely defective. Thus, if it is placed in any position, when his eyes are closed, he has difficulty in finding the index finger, and even if he succeeds in striking some other portion of the hand, such as the middle finger, he cannot immediately discover the index finger from its relative position. Examination with Horsley's plate demonstrates this defect very clearly. He visualises strongly and obtains a clear mental picture of both hands. When his eyes are closed this mental picture of his normal hand alters with movement of any part of it; thus, if the index is flexed he sees the finger in its new position. But under the same conditions no amount of passive movement alters the mental picture of the left hand; consequently he refers any sensation evoked on the hand, after its situation has been altered, into its old position in space. For instance, he was asked to lay his hand on the table; after his eyes were closed the elbow was flexed passively to a right angle and when it had been supported in this position for some time various stimuli were applied to it. In his visual picture the hand still lay on the table, and, when asked to point with his sound index finger to the spot stimulated, it was in this direction he first attempted to find it.

He has a perfect knowledge of the position of the various segments of the left lower extremity.

Appreciation of passive movement is gravely affected at all joints of the left upper extremity below the elbow, but more particularly in the fingers of the left hand.

		Normal (Right).	*Affected (Left).*
Index finger	Flexion	2 2 2 2 1½	40+ 50+ 50+ 30 50+
	Extension	2 2 3 2½ 2	30+ 40 60+ 55 60
Elbow ..	Flexion	1½ 1½ 1 1½ 1½	10 7½ 8 6 7½
	Extension	2 2 1 1½ 2	6 6 9 8 6

These numbers give the angles in degrees of the smallest movements which were appreciated; wherever the numbers bear a → the movement was appreciated, but not its direction.

Localisation.—When he is asked to grope for the situation of a stimulated spot on the affected hand he can rarely find it on the first attempt, but he can describe without difficulty the position of the spot that is touched; it is obvious, therefore, that the errors he makes with the groping method are due to his want of knowledge of the position of the limb rather than to defective power of localisation. This is confirmed by observations made with both the original and the modified Henri methods, for the results obtained by both are as accurate on the affected as on the normal hand.

Compasses.—The power of discriminating two points is very defective on the left hand, but becomes steadily better as the limb is ascended. Thus on the normal palm a perfect reading can be obtained with the points 1·5 cm. apart, but in the left palm a threshold cannot be obtained even when they are separated to 6 cm.; on the normal forearm the record is perfect with the points separated to 5 cm., whilst on the left side a threshold cannot be obtained below 15 cm.; between the elbow and the shoulder the difference is considerably less, for although 6 cm. is required on the right side a perfect reading can be obtained on the left arm with the points 10 cm. apart. On the upper part of the chest the difference between the two sides is even smaller, and over the hypochondrium the thresholds are identical on the two sides. Step by step with this increased power of discrimination, the slowness and uncertainty of his replies steadily diminishes, until, when tested on the hypochondrium, they are as quick on the left half as on the right. No difference to this test can be found on the lower extremities, and the records obtained from the two sides are equally good.

Normal (Right).		
Palm. 1·5 cm.	1	II III I II II
	2	III I I II II I
Forearm, 5 cm.	1	IIII I II I II
	2	II IIII II I I
Arm above the elbow, 6 cm.	1	III II IIII I
	2	II III III II

Affected (Left).		
1·5 cm.	1	II IOII IIXX
	2	XII OXX XX XI
6 ,,	1	XXXI IIXXI I
	2	XXXI XXXXI X
10 ,,	1	II I III IXIX
	2	I IIXI IXXXX
15 ,,	1	IIII III III
	2	I IIII III II
7 ,,	1	XII XIXX XXX
	2	III XIIII I X
10 ,,	1	III IIII I II
	2	II IIXI II II

As soon as the points are applied successively, with only the fraction of a second between the moments at which the first and the second points touch the surface of the body, he recognises he double nature of the stimulus without difficulty. This was well shown by a series of observations in which the compass points were so applied that each fell on a different finger; when they were applied simultaneously, for instance to the index and middle fingers, he never recognised the double stimulus, or that he had been touched on two fingers; but as soon as a fraction of a second was allowed to elapse between the contact of the one point on the middle finger and the other on the index, he at once recognised that he had been touched with two points, and that they had fallen on two fingers. This is true for all the fingers.

Appreciation of weight is gravely disturbed on the left hand, whether the limb is supported or unsupported; he cannot even recognise with certainty the addition or removal of weights, such as 100 grm., to or from a weight of 15 grm. resting on the palm.

The power of appreciating *size, shape, form in three dimensions, consistence* and *texture* is lost in the left hand, and he complains that the test-objects do not seem to have shape or form. On the normal hand his power of recognising these tests is remarkably good.

Case 15.—To illustrate the effect upon sensation produced by removal of a portion of the cortex in the right parietal region.

George M., aged 48, formerly a foreman on a railway, is at present an out-patient under the care of one of us (G. H.) at the National Hospital. In August, 1905, he was admitted to hospital under the care of the late Dr. Beevor with the symptoms of an intracranial tumour. In May of that year he first had an attack of left-sided convulsions, which began in the hand and later affected the leg and this side of his face; the convulsions were preceded by numbness of the hand. This seizure was followed by others which seemed to have been exactly similar, and to have recurred at diminishing intervals. He suffered from a little headache on the right side of his head, but did not vomit.

On admission to hospital slight optic neuritis was present in both eyes, but no other abnormal signs could be found except a slight diminution of sensation on the left hand and forearm, affecting chiefly the sense of position, with "astereognosis." The reflexes at that time were normal. As the optic neuritis increased, and some weakness of the left arm developed, he was operated on by Sir Victor Horsley on October 31, 1905, and a large gumma attached to the dura mater was removed, with a part of the subjacent brain tissue to the depth of 2 cm., from over the right inferior parietal lobe; it probably involved the lower half of the postcentral gyrus and a part of the supramarginal convolution, and at its inferior angle it extended frontalwards over the fissure of Rolando. The tissue removed was almost circular and measured 6 cm. in diameter. This description of the site of the operative lesion can be confirmed at the present time by careful measurements of the trephine opening in the skull.

For a time after the operation there was considerable weakness of the left arm, reaching complete paralysis in the hand, and much disturbance of sensation, especially of the sense of position, in this limb. There was also complete left hemianopsia. The paralysis and the sensory disturbances diminished considerably, and in the following description we shall summarise the observations made on his state between October, 1910, and the present time.

Condition in 1910 to 1911

Since the operation he has suffered at rare intervals from slight left-sided epileptiform convulsions, for which he remains under treatment. In making the following observations we have been careful to avoid periods in which there was a risk of confusion from postepileptic phenomena.

He is an intelligent man, and is now actively engaged in selling newspapers. His memory and attention are good, and he submits willingly to protracted examination. Speech is not affected, and there is no apraxia. Smell, hearing, and taste are unaffected, and at present the visual fields are not contracted.

Cranial nerves.—The functions of the cranial nerves are unaffected, except that the volitional movements of the left angle of the mouth are a little slower and weaker than on the right, and that the tongue is protruded slightly to the left.

Motor system.—The right limbs are in every respect unaffected. There is a slight general wasting of the muscles of the left hand and forearm, but otherwise those of the two sides are equal in bulk. The tone of the muscles of the arm, and to a less extent of those of the leg, is increased, and the rigidity of the limbs offers a considerable resistance to passive movement; there is also a tendency to contractures, especially in the arm, but the range of voluntary movement is fair. The strength of all the arm-movements is diminished, but the leg is almost as strong as its fellow: the movements are awkward and slow, but not definitely ataxic. No involuntary movements occur. Gait is almost natural, but he drags the left foot when it is cold and numb.

Reflexes.—The left arm-jerks are exaggerated, and the left knee-jerk is a little brisker than the right. Ankle clonus cannot be obtained, and both plantar reflexes give flexor responses.

Spontaneous sensations.—He complains of a numbness or "a sleepy feeling" in the left hand, especially in the fingers; here it is constant but varies in intensity. There is also some numbness of the left leg, chiefly over the foot. When he wakes at night he does not know the position of the left arm until he touches it or moves it about. He has no visual memory, and when he closes his eyes he sees no mental picture of either hand.

Tactile sensibility.—He cannot appreciate cotton wool touches with certainty on the hairless parts of the left hand, and even on the hair-clad parts many stimuli evoke no response. This diminution of sensibility grows less towards the proximal portions of the limb, but he states that over the whole left upper extremity sensations of contact are "duller" than over similar parts of the right side. On the right hand a hair of 21 grm./mm.^{2} is obviously above the threshold, and 23 grm./mm.^{2} gives perfect readings; but on the left hand his answers are irregular and tend to be disturbed by hallucinations and persistence. Moreover, although he can appreciate 21 grm./mm.^{2} on the affected hand, increasing the strength of the stimulus makes no constant improvement in the proportion of correct answers.

	Normal hand (Right).	Affected hand (Left).
21 *grm./mm*^{2}	IIIIIIOOIIOIIII	
23 *grm./mm*^{2}	IIIIIIOIIIIIIII	
21 *grm./mm*^{2}		IIIIIIOOIOOIIOOO
23 *grm./mm*^{2}		IIOOIIOOIOOOIOIO
35 *grm./mm*^{2}		IOOOIOOOIOOOIOIO
70 *grm./mm*^{2}		IIIOIIOOIIIOIOOO
100 *grm./mm*^{2}		IIOOIIOOIIIOIIOO
21 *grm./mm*^{2}		OIIOIOOOOOIOIIIO
23 *grm./mm*^{2}		IIIOIIIOIIIOIIIO
100 *grm./mm*^{2}		IIIOIIIIIIIIIIIO

To show the results obtained when the affected hand is stimulated in a consecutive series with von Frey's hairs of different strength.

Even the application of 32 grm. on a disc 3 mm.^{2} could not evoke a perfect series of replies, although he was sensitive to the contact of the same instrument weighted with 2 grm. (*vide* p. 573). Thus it is obvious that in this case a tactile threshold cannot be obtained to measurable stimuli.

Roughness.—The threshold obtained with Graham-Brown's instrument is identical on the two hands, and there is no difference in the reactions evoked.

Tickling and scraping.—There is no difference in reaction from the two sides, but he says that cotton wool rubbed across the hair-clad parts of the left hand tickles slightly less than on the right.

Vibration.—The tuning fork is appreciated everywhere, but the sensation it evokes seems to him fainter on the affected than on the normal hand. Moreover, vibration can be appreciated on the right hand for several seconds after it no longer causes a sensation on the left.

Sensibility to pain.—He can appreciate the prick of a pin everywhere on the affected side of the body but says, "It is not quite so sharp, and not so plain" as on the normal side. This want of "plainness" on the left hand and forearm is associated with an apparent slight raising of the threshold to measured pricks; this is more probably due to an affection of the discriminative rather than of the painful elements of the stimulus. There is no difference in the affective reactions from the two sides.

The readings of the pressure algometer are identical on the two halves of the body.

Thermal sensibility.—To the ordinary clinical tests sensibility to heat and cold appears to be unaffected, and there is no difference in the reactions from any part of the two sides of the body. But more careful examination shows that the neutral zone is considerably enlarged on the left hand; thus on one occasion it lay between 29° C. and 31° C. on the normal hand, whilst on the affected hand all temperature between 27° C. and 36° C. seemed to be neither hot nor cold. Not only is the range of the neutral zone increased, but the responses from the affected hand, compared with those from normal parts, are slow and irregular. Moreover, the power of comparing two thermal stimuli applied either together or in sequence to the left hand is diminished; for instance, although he can distinguish with certainty 40° C. and 50° C. on the normal hand he is often unable to say which is the warmer to the left hand, although both appear to him to be warm.

Sense of position.—He is unable to recognise accurately the position in which his left hand and arm may be placed, and the sense of posture is also gravely defective in the left lower extremity.

The appreciation of passive movement.—Passive movement of the fingers and wrist cannot be appreciated even when they reach the extreme range possible without exerting tension on the muscles. He can recognise movements of large range at the elbow, but they must make an angle of at least 60° before he can recognise whether the joint is flexed and extended. Even at the shoulder a large range of movement is required for appreciation.

Localisation.—When examined by naming, or by our modified Henri method, localisation was found to be seriously affected on the left upper limb: out of fifty-three contacts on the left hand, twelve only were correctly placed, while on the normal hand he made no error in forty-five tests. This defect is equally evident when pricks are substituted for tactile contacts, and consequently it cannot be due to the disturbance of tactile sensibility.

Compasses.—The power of recognising the two points in this test is completely abolished on the left hand and forearm, whether they are applied simultaneously or successively. Moreover, the records are equally bad whether we use the ordinary blunt points or replace them by needles, so that every contact produces a prick.

Thus, on the dorsum of the right forearm a perfect reading can be obtained with the points separated to 4 cm., while on the affected forearm he fails to discriminate them when 20 cm. apart, even when they are applied with an appreciable interval between the two contacts.

Appreciation of weight.—The power of appreciating weight, even on the normal hand, is not acute. He can recognise the difference between 60 and 100 grm., but he is not uniformly correct with 120 and 200 grm., when these weights are applied successively to the normal hand. But in spite of the comparatively high threshold on the normal hand, the difference between the two hands to this test is very striking; for instance, when 30 grm. was placed on the fully supported left hand he recognised the contact, but not that the object had any weight, and even when 600 grm. was added to it and then removed he simply said: "You have moved the thing in my hand," and did not know that the weight had changed. When 60 grm. was placed in the normal hand and he was asked to compare it with the same weight in the affected hand by weighing with the unsupported hand, he said: "There is a weight in the right hand only."

Appreciation of size, shape, form and consistence.—All these faculties are entirely abolished on the left side. Moreover, he insists that in every case he can "feel" the test-objects placed in his hand, but he "has no idea" of their size, their shape, their form, or their consistence.

Visceral sensibility, as tested by pressure on the testicles and examination of the sensibility of the glans penis, is unaffected.

Case 16.—To illustrate the sensory changes found twenty-three years after an injury to the left cerebral hemisphere.

Arthur William L., aged 42, is an out-patient under the care of one of us (G. H.) at the National Hospital. He was an officer in the merchant service. In April, 1887, he fell down the hatchway of a ship, injuring his head, and lay unconscious for three weeks. When he regained consciousness he was in a hospital in San Francisco; his right limbs were paralysed and he was unable to speak. During the five months he remained in hospital he regained some power in the right limbs. On the voyage home to England he began to suffer with convulsive attacks which affected the right hand and the right side of his face. He was admitted to the National Hospital under the care of Dr. Ramskill in November, 1888. There was then slight weakness of the right side of his face and considerable hemiplegic paresis and rigidity of the right limbs, with contractures of the fingers of the right hand. The right knee-jerk was brisker than the left, and right ankle clonus was obtained. While in hospital he had several localised fits, which began either in the right thumb or in the fingers of the right hand; in several the convulsions were limited to the hand, but in others the right side of the face was also affected.

On April 2, 1889, Sir Victor Horsley operated and found a fracture of the skull which ran from before backwards across the fissure of Rolando. A large portion of the skull was removed, first over the region of the motor centres for the thumb and fingers, and then upwards to within 2½ cm. of the middle line. The dura mater was adherent to the cortex and a subdural cyst was found at the posterior part of the opening. After the cortical vessels had been ligatured a portion of the damaged cortex, about 5 cm. in diameter, was removed; this included, as far as could be determined, the centres for the fingers and thumb.

CONDITION IN 1910

He still suffers, at rare intervals, from local fits in the right hand, which occasionally spread more widely. Our observations were made for the most part in 1910, and we shall summarise in this account his condition towards the end of that year. There is at present no asphasia or apraxia: he is educated, fairly intelligent, and spends much of his time in playing chess matches.

Special senses.—Smell, taste, hearing and visual acuity are normal and the visual fields are not restricted.

Cranial nerves.—There is slight weakness of the right side of the face in voluntary movement, and the tongue deviates slightly to the right, but the functions of the cranial nerves are otherwise normal.

Motor system.—The right arm is smaller than the left and its muscles are firm and rigid; the wrist and fingers are held in a permanently flexed position, and contractures limit the range of passive movements at all joints. There is no power of movement of the fingers and hand, except that the fingers can be slightly flexed as a whole. Pronation and supination are impossible, and flexion and extension of the elbow are restricted and feeble; he can carry out all the movements, except rotation, of the right shoulder, but they are feeble and he cannot bring the arm into a horizontal position. Voluntary movements of the right foot are also lost, but those of the knee and hip are fair in range and power. There is considerable rigidity of the whole limb, but no contracture except of the calf-muscles. He walks with a typical hemiplegic gait; the right leg is advanced by circumduction and he tends to drag the foot.

Reflexes.—All the deep reflexes are exaggerated on the right side and ankle clonus can be obtained; the right plantar reflex gives an extensor response, and the abdominal reflex is much diminished on this side.

Spontaneous sensations.—He is not a good subject for introspection, but he says he thinks that the right arm and leg " go to sleep more easily than the left "; when he wakes up at night he is unable to find his right hand until he has groped for it. He has never experienced pain or tingling in the affected side.

Tactile sensibility.—When a wisp of cotton wool is rubbed across the affected hand he appreciates most of the contacts, even on the palm, but he says that " the feeling is weaker " on the right than on the left, and that "it seems plainer" on the normal hand. There is no similar difference between the two lower limbs, where he appreciates contacts as constantly on the right as on the left. He has a high threshold to von Frey's hairs on the normal hand, but on the affected side no threshold can be obtained even to 100 grm./mm. To the weight-aesthesiometer he gives a perfect series of answers on the left hand with a pressure of 2 grm., but on the affected a threshold cannot be obtained even with a pressure of 32 grm., although he responds to 2 grm. Moreover, increasing the strength of the stimulus makes no appreciable difference in the proportion of right answers; in fact, a better reading was obtained with 2 grm. than subsequently with 32 grm. With von Frey's hairs there is a great tendency to persistence and hallucinations, but this is much less evident during testing with the weight-aesthesiometer.

Roughness.—With Graham-Brown's instrument the same threshold is obtained on the two hands.

Vibration is everywhere appreciated, but on the right hand he said "it felt weaker" than on the left, and the period during which it can be appreciated is considerably shortened.

Tickling and scraping.—To tickling and scraping there is no difference between the palms, or the soles of the two feet.

Sensibility to pain.—When repeatedly pricked in any one area with a pin he says "it is stronger on the left side than on the right, but it does not hurt me more." Occasionally, too, he finds the prick "sharper" on the left hand. There is, however, no difference in thresholds on the two sides to measured prick or to pressure-pain.

Thermal sensibility.—The paralysed hand is usually blue and cold and is, therefore, unsuitable for the finer testing of thermal sensibility; but in spite of this he is able to recognise cold up to 15° C. and heat from 45° C. upwards. More satisfactory observations can be obtained from the arm above the elbow. On the normal side the neutral zone lies between 27° C. and 32° C., whereas on the affected side it extends from 25° C. to 38° C. He complains that he can "feel warmth and coldness quicker on the left side than on the right," and adds, "I have to wait a minute to be sure on the bad side."

Sense of position.—The power of recognising the sense of position of the right upper extremity is lost; he has no idea where it lies in space. There is also considerable loss in the right lower extremity, especially below the knee.

Appreciation of passive movement is also lost in the right fingers and wrist and is much diminished at the elbow; here a movement through an angle of even 60° was occasionally not appreciated, and the smallest movement he was able to recognise exceeded 40°. At the normal elbow he is always able to recognise a movement of 3°, and not infrequently indicates correctly the direction of a movement that does not exceed 2°.

Localisation is remarkably accurate on the normal hand but is gravely affected on the right. When tested by the modified Henri method, he says to every contact, that he can feel it but has no idea where it is.

Compasses.—Readings on the dorsum of the hand and on the forearm showed that the power of discriminating two points is completely lost on the affected side, whether the two contacts are made simultaneously or successively.

Appreciation of weight.—He is completely unable to recognise the difference between two weights in the supported or unsupported hand; thus if equal weights are placed in the two hands he is conscious of the weight on his left palm, but does not recognise that the object on his right has any weight. Even when 500 grm. are placed in his affected hand he recognises that something is in contact with it, but does not appreciate that it is a weight.

The *appreciation of size, shape, form in three dimensions*, and the recognition of familiar objects, are abolished in the right hand, although to all these tests he is accurate on the normal side.

Case 17.—To illustrate the application of our methods to a patient with aphasia due to the removal of a portion of the cortex in the left parietal region.

Edmund M., now aged 46, is at present an out-patient under the care of one of us (G. H.) at the National Hospital. He was admitted to the hospital under the care of Sir William Gowers in May, 1904, complaining of headache, vomiting, fits, weakness of the right arm, and difficulty of speech. These symptoms began eleven months before admission. In most of the fits he lost consciousness without local convulsions, but during the few weeks previous to admission he had had seizures which began with twitching of the right fingers; after these slighter attacks speech was particularly affected. Several of these occurred when he was in hospital, but convulsions were not observed in any of them.

At that time he showed distinct signs of aphasia; the right upper extremity was weak, but though he dragged the right foot no actual loss of motor power could be demonstrated in the right leg. The deep reflexes were brisker on the right than on the left half of the body, the plantar reflexes gave flexor responses, and ankle clonus could not be obtained. He complained of numbness in the right hand, and on examination tactile sensibility was found to be slightly defective over the right arm and leg; the power of appreciating the position of right limbs was also disturbed and touches were badly localised. He was able to recognise objects placed in his right hand. Smell and taste were unaffected, hearing was poor in both ears, but bone conduction was better than aerial. Vision was fair ($\frac{6}{12}$ in both eyes), but there was slight peripheral contraction of the right halves of the visual fields. There was intense optic neuritis in both eyes. On June 21, 1904, a large gumma was removed by Sir Victor Horsley from over the left parietal lobe: it was firmly attached to the dura mater and measured about 6 by 10 cm. in transverse diameter. Brain-tissue to a depth of about 2 cm. was removed with it. From the description written at the time of the operation, and from subsequent measurements of the trephine opening in the skull, the centre of the portion removed lay over the supramarginal gyrus. He recovered rapidly from the operation, but has since remained under treatment, as he is liable, at rare intervals, to convulsive attacks affecting his right side.

Condition in 1909 to 1911

The larger number of our observations have been made between June, 1909, and the present time, and in the following account we will summarise his condition during this period. At present he is unable to read or write, but he can carry out simple orders without mistakes; he occasionally fails, however, to comprehend more complex commands and longer sentences. He talks readily and does not as a rule use wrong words. There is no apraxia.

Special senses.—Smell and taste appear unaffected. There is slight middle-ear deafness on both sides, greater on the right than on the left. Vision is now good in both eyes, but there is right homonymous hemianopsia.

Cranial nerves.—The functions of all the cranial nerves are normal, the pupils are equal and react well, and there is no asymmetry of the face at rest or in movement.

Motor system.—The muscles are well developed in both right and left limbs, and there is no rigidity. The grasps are equal when he can look at his hands, but if his eyes are closed the right hand is clumsy and definitely less powerful. Although a right-handed man, he always uses his left hand to tie a knot or to button his clothes. He walks well, but says the right leg tires easily.

Reflexes.—The tendon-jerks are brisk but equal on the two sides, there is no clonus, and both plantar reflexes give flexor responses.

Spontaneous sensations.—He complains that his right hand seems "dull," as compared with the left, but he cannot explain fully in what this difference consists. This "dulness" extends over the whole right half of the body, but is less on the foot than elsewhere. He has no pain or tingling.

Tactile sensibility.—He can appreciate cotton wool contacts over all hair-clad parts of both sides of his body, but he says "the touches are plainer" on the normal than on the affected side. On the right palm he frequently fails to recognise such contacts as evoke constant responses from similar parts of the left hand. To von Frey's hairs the tactile threshold is high even on the normal hand; thus although he responds to 21 grm./mm.^{2} he cannot give a perfect series of answers under 35 grm./mm.^{2} On the affected hand he also responds to 21 grm./mm.^{2}, but even with 100 grm./mm.^{2} the series of answers is gravely defective. Moreover, increasing the strength of the stimulus does not produce a corresponding improvement in his answers.

Roughness.—As measured with Graham-Brown's instrument, the threshold is found to be the same on the two halves of the body.

Tickling and scraping.—We can recognise no difference in the effect produced by tickling or scraping on the two sides of the body.

Vibration seems to be equally well appreciated on the two halves of the body, but we found considerable difficulty in determining any finer differences, as the relative length of time during which the fork can be appreciated.

Sensibility to pain.—We can find no difference in the thresholds on the two sides to measured prick or pressure-pain.

Thermal sensibility.—We are unable to find any gross differences between the appreciation of temperature on the two sides of the body, and he seems to be able to recognise correctly the relative hotness or coldness of two temperatures on the same side of the thermal scale. Owing to his speech-defect, finer tests, as the determination of the neutral zone, are difficult and unsatisfactory.

Sense of position.—He is unable to recognise accurately the position in which the affected arm is placed, and by Horsley's method the records obtained, when the normal hand seeks the affected index, are much worse than when he points with the affected hand to the normal fore-finger. There is also defective appreciation of the position in space of the right lower limb.

Appreciation of passive movement is gravely affected in the whole of the right upper extremity and to a less degree in the right leg. It is difficult to estimate the amount of this defect, as the patient frequently replies that a movement has occurred when none has been made.

Localisation is seriously affected on the right hand; this faculty was tested by various methods, but all yielded the same results. As a rule he attempts to localise the spot stimulated, but often gives up at once, saying, "Yes, I feel it, but I have no idea where it is." He frequently moves the finger that is touched, but even then does not succeed in determining which it is.

Compasses.—The power of discriminating the two points is gravely affected on the right hand and arm. Thus a perfect reading can be obtained on the back of the normal hand with the points separated to 3 cm., but on the right he is completely unable to distinguish them even when they are 8 cm. apart. Moreover, this loss is equally distinct whether the points are applied simultaneously or successively with an appreciable interval of time between the contacts.

The *power of estimating weight*, either on the supported or the unsupported hand, is completely lost on the right side.

The *appreciation of size, shape, form in three dimensions*, and the nature of common objects placed in his right hand, are completely lost, whereas in the left hand he is remarkably accurate to all these tests.

Case 18.—To illustrate the application of our methods in a case of cerebral tumour before and after successful operation.

William S., aged 51, was admitted to the National Hospital on July 21, 1911, under the care of Dr. Tooth, to whose kindness we are indebted for the opportunity of making the following observations. He had had syphilis ten years previously, and his right eye was destroyed by an accident five years ago. He had been otherwise well till May, 1911, when he began to suffer with attacks of pain of short duration, "like an electric shock," which always began in his left foot, ascended this leg to the hip, then passed up the left side of his body to his shoulder, and into his left arm and this side of his face. At first these attacks consisted in sensory phenomena only, but from June 7 they were followed by clonic spasms of the left limbs, always beginning in the foot, and jerking of his head to the left. His limbs were weak after each of these attacks and remained permanently so from early in June. When he came under observation hearing and vision were unaffected, but optic neuritis was commencing; the functions of the cranial nerves were undisturbed and the pupils reacted briskly. The right half of the body was normal but the left limbs were weaker, the leg more so than the arm: they were also slightly rigid and all their movements awkward and clumsy. The left deep reflexes were exaggerated, ankle clonus was easily elicited on the left side, and the plantar reflex was of the extensor type.

Condition of Sensation before Operation

The condition of his sensation was carefully investigated at the end of July and in the beginning of August, but as these observations are less valuable for our purposes than those made after the progressive disease was removed, they will be recorded as concisely as possible.

Spontaneous sensation.—He complains only that his left leg occasionally feels numb, and that "I don't seem to have the proper feeling in the left arm or leg."

Tactile sensibility.—He appreciates all contacts of cotton wool on the hair-clad parts of the affected side, but says they are "less plain" than on the normal; he misses many contacts on hairless parts, such as the palm. A definite threshold cannot be demonstrated with von Frey's hairs or with the pressure æsthesiometer, even to a pressure of 35 grm., and fatigue can be induced with unusual ease over the affected parts.

Roughness.—The same thresholds are obtained on both sides with both Graham-Brown's instrument and the sand-paper tests.

Tickling and scraping evoke a "stronger sensation" on the normal than on the affected side.

Vibration.—The tuning fork can be appreciated everywhere on the affected half of the body, but the sensation is "less plain" than over normal parts. Moreover, when the fork has ceased to produce a sensation on the left half of the body it can be appreciated for at least five seconds longer, if immediately transferred to the corresponding part of the normal side. The fork also seems to beat faster on the normal side.

Sensibility to pain.—Pin-pricks can be appreciated everywhere, but they appear "not quite so sharp" on the affected half of the body. He does not react excessively from either side. The threshold, as measured with the algesimeter, is identical on the two halves of the body, and the readings of the pressure algometer show no material difference.

Thermal sensibility is not disturbed on either side.

Sense of position is seriously affected in the left arm and leg, and all segments of these limbs must be moved through considerable angles before passive movement can be appreciated.

Localisation is also much affected: when tested with tactile stimuli he frequently said, "I can feel it, but I can't be sure where it is."

Compasses.—This faculty is very much diminished. A threshold cannot be obtained on the affected hand, even when the points are applied successively, though the normal palm gives a perfect reading with the points 1 cm. apart.

Appreciation of weight.—He cannot recognise the difference between two weights placed on the hands, supported or unsupported, nor the addition or removal of weights on the affected palm.

The *appreciation of size* is disturbed on the affected hand, but not completely lost. He is unable to recognise the test-objects we generally employ to test the *appreciation of shape*. He can, however, recognise the three dimensional objects.

The *appreciation of texture* is also lost in the affected hand.

Operation

On August 30 Mr. Sargent operated, making a large osteoplastic flap in the right side of the skull, which exposed the upper end of the central gyri. Evidence of disease was at once seen in the postcentral gyrus, and a horizontal incision was made into it at about the level of the upper genu of the fissure of Rolando. Through this incision a large circumscribed, partly encapsulated tumour, measuring 5·5 by 4·5 by 2·75 cm., was removed. Microscopical examination showed that it was a glioma. It lay in the subcortical white matter near the surface, and apparently not far from the mesial surface of the hemisphere. In its removal a considerable portion of the postcentral gyri above the level of the superior genu of Rolando was necessarily destroyed, but as far as could be seen the operative lesion did not affect any part of the brain in front of the central fissure.

He recovered quickly and satisfactorily from the operation, and his condition in October, 1911, was as follows.

Condition One Month after Operation

The functions of the *cranial nerves* and *special senses* are still unaffected.

Motor system.—There is comparatively little loss of power in the left upper limb; the weakness of grasp is due chiefly to the sensory disturbance. The movements of the limb are clumsy, but their range is not restricted. The left leg is relatively weaker, but all its movements can be executed with fair power through a normal range; it is, however, slightly rigid. He can walk without assistance with a slightly hemiplegic gait, the left limb being advanced by circumduction.

Reflexes.—All the deep reflexes are increased on the left side, but ankle clonus cannot be obtained. When the left knee is extended the plantar reflex is of the extensor type, but when flexed undoubtedly flexor.

Spontaneous sensation.—He complains of no numbness or tingling in the affected side, but when the hand is touched "it does not feel the same" as the normal side. He generally knows where the arm lies, but when the left foot is under his chair he is less certain of its position.

Tactile sensibility.—He can appreciate all contacts of cotton wool when rubbed across the affected foot, on both hairless and hair-clad parts, but he always says that the sensation is "less plain" than on the normal foot. But if the cotton wool is simply brought into contact with the skin without movement he fails to appreciate many contacts on the left side, although he misses none on the normal foot. There is no demonstrable disturbance of sensibility to cotton wool on the hand.

Examination with graduated hairs, or with similar methods, shows all the phenomena we have already described; fatigue is produced with unusual ease, the sensations persist, and hallucinations disturb the examination. A threshold can be, however, obtained on both the hand and the foot, though increasing the strength of the stimulus does not always give a corresponding increase in the proportion of correct answers.

Roughness.—No difference can be discovered between the power of appreciating roughness on the two halves of the body, and an identical threshold can be obtained from the two hands and the two feet.

Tickling and scraping.—When the affected sole is tickled, he says "it is not so plain" as on the normal side, and the reaction evoked is distinctly less.

Vibration of the tuning fork is appreciated everywhere; but on the affected hand and foot it does not seem so plain as on the normal side. The shortened power of appreciating the tuning fork is no longer so definite as before the operation, but he still insists that on the affected foot it seems to be beating slower than on the normal side.

Sensibility to pain.—There is no diminution of sensibility to prick on the affected half of the body, and identical thresholds can be obtained on both sides.

Thermal sensibility.—The thresholds for heat and cold are the same on the two hands; the neutral zone lies between 27° C. and 30° C. But there is a distinct difference between the two feet; thus, though the neutral zone on the right foot lies between 27° C. and 30° C., it extends from 24° C. to 35° C. on the affected sole. He is generally able to recognise correctly the difference between two temperatures on the same side of the scale, provided they differ by 10° C.

Sense of position.—There is considerable loss of the power of recognising the position of the left lower extremity, and to a less degree in the distal segments of the upper limb.

Appreciation of passive movement is also defective in the left limbs. Movements of the normal knee of from 1° to 2°, for instance, can be constantly appreciated, but on the affected side no movement under 12° was appreciated, and on several occasions a range of 25° was necessary for recognition.

Localisation, as tested by the modified Henri method, is perfect on both the foot and the hand; in this respect he has improved greatly since the operation.

Compasses.—On the normal sole a good reading was obtained when the points were 2 cm. apart, but on the affected side a series of correct answers cannot be obtained even at 10 cm. The difference is much less between the two palms; on the normal hand he could discriminate the two points when 1 cm. apart, and he made no mistakes when they were separated to 3 cm. on the affected palm. He is now able, however, to appreciate the two points when they are applied successively.

Appreciation of weight.—The power of discriminating weights placed on the unsupported hand is obviously defective. There seems to be also a slight defect in the recognition of addition to and removal of weights from the palm, but no definite difference can be demonstrated in the power of discriminating two weights placed one after another on the fully supported hand; it must be remembered, however, that the hand is now very little affected, and that it is impossible to test accurately the discrimination of weights on the foot.

The appreciation of size, shape and form.—The appreciation of size alone can be tested on the foot, and he is certainly slower and less certain in his answers from the affected side; further, the difference between the test-objects must be considerably greater than is necessary on the normal sole. On the left hand, where the disturbance of sensibility is much slighter, he can appreciate size, shape, and three-dimensional form as well as on the unaffected side.

The power of recognising *consistence* and *texture* can be tested on the hands alone, and here no definite difference can be discovered between the two sides.

SENSATION AND THE CEREBRAL CORTEX

By HENRY HEAD, M.D., F.R.S.

CHAPTER I

INTRODUCTION

We tend habitually to speak of all varieties of general somatic sensibility in terms of touch, pain, heat and cold; for these categories seem to accord best with what we gather from introspection. To these elementary sensations it is customary to add a hypothetical "joint-sense," and the whole complex is supposed to be transformed by association and judgment into the mental processes by which we become aware of the physical qualities in the world around.

Moreover, according to the doctrine of specific nerve energy, as it is usually held, each psychical act of sensation is associated on the physical side with certain distinct processes, which, starting in the peripheral end-organs, pass unaltered to the cortex of the brain. Here, according to the usual supposition, each specific form of nerve energy evokes those changes which underlie its peculiar aspect of sensation.

Such a view of the physical mechanism and nature of sensory processes was not unreasonable in an age ignorant of the gradual evolution of the human nervous system. Man was thought to have been created perfect, armed with apparatus to receive and conduct the special processes, which underlie each fundamental sensory experience revealed to him by introspection.

This conception of man as a created being has long passed away, but the manner of regarding sensation, to which it gave rise, still dominates psychological teaching. Even the neurologist, who is in daily touch with the consequences of lesions to the nervous system, tended, until recently, to speak of sensory impulses as if they were invariably grouped into those subserving touch, pain, heat and cold. This arose in the main from two causes. His almost complete preoccupation with structure rather than function compelled him to consider the central nervous system as something stable, developed it is true from that of lowlier organisms, but fixed and unalterable in its action. He did not recognise that all the processes of its functional evolution were still evident in its physiological activities. Even now, the conception that a stimulus may be effective or entirely ineffective, according to the conditions which have preceded its application, has made little impression on practical neurology.

Preoccupation with the sensory effects produced by lesions of the spinal cord also inclined the clinician to accept the fundamental division of afferent impulses into those for touch, pain, heat and cold. For spinal injuries notoriously tend to disturb these four modes of sensation independently of one another. But, as soon as disorders of sensation came to be studied more closely, it was obvious that something further was required to explain even so simple a problem as the changes produced by a lesion at this anatomical situation in the nervous system. Four specific groups, corresponding to touch, pain, heat and cold, were obviously insufficient to contain all the impulses originated at the periphery by the impact of a stimulus. For it is now universally acknowledged by those who have had the opportunity of observing cases of injury to the spinal cord, that all these forms of sensibility may be preserved, and yet the patient be unable to recognise the spacial relationships of the affected limb, or to appreciate movements carried out passively. Power to recognise the posture of the affected limb, to discriminate the two compass points applied simultaneously and to appreciate the vibration of a tuning fork may be disturbed, although every other form of sensory activity is perfect.

As soon as it was clear that these aspects of sensation depended on the integrity of the posterior columns, it was thought imperative that they should receive a name. Nothing could have been more unfortunate for the progress of knowledge than the names selected. Clinicians, seeking for a sign that would reveal the condition of the posterior columns, concentrated their attention on one or other of the groups of impulses passing upwards in this portion of the spinal cord, oblivious of the general principles underlying their conduction. Hence the terms, "joint-sense," "deep sensibility," "vibratory sense," and "stereognosis," which give a most inadequate view of the part played in sensation by the posterior columns.

For the neurologist, who speaks of the "joint-sense" as dependent on these columns, forgets that pain is a most important element of the sensations arising from joints. "Deep sensibility" is a sufficiently accurate name for those impulses which arise in subcutaneous structures, such as bones, joints and tendons: but it can never be disturbed as a single group, except by a lesion of the deep afferent fibres of the peripheral nerve. The changes, which result from destruction of the posterior columns of the spinal cord, correspond to a fraction only of such impulses.

On the other hand, "bathyæsthesia" is, strictly speaking, of too special a significance. It was invented to indicate the faculty of recognising the position of the limbs in space and of appreciating the vibrations of a tuning fork, in as far as they were disturbed by lesions of the spinal cord. But an injury of the posterior columns may also destroy the power of appreciating the size, shape and relative weight of objects placed in the affected hand; to this loss of sensibility the inadequate name of "astereognosis" has been applied. For "stereognosis" signifies ability to recognise the solidity of objects by touch, and cannot by any stretch of terminology be made to include the power of appreciating weight.

Any attempt to fit the sensory disturbances, produced by injury of a nerve trunk, into four primary categories of touch, pain, heat and cold, tends to even worse confusion. For, when one of the larger nerves is divided, it may be that pressure can be perfectly appreciated, though sensibility to lighter contacts is abolished; and pressure may evoke pain in parts insensitive to a prick or a burn. In the same way, discrimination of two points may be destroyed, though recognition of posture and passive movement is maintained unimpaired. Moreover, as far as the peripheral mechanism is concerned, sensibility to heat can be shown to be a complex process, involving the simultaneous activity of several different end-organs.

As each new fact of sensory dissociation became established, the conception of the part played by the nervous system became more confused and the nomenclature more chaotic. The psychologist, who was not in direct contact with the facts, was content to explain the phenomena which underlie sensation as divisible into four groups of specific impulses aided by a hypothetical "joint-sense"; these, elaborated by the mental processes of association and judgment, seemed all that was required. The attitude of the neurologist varied between an uncritical agnosticism and a determination to square his observations on injuries of peripheral nerves with his conception of spinal dissociation.

Obviously, some link was missing in the chain of reasoning which would harmonise those forms of sensory loss presented by lesions of the spinal cord with the apparently impossible inductions of those who worked on the peripheral nervous system. This was found in the conception that afferent impulses underwent regrouping on their way from the peripheral end-organs to their final termination in the highest receptive centres. Here was the means by which peripheral impulses, with their opportunist or developmental grouping, could be recombined in accordance with their sensory qualities.

Each peripheral end-organ is a specific resonator attuned to some aspect of physical vibration. It responds by producing an afferent impulse stamped with the characteristics peculiar to the organ in which it has arisen. Each of these impulses acts in turn on a series of receptive mechanisms within the central nervous system, which are themselves attuned to certain physiological qualities; here, those of like sensory disposition are gathered together, whatever their peripheral origin. Peripheral end-organs respond to physical changes in their environment, whilst these endo-medullary receptors react specifically to the welter of afferent impulses which reaches the central nervous system.

In this way, afferent impulses of like sensory quality become gathered together in their passage through the spinal cord and brain-stem. At the termination of the fillet, their grouping so closely corresponds to the four qualitative aspects of sensation, with the addition of certain spacial attributes, that it would almost seem as if no further integration were necessary.

But it is in the subsequent fate of these regrouped afferent impulses that the bankruptcy of the older conceptions of sensory activity is most evident. It has long been recognised, that a gross lesion of the so-called "sensory cortex" does not abolish any of the four primary qualities of sensation. An injury of the spinal cord or brain-stem may produce complete loss of sensibility to pain, heat or cold in the affected parts: any one mode of sensation may be destroyed or preserved independently of the others. But when we attempt to investigate the effects of a lesion of the cerebral cortex on sensation, the problem seems insoluble: the patient appears to be untrustworthy, sometimes he appreciates a touch, at others a stronger stimulus passes unrecognised. Heat and cold are not confused, but the patient may be uncertain whether a warm object is hotter or colder than one of an obviously different temperature, which he had held in his hand a few minutes before. Inconsequent answers, hallucinations, uncertainty dominate the records from the affected parts; he cannot be said either to appreciate or not to appreciate tactile or thermal stimuli; and yet he may be remarkably trustworthy to every test applied elsewhere.

The clue to this condition, so disconcerting to the views of the introspective psychologist, is given by the behaviour of the optic thalamus. Until recently, the part played by this organ in sensation was unknown. But we now recognise that it is the seat of those physiological processes which underlie crude sensations of contact, pain, heat and cold, together with the feeling-tone they evoke. The essential organ of the optic thalamus is the centre for the affective aspect of sensation, whilst discrimination and spacial projection are the product of cortical activity.

Thus it is evident that, between the response of any peripheral end-organ to a physical stimulus and the final impact of the afferent impulse on the sensory centres of the cortex and optic thalamus, lie the levels of physiological activity. At the one pole is the external universe, whilst at the other we reach the primary mental states of sensation and feeling. Between them the diverse effects, produced by a physical stimulus on the receptive mechanisms of the body, are subjected to infinite modifications of which we can never be conscious under normal conditions.

This conception of levels of activity within the nervous system was one of the leading aspects of Hughlings Jackson's teaching. To him a "level" was always one of function rather than of structure; when he spoke of the "cerebellar level," he implied the peculiar influence which he attributed to the action of the cerebellum on the motor apparatus. But the overwhelming preoccupation of neurologists with anatomy has led them to adopt the convenient term "level" in an anatomical rather than in a physiological significance. Throughout this paper, I shall use the word in its strictly functional sense, unless it is preceded by the word "anatomical." For the activities of any one "anatomical level" may be widely different in the functional hierarchy. Injury to the sensory cortex not only disturbs the power of attention and discrimination but also produces hypotonia. An even more remarkable example is seen when the spinal cord is gravely injured at any one point, so as to destroy its lateral and posterior columns; the anatomical level is given in terms of segments, but the consequences from the point of view of afferent impulses belong to at least two functional levels. Destruction of the posterior columns has blocked peripheral impulses running in their primary combinations; the lesion of the lateral columns, on the other hand, has interfered with impulses of the secondary level, which have already undergone qualitative regrouping.

It is obvious, therefore, that, if we are to understand the sensory effects produced by a lesion of any part of the nervous system, we must record the reaction of the affected parts to each test in turn, noting which stimulus is capable of evoking its appropriate sensation and which of them is not appreciated, or induces an abnormal response. All general nomenclature must be avoided and we must be careful not to speak in terms applicable to one sensory level, when describing the changes which occur at another. Then only can we say that, at this particular level, sensory impulses are grouped in such and such a manner.

This has been our aim throughout the series of researches on disturbances of sensation in which I have collaborated during the last fifteen years. A number of selected tests were systematically applied in cases of definite injury to various parts of the nervous system, between the periphery and the cerebral cortex and the results interpreted in physiological terms.

The object of the following chapters is to demonstrate, by the same method of dissociated sensibility, the manner in which the cortex cerebri modifies the afferent materials it receives, to produce those physiological states which so closely underlie sensation.

But, in order that the nature of this activity may be clear, it will be necessary to recapitulate the various changes to which afferent impulses are subjected at different levels of the nervous system. None of these could be deduced by *a priori* reasoning. If I take into my hand a glass containing hot water, I receive the impression of its size, shape, weight, temperature, roughness or smoothness: I also know that it causes me pleasure or discomfort according to the heat of the water it contains. Each of these qualities, recognisable in my impressions of the glass of water, have behind them many sensory impulses, which have been modified and regrouped between their peripheral origin and central termination.

The actual afferent consequences produced by the glass of hot water cannot be deduced from any *a priori* reasons. All we can discover from introspection is that the object is of a certain size, shape, temperature and consistence; we must for ever remain ignorant of the nature of the impulses which underlie these sensory characters. But by observing the consequences produced by interference at various known points in the nervous system, we find that some impulses are intercepted, whilst others pass on to reach the highest receptive centres and form the underlying basis of an abnormal sensation. By analysis of such dissociations of sensibility, due to lesions at different levels of the nervous system, it is alone possible to unravel that vast mass of mechanical dispositions, which lie normally outside the field of consciousness.

CHAPTER II

THE INTEGRATION OF AFFERENT IMPULSES

§ 1.—The Peripheral Afferent System

Let us first of all consider the principles which emerge from the application of this method to the peripheral nervous system.

If the whole skin and superficial structures are rendered insensitive over an area of considerable size, without at the same time disturbing any of the nerve fibres running from deeper parts, sensation is not abolished, but is profoundly modified. The affected part still retains many sensory faculties usually attributed to end-organs in the skin; and yet it is innervated solely by the deep afferent system supplying the connective tissues, muscles, joints, and tendons. The experiment on my arm showed that pressure and jarring contacts were quickly appreciated, and localised with remarkable accuracy. Roughness was recognised as perfectly as on the normal hand. Even contacts, which would usually have been called "light touches," evoked a sensation provided they depressed the surface of the skin; but grave deformations caused by pulling the hairs passed entirely unnoticed. A large part of our normal sensibility to touch depends on this deep system of afferent fibres, which was allowed to remain intact in my experiment.

To these deep end-organs we also owe the power of responding to certain aspects of pain. For, although the denervated area on the back of my forearm and hand was completely insensitive to the pain of a prick and a burn, the discomfort produced by excessive pressure was even more pronounced than over similar parts on the normal hand. Moreover, the cramp caused by repeated electrical stimulation of the muscles was at once appreciated as a most unpleasant sensation. Evidently, then, pain as we know it in daily life may be the result of two sets of impulses, one starting from the surface and the other from the end-organs of the deep afferent system.

We have already mentioned the accuracy with which the position of the spot touched can be localised, when a part is endowed with deep sensibility only. Another faculty, which depends entirely on the integrity of this afferent system, is the power of recognising movement and appreciating the position of any part of the limb. Here, impulses from the surface of the body play little or no part; in all cases where this aspect of sensibility was found to be disturbed from a lesion of peripheral nerves, we were able to prove that the deep afferent fibres had been injured in some way by the lesion. Yet in spite of the ease with which the spot touched can be localised and posture appreciated, the two points of the compasses cannot be discriminated, when they are applied strictly simultaneously. Here we discover the first of those dissociations in spacial recognition, so disconcerting to the conventional psychologist.

Evidently, the deep afferent system is adapted to react to all contact stimuli, other than the lightest touch or movement of the hairs. It is also the means by which we become aware of the situation of a stimulated point and of the posture and movement of any part of the body or limbs. Again, it is the channel for evoking all those forms of pain and discomfort, caused by undue pressure, injury to the joints or abnormal muscular contraction.

So far the dissociation of function can be produced with ease and observed without difficulty. But, when we attempt to analyse the functions of the afferent mechanism which innervates the surface of the body, the problem is less easy experimentally. We are obliged in most cases to fall back on the process of regeneration to produce that dissociated sensibility, which reveals the composite nature of the cutaneous afferent system.

In the course of the experiment on my arm, we found that sensibility began to return to the skin a little over six weeks after the operation: within seven months the back of the hand was sensitive to pain, to cold, to heat and to any contact which moved the hairs. But the sensation experienced was peculiar and quite unlike any reaction from normal parts: for, although less easily evoked, it was unusually vivid. The pain of a prick was intolerable; cold was said to be colder and a suitable warm stimulus produced a more actively pleasant effect than over the normal skin. In this stage of recovery a high threshold was associated with a brisker response.

The sensation aroused within the affected area had certain other peculiar characteristics. It radiated widely and was not confined to the neighbourhood of the stimulated spot. Portions of the affected area seemed to be linked up together, so that stimulation of the one evoked a sensation of the same specific quality referred to the other. Thus, brushing the hairs, pricking or the application of heat or cold to the neighbourhood of the index-knuckle caused a diffuse outburst of the appropriate sensation over the dorsal aspect of the thumb. Moreover, the response was massive, diffuse and bore little relation to the measured strength of the stimulus, so long as it was effective.

It had long been known that certain minute spots in the normal skin were especially sensitive to heat, to cold, and to pain, although there was reason to believe they were not the cause of all its sensory functions. We were able to show that this punctate system was responsible for the peculiar mode of reaction, present during the first stage of recovery. This was particularly easy in the case of thermal stimulation. For, whenever a part of the affected area became sensitive to heat or to cold, one or more of these specific spots was discovered within it. Thus, five months after the operation, we found that a certain part of my thumb had become sensitive to cold; whenever the silver test-tube containing iced water was brought into contact with the dorsal surface of the first phalanx, it caused a brisk, diffuse sensation of cold. On testing this part with an ice-cold rod of not more than 1 mm. in section, a single spot was discovered, to which the sensibility of the whole area was due. No part of the affected skin on the back of the hand reacted to heat until nearly six and a half months after the operation. Then, for the first time, a region in the neighbourhood of the head of the first metacarpal bone responded to the warm test-tube. Here a minute spot was found, which subsequently proved to be one of the most constant and active of all the heat-spots on my hand.

These minute areas of specific sensibility can be discovered in the normal skin by suitable methods of examination; but they are not the only organs responsible for its sensibility, as is the case during the first stage of recovery. The skin between them is sensitive to touch and to temperature. This makes it impossible to carry out, on the normal hand, many of the most illuminating observations made, in my case, during the period when the skin was endowed solely with this punctate mechanism.

For sensibility to contact at this stage was due solely to the hairs; if they were carefully shaved away, I no longer responded to cotton wool moved lightly over the surface. Heat and cold could only be appreciated in parts, where we were able to demonstrate the existence of minute areas with their appropriate specific reaction. If, as was not infrequently the case, a portion of the skin, one or more centimetres square, was devoid of heat-spots, that part did not respond to temperatures between 40° and 45° C., even if stimulation was made with a flat-bottomed tube covering the whole of that area.

These heat- and cold-spots are scattered irregularly about the surface of the body. Within an area of 5 cm. square upon the back of my hand, we discovered sixteen heat-spots during the first stage of recovery. These were not increased in number as sensation became further restored; on the contrary, some of them became more difficult to discover, owing to the way in which their vivid reaction was controlled. The cold-spots within the same area in my case numbered about sixty-eight in all, of which twenty-eight belonged to the first grade in constancy and vividness of reaction; they were rarely, if ever, missed in the records extending over more than four years. For it must be remembered that one of the most striking characteristics of organs belonging to this punctate system, even in the normal skin, is the profound influence of general fatigue on their reaction. After a tiring day I could mark out those of first grade only, and could obtain no reaction from many second-grade spots, which were easily discovered after a night's rest.

The pain produced by a prick at various points within the affected area varied greatly in severity and in the ease with which it could be evoked. But the pain-spots are so numerous within any one centimetre square that their position cannot be determined with the certainty of those for heat and cold.

But all the organs of this punctate mechanism possess certain characteristics in common. They regenerate with great rapidity after the peripheral nerve has been successfully united, and for many months the reaction of the skin to contact, to pain, to heat and to cold shows that they alone are responsible for any sensibility it may possess.

Each sensory spot reacts to effective stimulation in a strictly specific manner. Thus, when a cold-spot is touched with a suitable metal rod recently removed from iced water, the sensation is one of cold; but when the same rod, heated to between 45° and 50° C., is brought into contact with a cold-spot, the sensation evoked is equally one of cold. Ice and water at 45° C. happen to be able to excite the cold-spots, and in both cases the result on consciousness is the same, in spite of the physical difference in the stimulus.

Another important and characteristic function of this punctate system of cutaneous sensibility is the mode of its reaction. This can be tested most accurately by experiments on the heat- and cold-spots. The response to a stimulus capable of exciting one of these organs is not strictly graduated by its intensity, but is arranged more nearly on the "all or nothing principle." This reaction occurs over a limited range, the heat-spots responding to temperatures above about 38° C., the cold-spots to those below about 26° C. Once the stimulus is effective, it matters little how cold or how hot it may be; end-organs of this class indicate its quality, not its intensity.

A natural consequence of this mode of reaction is the overwhelming importance of the extent of surface covered by the stimulus rather than its intensity. For it is obvious that if one cold-spot can be excited to vigorous activity by 20° C., a stimulus at the same temperature, sufficiently extensive to cover many cold-spots, will seem to be far colder although in reality its intensity is the same. Thus, whenever we are dealing with these primitive end-organs, extensity is of greater sensory importance than intensity. This is exquisitely shown by the following experiment, carried out repeatedly on my hand, during the period when it was innervated solely by this punctate system of end-organs. A group of cold-spots was carefully marked out and one of them was stimulated with an ice-cold rod which just covered it; the sensation produced was one of cold. But, when a small flat-bottomed tube containing water at 20° C., was placed over the whole group of spots, I thought it was much colder than the iced rod. Time after time the more extended stimulus of less intensity produced a greater sensory effect than the more intense stimulus of less extent.

I have already pointed out, that one peculiarity of the reaction from any part of the surface, innervated solely by this punctate system, is the diffuseness and wide radiation of the sensation evoked. When any hair-clad part, such as the back of the hand, is stroked with cotton wool an intense "tingling" and "itching" is produced over widely remote parts of the affected area. This sensation disappears, when the skin is carefully shaved, and is due to movement of the shaft of the hairs: it is not a function of the skin as a whole. In the same way, any effective hot, cold or painful stimulus produces its specific sensation, which is referred to the same remote parts of the affected area, irrespective of any difference in quality.

This punctate afferent mechanism we have called "protopathic," on account of its primitive characteristics. These are shown in the early restoration to activity of its end-organs after the nerve has been reunited. Secondly, each set of end-organs responds in a strictly specific manner, as shown by the remarkable phenomenon of "paradox cold": for it matters little to the cold-spots whether the stimulus is at 15° C., or 45° C., provided it is capable of evoking a response. If so, the sensation is one of cold. A third primitive character appears in the nature of the reaction. The end-organs of this system tend to react on the "all or nothing" principle, and stimulation evokes a response, not strictly graduated according to its intensity. This explains the predominant effect of the extent of the stimulus and the relatively small part played by its intensity. Lastly, all sensations, which arise from uncontrolled protopathic activity, tend to radiate widely and to be referred into remote parts, a condition incompatible with a high degree of spacial discrimination.

Superposed on this older mechanism is another cutaneous system of later development and higher functions, which we have called "epicritic." When a nerve trunk has been successfully united, heat-, cold- and pain-spots are restored to full activity, many months before there are any signs of returning epicritic sensibility. But, as soon as it begins to appear, the mode of reaction changes. The diffused sensations, so characteristic of protopathic activity, give place to a more strictly localised response; radiation no longer occurs into remote parts of the affected area. At the same time, the power returns of distinguishing two compass-points, applied simultaneously. This is essentially an ability to recognise objects in two-dimensional space, and it is this faculty which checks and controls the diffuse reaction, characteristic of protopathic sensibility. For, if we are conscious of the extent of surface covered by the stimulus, radiation into remote parts and wide diffusion become impossible.

The "all or nothing" reaction of the heat- or cold-spots also gives place to one graduated more closely according to the intensity of the stimulus. At the same time, the affected part becomes sensitive to temperatures that lie in the middle of the scale (27° to 38° C.).

Another remarkable change, due to the restoration of epicritic sensibility, is shown in the return of the power of adaptation to varying temperatures. If, under normal conditions, the hand has previously been exposed for some time to warmth, an object at a certain temperature, such as 29° C., may seem to be "cool," whilst conversely, if it has been adapted to cold, the same stimulus may appear to be "warm." So long as my hand remained in the protopathic condition, no such adaptation was possible, and any effective thermal stimulus was invariably thought to be hot or cold, irrespective of the temperature to which it had been previously exposed (p. 292).

The activity of the epicritic system is essentially modulated according to the intensity and locality of the stimulus. It is concerned with the finer degrees of tactile and thermal discrimination and in this way is opposed to, and controls, the diffuse "all or nothing" reaction of protopathic sensibility.

It has been objected, that protopathic and epicritic sensibility are not the outcome of the activity of two peripheral systems, but are stages in the restoration of function of the divided nerve. In fact, many observers call the former a state of "paræsthesia," and are satisfied that they have thereby sufficiently explained its peculiar reactions. The improbability of such a view is shown by the following observations made on my hand.

Throughout the protopathic stage of recovery, the vividness and extent of the reaction became steadily greater with the gradual return of sensibility to pain and the increasing number of heat- and cold-spots. But this massive and radiating response was curtailed, or even abolished, at the height of its development with the first signs of returning sensibility to light touch and to minor degrees of heat. Had protopathic sensibility been but a half-way house on the road to recovery, we should have expected its steady increase to be associated with a simultaneous decrease in radiation and reference. But this is not the case; the return of epicritic impulses diminishes protopathic activity, as expressed in the sensations evoked by adequate stimulation of the end-organs of this system.

How completely this is due to control by a separate and dominant system over the activity of one or more primitive functions was shown by the behaviour of my hand when cooled. Epicritic sensibility is liable to be affected by the general action of external cold, especially before it has been completely restored. At a time when almost the whole of the back of my hand had so far recovered that referred sensations could no longer be produced, it was rapidly cooled; radiation and reference returned as vividly as of old, and the hand was thrown back for a time into a purely protopathic condition. The newly recovered activity of the high-grade epicritic mechanism was disturbed by the cold, and protopathic impulses, previously inhibited, now passed on uncontrolled.

This control can be exerted, even by epicritic impulses from the adjacent normal skin, if normal and abnormal parts are stimulated simultaneously. When a cold tube was placed so that it fell just within that part of the dorsum of the hand which was in a purely protopathic condition, a vivid referred sensation was always experienced in the thumb. But when the base of the tube fell partly within this area and partly over the adjacent normal skin, reference to the thumb was abolished. The only sensation produced was one of coldness around the spot on the back of the hand in contact with the tube.

Occasionally it happens by a fortunate chance that, after division of cutaneous nerves, some part of the denervated area retains its epicritic sensibility, though insensitive to prick and to heat and cold. With the return of these aspects of sensation, pain-, heat- and cold-spots make their appearance, but are accompanied by none of the usual radiation and reference into remote parts. For in this case protopathic sensibility is restored to a part already actively epicritic: it therefore comes back under control from its first restoration.

Some might object that such dissociations are purely pathological, the product of extraordinary conditions, in no way comparable to normal sensory states. But in the glans penis we find an organ endowed with sensibility to deep pressure, but otherwise reacting exactly in the protopathic manner. It is insensitive to light contacts, insufficient to arouse sensations of pressure-touch. It is endowed with pain-spots and with heat- and cold-spots which react vividly to appropriate temperatures only. The response is diffuse, and the extent of the stimulus is of more importance than its intensity. Here, then, is a normal organ endowed with an exactly similar sensory mechanism to that which we believe exists as a primitive afferent system in the skin (p. 274).

Such a form of sensibility is capable of an affective, rather than a discriminative, reply to external stimuli. It forms an admirable warning mechanism; for it can give either a painful or a pleasurable answer, which admits of no hesitation. Repulsion or attraction must follow as soon as a sensation of this order is developed.

With the advent of the epicritic mechanism, the response is no longer massive and diffuse, but strictly localised. This renders it easy of control, and admits of choice in the motor response. The surface of the body can also become adapted to stimuli to which it has been exposed for any length of time: thus, the same external physical condition no longer evokes of necessity the same sensation, and the central nervous system ceases to react with the same vigour to constant stimulation.

Here, in the dominance of a reaction based on intensity over one dependent mainly on the extent of the stimulus, we see the elements of that struggle between the discriminative and affective aspects of sensation, which forms so important a factor in the activity of the human mind.

§ 2.—Synthesis and Control of Afferent Impulses underlying Sensations of Pain, Heat and Cold

All the incongruous impulses, generated in the various peripheral end-organs, can never affect consciousness at the same moment: some succeed in forming the basis of sensation, whilst others are inhibited and would never be recognised were it not for the facts of dissociated sensibility. During their passage through the central nervous system, they sooner or later undergo integration, carried out partly by combination into specific groups and partly by selective inhibition. Of these two processes the former, as far as painful and thermal sensibility are concerned, takes place at the first synaptic junction in the spinal cord.

As soon as the impulses arising in the deep system and in the two cutaneous mechanisms reach the spinal cord, they undergo regrouping. All those capable of evoking pain, whether from the surface or from deeper structures, are picked up by intramedullary receptors, which guard the entrance to the secondary tracts, devoted to conduction of this specific aspect of sensibility. In the same way, the afferent consequences of all stimuli capable of evoking a sensation of heat, whether of epicritic or protopathic origin, are gathered together into special secondary tracts. An analogous synthesis occurs of those impulses, arising from stimuli on the cold half of the thermal scale.

The underlying factors of these three primary modes of sensation are selected and integrated, to pass on in separate tracts as high as the optic thalamus. As soon as the first synaptic junction is passed, on the passage upwards of afferent impulses, the characteristic features of protopathic and epicritic sensibility disappear. A lesion of the spinal cord, which destroys sensibility to pain, tends to abolish it, whatever may be the source of the impulses on which it depends. In the same way with heat or with cold, each specific aspect of sensation is disturbed, regardless of the system of end-organs in which the physical changes arose. Moreover, sensibility to pain, to heat or to cold may be affected independently of one another, a condition impossible as a consequence of any lesion of the peripheral nervous system. We believe that these intramedullary receptors may be compared to resonators placed in a concert hall; they pick up, and respond to, those impulses only to which they are attuned, irrespective of the instrument that produced them.

The changes, which occur at the first synaptic junction, result in the sorting of afferent impulses into specific sensory groups; those originated by similar properties of an external stimulus are gathered together, although they may have arisen in end-organs of different peripheral systems.

But such specific combination would in the end be useless without selective inhibition. A temperature of 45° C. can stimulate the heat-, the cold- and the pain-spots, and gross confusion would result, if such a stimulus were able to evoke at the same moment sensations of pleasant warmth, ice-cold and pain.

The following experiment shows how complete may be this selective inhibition. Take a metal rod with a blunt end measuring not more than 1 mm. in diameter and cool it to 15° C. or below. On carefully exploring the back of the hand, spots will be discovered where the rod produces a peculiarly vivid sensation of cold. These are the cold-spots. Now heat the metal rod to 45° C. and place the end so that it exactly covers one of the spots; if the experiment is carefully carried out, you will experience a sensation of coldness as if the rod had been dipped in cold water. This is the condition known as "paradox cold." Take a flat-bottomed metal tube, containing water at 45° C., of such a size that it will cover many cold spots and the skin around them. Lay this on the back of the hand and you will experience a pure sensation of heat: and yet we know that this temperature is capable of evoking a sensation of cold, if it is applied to each of the cold-spots individually. Under normal conditions, however, the effect produced by stimulating the cold-spots is dominated, before it can disturb consciousness, by the coincident impulses, due to the action of the same external physical agent on the mechanism which responds to heat.

The behaviour of the glans penis forms another excellent illustration of such inhibition. It is not uncommon to find that the punctate end-organs with which it is endowed are not uniformly distributed; the tip of the glans around the meatus may be devoid of heat-spots, but sensitive to cold and to pain. In such a case we carried out the following remarkable experiment. The end of the penis was dipped into a glass containing water at 40° C.; since no heat-spots were present and this temperature has no effect upon the cold-spots, the only sensation evoked was a peculiarly disagreeable pain. When, however, the temperature of the water was raised to 45° C. pain was to a great extent displaced by a vivid sensation of cold, due to stimulation of the cold-spots. An elevation of temperature, which might have been expected to evoke greater discomfort, ceased to be strictly painful, because of the appearance of the specific sensation of cold. But around the corona the penis is always well furnished with heat-spots, in addition to those for cold and for pain; as soon, then, as the water at 45° C. covered the corona, without reaching the foreskin, both cold and pain disappeared, giving place to an exquisitely pleasant sensation of heat (p. 276).

The following observation made on my hand, during the later stages of regeneration, shows the same phenomena from another aspect. The dorsal portion of my thumb had so far recovered that contact with a large vessel containing water at 40° C. produced a pleasant, well-localised sensation of warmth. But, at the same time, the skin in the neighbourhood of the index knuckle was in a condition of pure protopathic sensibility, and a cold tube applied to this area evoked a diffuse and vivid outburst of cold referred to the back of the thumb. It was, therefore, possible to stimulate the skin of the thumb with heat, and, simultaneously, to evoke a sensation of cold referred to the same area. As soon as this was brought about, all sensations of heat and of cold ceased in the thumb and were replaced by pain. When, however, the cold tube was removed from the neighbourhood of the index knuckle, the direct effect of the hot stimulus in contact with the thumb reasserted itself, as pleasant warmth and the pain disappeared.

In none of these instances was the process of selective inhibition in any way conscious. The sensation evoked was a definite one of heat, of cold or of pain. The whole process takes place on the physiological level and would have remained for ever incomprehensible, had it not been for the phenomena of sensory dissociation.

Unlike the regrouping of afferent impulses, this selective inhibition does not occur at the first synaptic junction. For, in cases where an intramedullary lesion destroys all sensibility to heat without affecting that to cold, a temperature of 45° C. applied to the anaesthetic parts may still evoke paradox cold (Case 7, p. 429). In the same way, if all sensibility to heat and cold is abolished in consequence of an intramedullary lesion, but the appreciation of painful stimuli is unaffected, it is easy to show that temperatures between 40° C. and 45° C. are capable of producing pain. Thus, a single physical stimulus, such as a temperature of 45° C., may start changes in peripheral end-organs, which pass up all the secondary tracts devoted specifically to the impulses of pain, of heat and of cold. Final integration by selective inhibition must take place at a level above the termination of these columns in the optic thalamus.

§ 3.—Tactile Sensibility and Localisation

Painful and thermal stimuli generate impulses that are more easily analysed by the dissociation method than those due to contact of some external object with the surface of the body. But tactile sensibility is equally the result of incompatible impulses which never, under normal circumstances, affect consciousness, until they have undergone combination and selective inhibition.

When any considerable area of the skin is rendered insensitive without disturbance of deep sensibility, as was the case in the experiment on my hand, that part of the body still responds to contact. Slight pressure on the abnormal area can be appreciated and localised, whilst touches with cotton wool and deformations of the surface, caused by pulling the hairs, remain completely unperceived. Whether a sensation was or was not elicited, when a thick camel-hair brush was applied to the dorsum of my hand, depended largely on the way the brush was used. If applied suddenly and vertically to the skin, so as to cause a jar, a slight tactile sensation was produced: but, when the pressure was made more gradually, it was not appreciated until the brush was distinctly bent. In the same way, stroking the part gently with a wisp of long-fibred cotton wool was entirely unperceived; but cotton wool balled together into a "swab," such as is used for sponging a wound, caused a sensation, if pressed upon the affected part. The more gradually contact was established and the smaller the pressure applied, the less likely was it that a sensation would result. All observations show, that parts endowed with deep sensibility are especially sensitive to jarring impact.

Measurements revealed that, whereas the normal skin on the back of my hand was sensitive to the contact of hairs of from 8 to 21 grm./mm.^{2} (1 to 5 grm./mm.), the part innervated by the deep system alone did not respond to 23 grm./mm.^{2} (8 grm./mm.).

Deep sensibility may, therefore, endow the body with a remarkable power of responding to contacts so slight that, under ordinary conditions, they would have been spoken of as "light touches." This is no pathological state: for, during the period when the skin of my hand was entirely insensitive, I frequently found extreme difficulty in marking out the affected area by means of light pressure. When the back of my hand was stimulated by pressure with the round head of a pin, no essential difference would be noticed between the quality of the sensations on the normal and affected parts.

This power of recognising contact carries with it remarkably accurate localisation. When, before any recovery had taken place, I was asked to indicate the spot touched, my answers were as accurate on the one hand as on the other.

This faculty of indicating the situation of a touch was not associated with any power to discriminate two points applied simultaneously to the skin, even when separated to the greatest distance possible over the affected area on the back of my hand. But two points applied successively were at once recognised, even when they were not more than 1·5 cm. distant from one another. Here then we find a remarkable dissociation between the one- and the two-dimensional aspects of spacial sensibility. A single spot, or two spots touched in succession, could be localised with normal accuracy, but the strictly simultaneous stimulation at two points on the surface of the body could not be recognised as more than one contact.

With the return of protopathic sensibility, this power of localisation is profoundly disturbed. For one of the chief characteristics of the reaction of this primitive cutaneous system is its diffuseness and tendency to cause sensations referred to remote parts. If, during this stage of recovery, cotton wool was rubbed over a small hair-clad portion of the affected area a peculiar widespread tingling was produced. This response had the same fundamental features as that from the heat-, cold- and pain-spots. It was strictly confined to the hairs and was absent from hairless parts, such as the radial aspect of the thenar eminence. If all the hairs were carefully shaved, the protopathic area became insensitive to cotton wool and all diffuse reaction to contact ceased. Moreover, the remote sensation due to stimulating the hairs with cotton wool was referred into exactly the same parts as the pain evoked by pulling them individually, or by exciting the heat- and cold-spots of the same area.

So long as the affected portion of my hand was innervated by deep sensibility only, the position of a touch was well localised, if sufficiently heavy to be appreciated. With the first signs of returning protopathic sensibility, localisation became gravely disturbed, for there are but few stimuli of daily life which do not excite some other sensation beside those of contact. The more nearly the stimulus consisted of pure tactile pressure, the easier was it for me to indicate the spot to which it was applied. But, when it was produced by rubbing the hair-clad parts firmly with a swab of cotton wool, or by pressure with the end of a cold test-tube, the diffuse radiation was so great that no correct localisation was possible. Here the return of sensibility was actually associated with disturbance of a power already possessed by the affected parts.

With the first return of epicritic sensibility, reference occurs less frequently and radiation is diminished. The affected parts become sensitive to touch, even when the hairs are shaved, and measured tactile stimuli of 21 grm./mm.^{2} or less are distinctly appreciated. During this stage of recovery it grows increasingly possible to recognise the duality of two spots touched at the same moment, and the compass test begins to show the existence of some tactile discrimination.

All tactile impulses, whatever their peripheral origin, become ultimately combined by the time they reach the upward termination of the spinal cord. But the course they follow differs from that of impulses arising from thermal and painful stimuli, in that a double path is open to the tactile impressions of each half of the body throughout the greater part of their intramedullary course. In the larger number of cases of loss of sensation produced by a lesion in the opposite half of the spinal cord, pain, heat and cold only are affected. But, in a few instances, this loss is accompanied by a definite disturbance of tactile sensibility; such change is always associated with some injury to the posterior columns on the side of the loss of sensation, accompanied by more or less destruction of the antero-lateral aspect of the opposite half of the spinal cord. For, in order that tactile sensibility may be affected from an intramedullary lesion, it is necessary not only to injure the crossed secondary paths, but also to disturb the conduction of the primary path for tactile impulses in the posterior columns. For this reason, sensations of touch and pressure are much less frequently affected in cases of Brown-Séquard paralysis than those of pain, heat and cold.

If, however, tactile sensibility is either abolished, or even diminished, it is affected as a whole. Impulses, originating from the surface and from the deep parts, have been combined and all distinction is lost between those arising in different peripheral systems. The lightest touch and the heaviest pressure, short of discomfort, form the two ends of a graduated tactile scale. Whenever it would seem as if some lesion of the spinal cord had destroyed sensation to light touch, but left that to pressure unaffected, careful measurements will show that the tactile loss is greater than could be accounted for by the abolition of cutaneous sensibility alone. Not only is light touch abolished, but the lesser grades of pressure are also affected, and many stimuli, which would have been sufficient to excite deep sensibility, fail to arouse appreciation.

It is probable that, in this synthesis of tactile impulses, the peculiar effect produced by brushing the hairs of my hand in the protopathic stage still remains as the quality we recognise as " tingling " or " itching." Such sensations, arising from the normal skin, closely resemble a modified and controlled form of the widely diffused reaction, caused by brushing the hairs in this stage of recovery. These impulses travel up the spinal cord in conjunction with others of tactile origin. For, if all sensibility to pain, heat, and cold is destroyed in consequence of an intramedullary lesion, but touch remains unaffected, tingling and itching can still be produced by stimulating the hairs, and the sole can be tickled so as to evoke either pleasure or discomfort.

Throughout their whole course, within the limits of the spinal cord, tactile impulses are associated with the power of localising the position of the spot touched. All recognition of the posture of the limb in space may be lost, and discrimination of two points may be impossible, but localisation will not be affected, unless tactile sensibility is disturbed. But, above the nuclei of the posterior columns, tactile impulses tend to separate from those which underlie the power of appreciating the situation of the stimulated spot. The long connection of topical localisation with the integrity of one or other form of tactile sensibility is then broken for the first time.

§ 4.—Other Spacial Aspects of Sensation

When the sensory supply of a part of the body consists of the deep afferent system only, the patient can recognise its position in space, and can estimate the direction and extent of passive movements as certainly as on the normal side. Complete division of all cutaneous nerves to a finger in no way affects the power of appreciating relationships in three-dimensional space.

The presence of deep sensibility only is sufficient also to endow the affected area with remarkably accurate localisation, provided sufficient pressure is used to induce a sensation of contact. But tactile discrimination is impossible; the patient cannot distinguish two points of the compasses, when separated to the farthest distance within one segment of the limb.

Thus, the deep afferent system gives origin to all the impulses which are concerned with three-dimensional recognition and to many of those responsible for accurate localisation of the stimulated spot: but it plays no part in the appreciation of tests in two-dimensional space. When we consider how closely this aspect of sensation depends upon impulses from the surface of the body, it is not difficult to understand the reason for this peculiar dissociation.

Tactile discrimination is closely bound up with the integrity of the epicritic system. During the protopathic stage the reaction to contact is massive and diffuse: it is impossible to indicate accurately the position of the stimulated spot, and two points cannot be distinguished. Contacts with two points of the compasses simultaneously, or with one point only, are confused and the sensory response bears no obvious relation to the single or double nature of the stimulus.

One of the earliest signs of returning epicritic sensibility is the appearance of tactile discrimination. At the same time, the reaction becomes less diffuse, and sensations are no longer referred to remote parts of the affected area. One of the most potent methods by which the presence of epicritic sensibility controls the vehemence of protopathic reactions depends on this recognition of two-dimensional relationships. The widespread reaction is not only inhibited by the impulses underlying tactile discrimination, but the ultimate sensation is restricted approximately to the area stimulated. As soon as this direct relation between the superficial extent of the stimulus and the sensory reaction is established, it becomes possible to compare the relative intensity of two external stimuli. A tube containing water at 20° C. is no longer thought to be "colder" than a metal rod of considerably smaller superficial area at the temperature of ice; for this error of appreciation depends on the more massive reaction evoked by the larger of the two stimuli, which renders impossible any accurate comparison of their relative intensity. Epicritic sensibility controls the diffuse "all or nothing" protopathic reaction in two ways. It endows the afferent mechanism with the power of adaptation, so that its response depends not only on the sensory quality of the stimulus, but also on the previous experiences to which it has been recently exposed. Secondly, it gives to the affected area the power to respond to relationships in two-dimensional space, and probably in this way curbs that radiation and reference into remote parts so characteristic of the protopathic response.

Tactile, painful and thermal impulses ultimately cross to the opposite side in their passage through the spinal cord, and as soon as they have passed into secondary tracts show evidence of recombination. But those which underlie spacial recognition in two and three dimensions do not cross, until they reach the nuclei of the posterior columns at the upper end of the spinal cord.

Experimentally, this is a most fortunate condition, for it enables us to study the changes in sensation produced by the destruction of these spacial elements, in parts of the body otherwise of normal sensibility. An injury, confined to one half of the spinal cord, may cause loss of power to recognise posture and passive movement, together with want of discrimination of the compass points on the side of the lesion, whilst every other disturbance of sensibility it may produce will be found on the opposite half of the body. We can therefore investigate the nature and consequences of this defective spacial recognition, unhampered by any other concomitant sensory loss; and, if the lesion lies sufficiently high in the cervical region to affect the hand, we can test its effect upon the appreciation of size, shape and weight.

Head and Holmes (p. 537) have described such a case of lesion of the second cervical segment, the highest point that can possibly be affected within the limits of the spinal cord. The patient was at first paralysed in the right arm and leg; but this passed off, leaving him capable of every movement, though somewhat weaker in the right hand than in the left. When he came under observation two years later, the deep reflexes in the right arm and leg were exaggerated and the right plantar gave an upward response. Motion and reflexes were completely unaffected on the left half of the body, and it is obvious that the lesion must have occupied the right half of the spinal cord only.

As is usual in such cases, pain, heat and cold were not appreciated over the whole of the opposite half of the body. All forms of tactile sensibility were however completely preserved, the position of any part of the left upper or lower extremity could be recognised with ease and passive movements were appreciated within normal limits. The compass points could be accurately distinguished and topical localisation was perfect.

When, however, we turn to the condition on the right half of the body, the side of the lesion, the condition was almost the exact opposite. Sensibility to touch, pain, heat and cold was perfectly preserved, but the patient was unable to recognise the posture of his right arm and leg, and could neither name nor imitate correctly the positions into which they had been placed. The compass points could not be distinguished on the right palm, even at a distance of 6 cm. from one another. All power of recognising size, shape and form in three dimensions was lost in the right hand, in spite of the fact that tactile sensibility was perfectly preserved. When some common object, such as a key, a coin, or a pencil, was placed in his right hand he was unable to say what it was. He could not estimate weight, nor recognise the relative hardness or softness of things held in the right hand.

In this case the power of appreciating relations in two- and in three-dimensional space was grossly disturbed on the right half of the body, whilst "spot-finding," or one-dimensional localisation, remained unaffected. Within the limits of the spinal cord, this faculty is still linked up with impulses underlying the qualitative aspects of sensation which finally cross to the opposite half of the spinal cord. But those responsible for postural recognition and the discrimination of two contacts remain uncrossed in the posterior columns, throughout the whole of their course within the spinal cord.

Now it is obvious that these columns consist mainly of projections from the peripheral nervous system. No synaptic junction guards their entrance and none of their exogenous fibres cross to the opposite side, as is the case with every secondary sensory path. They are not specific tracts and, from the functional aspect, do not belong to the intramedullary system. Every afferent impulse, which enters the spinal cord, travels for a longer or shorter distance in the posterior columns. Some, like those capable of exciting sensations of pain, of heat or of cold, are rapidly combined and pass away into specific tracts on the opposite half of the spinal cord and brain-stem; they run, without further interruption, to end in the receptive centre of the optic thalamus. Others, like those concerned with sensations of contact, seem to follow a double path. Finally, however, of all the afferent impulses, which enter some distant segment of the spinal cord, none remain in the posterior columns, except those which underlie recognition of changes in two- and three-dimensional space. At the extreme upward termination of the spinal cord, these pass into the posterior column nuclei and cross to the opposite half of the nervous system. Up to this point, they have remained impulses of the primary level, which happen to have formed more or less qualitative groups in consequence of the gradual passing away of their peripheral companions; in the posterior column nuclei, however, they undergo their first re-grouping and travel on in specific sensory tracts.

Above the posterior column nuclei, impulses underlying the appreciation of posture and passive movement become separated from those concerned with tactile discrimination. These two aspects of spacial sensibility may be completely dissociated. Head and Holmes (p. 546) described a case of a lesion in the brain-stem where recognition of passive movement was disturbed in the hand of the opposite side, whilst the compass test gave identical results on the two halves of the body; the appreciation of size, shape and form in three dimensions was entirely unaffected.

All afferent impulses, which reach the optic thalamus, pass through the receptive portion of this organ on their way to their final sensory centres. But by the time they reach this junction in the nervous system, they have become arranged into physiologically specific groups; those associated with sensations of touch, of pain, of heat and of cold run in specific tracts to terminate in separate thalamic end-stations.

Such a mechanical arrangement is eminently comprehensible; for each of these categories corresponds to some aspect of sensation, which can be discovered by introspection. But our account of the arrangement and course of the impulses, which are concerned with spacial recognition, must seem entirely unreasonable to the *a priori* psychologist. As soon, however, as our conclusions are looked at physiologically, all difficulty disappears; for the method by which such impulses are integrated, on the physiological level, is admirably adapted to ensure the part which they must finally play in sensation.

An appreciation of the sensory aspect of movement in three-dimensional space depends on impulses arising in the deep afferent system, whilst the faculty of discriminating two or more points of contact on a flat surface is associated with the integrity of end-organs in the skin. The fibres of these two peripheral mechanisms are continued centralwards in the posterior columns of the spinal cord. These tracts are not, functionally, a portion of the central nervous system, as far as their exogenous fibres are concerned, and the impulses underlying spacial appreciation travel independently along each of the central projections of the two peripheral mechanisms in which they arose. They meet their first sensory synaptic junction in the cells of the posterior column nuclei. Here an opportunist anatomical arrangement becomes converted into a definite functional dissociation and, from this point onwards, each group of impulses travels in a separate specific tract.

Meanwhile, however, the long association of "spot-finding" with contact sensibility is also broken; one-dimensional localisation becomes separated from the power of recognising touch and pressure.

It is easy to see how this intimate connection, between the impulses underlying recognition of contact and of its point of impact, came about on the primary level. They arise simultaneously from the action of almost every external stimulus on the same two peripheral systems: the tactile aspect of pressure, and the power of appreciating the spot to which it is applied, are a function of the deep afferent mechanism, whilst recognition of the finer degrees of touch and their accurate localisation depend on impulses from the epicritic system on the surface of the body. First of all, integration must weld the physical substrata of these two aspects of contact sensibility and localisation into one coherent physiological group. This occurs in the secondary paths of the spinal cord and brain-stem. But, when we consider sensation from the psychical point of view, its spacial relations are indivisible; localisation forms an inseparable part of our appreciation of space. The impulses upon which it depends must, therefore, become detached from those underlying sensations of contact, in order that they may be combined into one coherent spacial group. Finally, all those impulses potentially capable of revealing spacial relations impinge upon the appropriate centre in the cortex of the brain, to give birth to those processes which immediately underlie the sensory aspects of space. This is an example of the rule, that the arrangement of the peripheral nervous system depends on structural and developmental conditions; that of the intramedullary level is essentially functional or physiological, whilst the final processes, which underlie sensation, are grouped according to categories that can be discovered by introspection.

§ 5.—Sensory and Non-sensory Afferent Impulses

When a tract degenerates in a centripetal direction, it probably conducts afferent impulses, but it is not, therefore, of necessity sensory in function. Some afferent impulses are destined never to affect consciousness, whilst others may or may not form the basis of a sensation, according to circumstances. This distinction has not been sufficiently emphasised, but is the key to many otherwise inexplicable arrangements in the central nervous system.

Thus, the posterior columns of the spinal cord conduct, amongst other impulses, those from the deep structures such as joints, tendons and muscles; on these depends our ability to recognise the position of the body in space. But, apart from this conscious recognition of posture, it is of supreme importance that the great centres for the maintenance of posture and bodily tone should receive afferent impressions from the joints. Impulses underlying deep sensibility, therefore, act upon the cerebellum and its allied centres, and in so doing remain for ever outside consciousness.

The afferent stream from deep structures, passing up the posterior column of the spinal cord, can affect two terminal centres. One of these is the cortex, with consequent recognition of posture and movement; the other, the cerebellar system, regulates and controls the postural and tonic aspects of muscular activity without in any way exciting consciousness directly. We know that some part of our body has assumed a certain position, or that a definite movement is taking place under the influence of the will; but the preliminary co-ordination of muscle-groups and shifting of tonic innervation, necessary for such changes, are carried on, without the accompaniment of any conscious process.

This is shown by the complete absence of sensory disturbance in uncomplicated lesions of one half of the cerebellum. Motion is gravely affected; the patient is unable to make rapid rotatory movements, or to touch his nose readily with the affected hand. He may titubate, or deviate grossly, when attempting to walk round a table, and be unable to stand on the affected leg, even when his eyes remain open. And yet the closest examination fails to reveal any want of recognition of posture, or passive movement, loss of vibratory sensibility, or other analogous defect.

Holmes ([54] p. 512) has given a striking example of the difference in this respect, produced by lesions of the cerebellum and of the cerebral cortex, and has incidentally exposed a fallacy in the deductions of other observers. He showed that, if a patient with a unilateral lesion of the cerebellum was told to compare two identical weights placed simultaneously one in each hand, the weight on the affected side was thought to be the heavier. Even when they differed from one another by one quarter (200 to 150 grm.), the lighter weight might seem to be heavier on the same side as the lesion. But this defect is not primarily one of sensation, for, if the same two weights were placed one after another on the affected hand, they were uniformly estimated correctly. When the patient was compelled to compare one weight, supported by a limb whose movements were inco-ordinate, with an identical or even heavier weight on the normal hand, he tended to overestimate the one on the affected side. But, if he was allowed to use the same defective mechanism to weigh both objects, he was able to gauge their relation as accurately as on the normal palm.

I can fully confirm these observations from experiments made upon a patient under my care with injury to one half of the cerebellum. Equal weights placed simultaneously in the two palms were invariably said to be heavier on the affected side. It was not until the relation became that of 100 to 40 grm., that he thought the two weights were equal. But, if they were placed one after the other on the affected palm, he had no difficulty in giving uniformly correct answers, even when they differed so little as 100 grm. and 80 grm. This was also the limit of his appreciation on the normal hand, and many healthy persons cannot even reach this standard of accuracy. The following experiment shows how completely the original failure to estimate weights, placed simultaneously on the two hands, was due to a disturbance of movement in the affected limb. When the two hands were completely supported and weights were placed one in each palm, he had no difficulty in recognising their identity, or the difference between 100 and 80 grm., provided he made no movement. That is to say, he could estimate correctly the relative pressure of the two weights, provided the muscles were at complete rest; but as soon as the hands were lifted, this perfect recognition was disturbed by the inco-ordinate movements in the limb on the side of the lesion, and he thought the weight on the affected hand was the heavier.

Throughout their passage within the posterior columns of the spinal cord, impulses concerned with the regulation of posture and movement are given off into direct cerebellar paths on the same side of the body. This is probably a reason why such afferent products of deep sensibility remain uncrossed, until they reach the nuclei of these columns at the termination of the spinal cord. By this time they have given off most of the impulses destined to influence unconscious postural activities, and the remainder become recombined and cross rapidly into secondary tracts of the brain-stem, to underlie conscious recognition of posture and movement.

Apart, however, from their unconscious effect in co-ordinating voluntary movement, these postural afferents exercise a profound influence on the character of spinal reflexes. When the cord has been gravely injured and the conditions are favourable to the return of activity in its severed portion, the response to stimulation sometimes assumes a massive and diffuse character. The lower extremity becomes flexed, the abdominal muscles contract, bladder and rectum are thrown into activity and the patient may sweat over those parts of his body, which are innervated from below the lesion. Whatever the position of the limbs or the site of the stimulus, the answer is of the same character, widespread and uncontrolled. In order that this mode of reaction may appear, the mechanism for postural co-ordination must have undergone such gross injury, that no efferent impulses from the mid-brain centres can pass through the damaged region. Consciousness appears to play no essential part in determining whether it shall appear or not; for the patient may be insensitive to all forms of stimulation, however intense, and may be unable to appreciate the posture and movements of the lower extremities, and yet this massive response be absent.

It is to these unconscious postural and spacial impulses that we owe the adaptation of spinal reflexes to the site of the stimulus and the position of the limb. They act in man upon centres of the mid-brain and pons, and so control the reflex motor activity of the cord through proprio-spinal paths and centres. So long as this mechanism is intact, the great postural centres can dominate spinal reflexes. The answer to stimulation is endowed with local and postural signature. Not only the nature of the stimulus but its superficial extent and the position of the limb determine the character of the motor response.

In addition to these afferent impulses which never reach consciousness, there are a number of others which do not normally excite sensation. Thus, many impulses from the viscera produce an appropriate reflex action, without primarily affecting consciousness. When, in the course of some experiments on visceral sensibility, I passed warm water into the gut through a colostomy opening, the patient complained that he wanted to defæcate; a reflex peristalsis was set up, of which he was conscious, although he failed completely to recognise the stimulus by which it had been evoked. Most of the afferent impulses from the stomach and intestines probably belong to this order.

But many impulses capable of forming the basis of a sensation are prevented under normal conditions from reaching the highest centres; or, if their forward path is not completely barred, they pass on in a profoundly modified form, in consequence of the concurrent activity of other sensory end-organs. The utility of this arrangement is obvious, especially in the case of those impulses which underlie discomfort or pain. Temperatures of from 40° to about 45° C. normally produce a pleasurable sensation of warmth; but, in the absence of the heat-spots and the epicritic thermal mechanism, such temperatures cause pain. This is well seen in the experiment on the glans penis, where a temperature which was exquisitely disagreeable became pleasant as soon as the warm water reached the area supplied with heat-spots.

It is obvious, therefore, that any temperature between 40° and 45° C. is an effective stimulus to the pain-spots. Every time the hands are dipped into water between these degrees, innumerable impulses are evoked which are potentially painful. But they are prevented from affecting consciousness by the coincident excitation of the sensory heat-mechanism in the skin; for a sensation of pleasant warmth is incompatible with the co-existence of pain.

As the temperature rises, these potentially painful impulses increase in strength, until they can no longer be inhibited; they then form the basis of a sensation of pain. Here, consciousness is not disturbed until impulses are produced, not only in themselves of sufficient strength to evoke a sensation, but able to overcome the inhibitory effect due to the activity of other specific end-organs.

In a similar way, the return of epicritic sensibility reduces the amount of pain caused by cutaneous stimuli, without at the same time raising the threshold. Radiation and reference are inhibited and the pain produced by a prick is restricted to the immediate neighbourhood of the spot stimulated. This diminution in extent reduces the amount of pain suffered by the patient, although the measured threshold for painful sensations may be actually lower than during the preceding protopathic stage.

Pain is the oldest defensive reaction, and potentially painful stimuli are the basis of all primitive reflexes. It is therefore most important that potentially painful impulses should be diminished in extent, or actually inhibited in favour of those sensory impressions more capable of leading to discrimination. The mechanism underlying the production of pain must however remain in full physiological activity, so that it may play its part in defence of the organism, when noxious stimuli reach a high grade of intensity.

Thus, we have been able to show that the existence of non-sensory afferent impulses plays an important part in determining the mechanical co-ordination of voluntary action and are also of paramount importance in the production of spinal reflexes. Moreover, the evolution of the more discriminative functions of sensibility is largely bound up with the control of afferent impulses, which, if they affected consciousness, would evoke sensations of pain and feelings of discomfort.

§ 6.—Feeling-Tone and the Optic Thalamus

Anatomically, the optic thalamus is one of the most intricate regions of the central nervous system; and, since most pathological conditions in this situation do not produce selective destruction, the clinical picture presented by a thalamic lesion is usually extremely complex. But, by a suitable choice of illustrative cases and by analysis of the symptoms they present, it is not difficult to discover the part played by this organ in sensation. For first of all, it is an end-station for all sensory afferent impulses, whence they start on two main lines to culminate in centres, which subserve two diametrically opposed aspects of sensation.

I shall not enter into the complexities of a case of thalamic disease; these are fully dealt with by Head and Holmes (p. 551 to 569), where many illustrative examples are given. My business here is to show the fate of those afferent impulses, ultimately destined to excite the activity of the cerebral cortex and so endow sensation with certain specific qualities, dependent for their existence on this centre. But it is necessary first to consider how the optic thalamus influences the general stream of impulses, which travel onwards from its receptive end-station.

Above this junction in the nervous system, afferent impulses have the opportunity of affecting two sensory centres: on the one hand, the essential organ of the optic thalamus, distinct from its receptive mechanism, and on the other the cerebral cortex. This essential organ of the thalamus is the centre of "awareness" for certain aspects of sensation. It responds to all stimuli capable of producing sensations of a change in state. Thus, contact, especially movement across the surface of the body, arouses in the patient's mind recognition that something is happening, although he may be unable to appreciate the quality or situation of the stimulus. The thalamic centre reacts to the affective aspect of sensibility; when the patient exclaims, "Something is happening to me, I am being hurt," instead of, "You are sticking a pin into me," he is emphasising the consequences of such thalamic appeal.

The essential organ of the optic thalamus is the centre for this aspect of sensation and responds to all stimuli capable of evoking either pleasure or discomfort. The feeling-tone of somatic or visceral sensations is the product of thalamic activity, and the greater the affective reaction to any stimulus the more certain is its thalamic appeal. Conversely, the more entirely any aspect of sensibility depends upon discrimination, as for instance the recognition of spacial relations, the less does it call upon the activity of the optic thalamus.

The sensory impulses evoked by a glass of hot water, held in my hand, influence my consciousness through these two centres. Recognition of contact, the sensation of heat and the pleasure or discomfort it gives me, according to the degree of temperature, are the product of thalamic activity, whilst the roundness, size and weight of the containing vessel, together with my power of appreciating the posture of the hand in which it lies, are the cortical aspect of the resultant general sensation.

During the passage through the secondary tracts of the central nervous system, sensory impulses undergo integration into groups of similar physiological significance. By the time they leave the receptive organ of the optic thalamus, this recombination on functional lines is complete, and, from this point onwards, sensory impulses travel in seven separable streams, each of which may be interrupted independently of the other.

The grouping at this level is still strictly physiological; each set of impulses arising from a certain aspect of peripheral stimulation still carries with it, not only the power of evoking a specific sensation, but also the capacity of endowing it with the appropriate feeling-tone. From the thalamic junction onwards, these physiological combinations have the opportunity of acting on two terminal centres. They can excite the essential organ of the optic thalamus, which is associated mainly with the affective side of sensation, or the so-called "sensory cortex," the centre for its more discriminative aspects. Each of these two end-stations reacts to the afferent quality to which it is attuned, and refuses to respond to those with which it is not in harmony.

How this selective reaction works in practice will be evident, if we consider in detail the constituents of each of these seven afferent streams.

(*a*) Tactile elements: This group contains all those impulses evoked by every form of contact, superficial and deep; they form a graduated scale from the lightest touch to the heaviest pressure, and include the physiological effects of moving rough objects across the surface, of stimulating the hairs, and of all manipulations which cause tingling and itching.

Now it is obvious that these impulses must make a double appeal. Sudden contact with some hard body, a rough object dragged across the skin, brushing the hairs and tickling stimuli are all sufficient to excite the thalamic centre; the sensations they evoke are heavily charged with feeling-tone. But a fine appreciation of the different degrees of tactile stimuli, or of the pressure of various weights placed on the fully supported hand, makes an appeal to the discriminative aspect of sensibility with which the optic thalamus has no concern.

(*b*) Painful elements: Here we find a condition the exact converse to that just described for the tactile elements. All painful or uncomfortable stimuli appeal mainly to the thalamic centre and, slightly if at all, to that in the cortex. But it is necessary at the outset to distinguish clearly between "discomfort" and "pain." Pain is a distinct sensory quality equivalent to heat and cold, and its intensity can be roughly graded according to the force expended in stimulation. Discomfort, on the other hand, is that feeling-tone which is directly opposed to pleasure. It may accompany sensations not in themselves essentially painful, as for instance that produced by tickling the sole of the foot. The reaction produced by repeated pricking contains both these elements; for it evokes that sensory quality known as pain, accompanied by a disagreeable feeling-tone, which we have called discomfort. On the other hand, excessive pressure, except when applied directly over some nerve trunk, tends to excite more discomfort than pain, and makes a more exclusively thalamic appeal.

The secondary tracts in the spinal cord, devoted to the painful aspects of sensibility, conduct all impulses, capable of arousing pain or discomfort, in connection with injuries to the superficial or deep parts of the body. But even before the fillet actually terminates in the optic thalamus, the more disagreeable stimuli, such as excessive pressure, can influence consciousness, though the affected parts are totally insensitive to the pain of pricking or burning. This is evidently the first indication of the ultimate action of all painful and uncomfortable stimuli on the affective centre in the optic thalamus. But, although the appeal of all such aspects of sensibility is overwhelmingly thalamic, it must not be forgotten that pain can be roughly graded according to the intensity of the stimulus; in so far, it is the product of cortical activity. How small is this element in most disagreeable stimuli is shown by the extreme difficulty in devising graduated painful tests, which are capable of giving measurable results.

(*c*) and (*d*) Thermal elements (heat and cold): The impulses underlying sensations of heat and cold travel up to the spinal cord and brain-stem in specific tracts, and still remain separable above the level of the thalamic junction. Each of these afferent groups can exert a profound influence, both on the essential organ of the optic thalamus and on the sensory cortex. Cold is almost universally uncomfortable, but heat may excite either pleasure or discomfort, according to the temperature of the stimulus; feeling-tone is always an important characteristic of thermal sensations.

But, apart from the affective aspect, we believe that the optic thalamus forms the physiological end-station for those activities which underlie the qualitative appreciation of thermal stimuli. A patient, in whom the sensory cortex has been thrown out of action, may recognise heat and cold correctly, although he is unable to appreciate the relation between two hot or cold objects. Crude sensations of heat and of cold are functions of the activity of the essential organ of the optic thalamus.

On the other hand, finer discrimination of thermal stimuli is a function of the cortex. The normal human being can distinguish different degrees of temperature with considerable accuracy, although they do not differ in quality from one another. Both 35° C. and 42° C. are said to be "warm," when applied to a sensitive part, such as the palm of the hand, but there can be no doubt that the latter is the warmer. This power of discriminating between two stimuli of the same sensory quality becomes less accurate the nearer they approach to the extremes of heat or of cold; for, at the two ends of the scale, the reaction tends to approximate to the "all or nothing" response, so characteristic of the heat- and cold-spots.

Thus, the optic thalamus forms the physiological end-station for those aspects of thermal sensibility concerned with feeling-tone and crude qualitative appreciation of heat and cold. The sensory cortex, on the other hand, is responsible for the faculty of discriminating quantitative differences in intensity.

(*e*), (*f*) and (*g*) Spacial elements: Above the level of the posterior column nuclei, impulses concerned with the three aspects of spacial recognition run in three separate streams, apart from those associated with sensations of touch and pressure. There is no evidence to show that these groups make any thalamic appeal. They are associated with purely discriminative processes, such as the power of appreciating posture, recognition of two or more simultaneous contacts and localisation of the stimulated spot.

On the integrity of each of these afferent groups depends the faculty of responding accurately to some more complex test. Thus, the group concerned with relations in three-dimensional space is not only responsible for our recognition of posture and passive movement, but also, at this level, endows us with the power of estimating correctly the difference between two weights placed on the unsupported hand one after the other. The act of "weighing" an object in the palm is a function of this stream of impulses.

In the same way, appreciation of the relative size and shape of flat objects depends on the same afferent group as the power of discriminating the two points of the compasses applied simultaneously.

Thus, in conclusion, we have been able to show that afferent impulses pass on from the receptive centre in the optic thalamus in seven separable streams. Each of these acts upon one or both of the terminal physiological centres. At the one pole stand the effects produced by painful stimuli, which profoundly affect the essential organ of the optic thalamus, but have little influence on cortical activity; at the other extreme we find the physiological substrata of spacial recognition, which appeal exclusively to the sensory cortex.

§ 7.—Discrimination and the Cortex Cerebri

The paths between the termination of the fillet in the optic thalamus and the essential thalamic centre lie in the body of this organ and cannot be completely interrupted without producing some destruction of incoming sensory impulses or injury to the centre itself. But the paths from the receptive end-station in the optic thalamus to the cortex pass by way of the internal capsule and the radiating fibres of the centrum ovale. These tracts are frequently interrupted by disease, and it is therefore possible to determine the nature and grouping of the sensory impulses, which they conduct to the cortical centres.

Lesions of these subcortical paths show that we are still dealing with physiological processes destined to excite those central activities which underlie the cortical aspects of sensation; the defects of sensibility are evidently due to the fact that certain afferent elements fail to reach the intact centres of the cortex.

We have described, in the previous section, the groups of afferent impulses which pass away from the terminal receptive mechanism in the optic thalamus to influence, on the one hand, its essential centre, and on the other the sensory cortex. Subcortical lesions reveal the same streams, differing only in the fact that they have shed all those elements capable of exciting thalamic activity. Thus, as before, each of the three groups of spacial elements seems to run independently of the others, and can be affected separately. Moreover, a loss of power to recognise posture and movement still carries with it inability to compare the weight of the two objects, placed successively on the unsupported hand, and defective discrimination of the compass points is associated with want of appreciation of relative size and shape in two dimensions.

At this level of the nervous system, an interference with tactile impulses does not prevent the patient from recognising contact or roughness. But it disturbs appreciation of the relative intensity of graduated tactile stimuli and of increase or diminution in weights placed on the fully supported hand.

Any disturbance that may be present in thermal sensibility is shown by defective recognition of the relation between temperatures of the same quality. The patient can still distinguish heat and cold, but cannot be certain if one warm object is warmer or cooler than another. At the same time, the neutral portion of the scale, where the stimulus seems neither hot nor cold, may be considerably enlarged. That is to say, any actual loss of sensation is found amongst those temperatures, which must be compared to be appreciated and are most susceptible to sensory adaptation.

Such are the materials out of which the cortex manufactures those physiological processes, which underlie certain specific aspects of sensation. When, however, we examine the sensory effects produced by a lesion of the cortex, we are no longer confronted with a gross physiological defect, but with what appears to be a want of attention; the patient seems to be untrustworthy. Sometimes he appreciates a touch, sometimes even a stronger stimulus fails to evoke an answer; he knows that the object in contact with the affected part is warm, but cannot tell whether it is hotter or colder than one he has previously held in his hand. Sensation is not abolished, but his answers are confused; and yet on further examination they are found to be unsatisfactory only in so far as they concern the affected part. Elsewhere, he may give results which in accuracy are up to or even above the normal average.

Analysis of this apparent untrustworthiness of the affected part shows that it depends upon three main factors. First of all, the answers given by the patient are inconstant; at one moment he seems to appreciate a stimulus of a certain intensity, at the next it remains entirely without effect upon his consciousness. Thus, it may be necessary greatly to increase the stimulus before a series of correct answers can be obtained, and not infrequently even then no regular response can be evoked. In such a case, we cannot work out a threshold, not because the patient never appreciates the stimulus, but because at every intensity it sometimes causes a sensation and sometimes passes unnoticed.

Secondly, a cortical lesion tends to destroy the power of appreciating the difference between two objects which have certain basic sensory qualities in common. Thus, the patient may no longer be able to tell which of two weights is the heavier, although they are of the same shape and cover an identical surface. He may also lose the power of recognising the relative size and form of objects and, although he can tell whether a fabric is rough or smooth, he may no longer be able to distinguish flannel from silk.

Thirdly, the cortex is responsible for the spacial aspects of sensation, and one of the most frequent consequences of a lesion in this situation is inability to recognise correctly the posture of the affected parts of the body; this is often accompanied by a more or less defective discrimination of the compass points and some want of power to determine the situation of the spot touched. But these changes in sensibility are curiously uncertain. A varying reaction to constant stimuli, hallucinations, and wrong answers of all kinds mar the measured records to an extent not usually present when the lesion lies at lower levels of the nervous system.

The cortex is the repository of past impressions and these sensory dispositions profoundly modify the effect produced on the arrival of fresh impulses. As far as the spacial aspect of sensibility is concerned, a disturbance of these sensory dispositions would be responsible for just that uncertainty of recognition of three-, two- and one-dimensional relationships, which actually follows a cortical lesion. For it would be impossible to discover the position of any part of the body, unless the immediate postural impressions were related to something that had preceded them. A direct perception of posture, analogous to that of roughness, cannot occur; in every case, the new position of the limb is related to some previous posture.

We have been able to show that the standard against which a change in posture is estimated is not an image either visual or motor; it lies outside consciousness. Every recognisable change in posture enters consciousness already charged with its relation to something which has gone before, and the final product is directly perceived as a measured postural change. For this combined standard, against which all subsequent changes in posture are estimated, before they enter consciousness, we have proposed the word "schema." Man perpetually builds up a model of himself, which constantly changes. Every new posture or movement is recorded on this plastic schema and the activity of the cortex brings every fresh group of sensations evoked by altered posture into relation with it. Immediate postural recognition follows as soon as this relation is complete. A cortical lesion tends to destroy such schemata and so disturbs the certainty of spacial recognition.

Inconstant recognition, want of appreciation of intensity and inability to relate and measure sensation are the consequences of a lesion in certain portions of the cortex. Attention can no longer move with freedom and certainty over the objects presented to it, so far as they arise in consciousness connected with sensory processes from the affected parts of the body. Obviously, then, the consequences of a pure cortical lesion produce changes of which the manifestations are essentially psychical. We are above the level at which the defects in sensibility are due to interference with afferent impulses and the disturbances produced by a cortical lesion are manifested in defective attention and discrimination.

CHAPTER III

THE METHOD AND AN ILLUSTRATIVE CASE

§ 1.—The Method

Such were the views we expressed on the activity of the cortex in the production of sensation. We had determined the manner in which the affected parts of the body reacted to a series of sensory tests, and were anxious to demonstrate the general afferent functions of the cortex, unhampered by an analysis of dissociated sensibility or questions of anatomical localisation.

But it is obvious that our tests were empirical, and, though each was selected to explore some special aspect of sensibility, we were not justified in correlating the numerical results yielded by one test with those of another. Even the three methods we used for estimating defects in spacial recognition could not be directly compared. Suppose, for example, that passive movements of less than 30° in extent were not appreciated, and the compass points could not be discriminated until they were separated by a distance of 3 cm.; how can we say which of these two aspects of spacial sensibility was disturbed to a greater degree? Both were obviously defective, but we cannot compare the relative amount of the affection.

Still less can we correlate directly the numerical results of tests depending on sensory impulses of a different order, such as those underlying spacial recognition or the appreciation of thermal differences. Yet before it is possible to analyse the part played by the cortical centres in sensation, it is essential to find some method of correlating the amount of sensory loss revealed by each test in turn.

Now Holmes and I had already seen cases, such as those described by Russel and Horsley [101], where the condition of the hand was not uniform. Some digits showed gross loss of sensation, others were normal or but slightly affected. Not only might the severity of the loss differ over each finger, but its character might not be the same even on neighbouring digits. When, for instance, the little finger showed gross loss of recognition of passive movement, of tactile discrimination and of localisation, it by no means followed that all these functions were disturbed on the ring finger. It was obvious that such cases give us the opportunity of determining the forms which sensory dissociation might assume when caused by a lesion of the cortex, and thus, incidentally, of grouping the main factors in its sensory activity.

For the more acute and severe the lesion, the wider will be the disturbance of function it produces, as far, at any rate, as the sensory cortex is concerned. This law holds, not only for sensation in its entirety, but also for any one specific aspect of sensibility; thus, in any particular case, one form may be disturbed over both hand and foot, whilst some other sensory quality is affected on the hand alone. Here we should be justified in saying that the more extensive loss signified a graver affection of the corresponding aspect of sensation.

The truth of this law will be abundantly proved by the many examples of sensory dissociation, which I shall consider more in detail later. But it is obvious that, in the light of such an hypothesis, cases where the various digits show different sensory dissociations become of fundamental scientific interest. Suppose, for instance, that one of the spacial aspects of sensibility were affected in four out of the five digits, whilst the power of appreciating graduated tactile stimuli was disturbed in the little and ring fingers only, we are justified in assuming that the lesion has produced a greater loss of spacial than of tactile appreciation. By determining the number of digits, which are shown to be affected to each sensory test, we are able to correlate the disturbance of the various aspects of sensation.

Once this relation has been established, the actual results of measurement can be roughly calibrated and compared. We may find that on one of the digits every form of spacial recognition is grossly affected, but on the neighbouring finger the three-, two-, and one-dimensional tests give different results. Passive movement may not be recognised with certainty, however extensive the range within normal limits, whilst the two compass points can be accurately discriminated if they are 3 cm. apart; "spot-finding," however, is not measurably disturbed, but the patient complains that it is more difficult to discover the exact point of contact than over similar parts of the normal hand. Here, then, on the same finger are three grades of loss. It is obvious that the three-dimensional test is grossly affected, because no threshold can be obtained. Discrimination of two points shows a smaller disturbance, for a threshold could be determined, although it was raised considerably above the normal. On the contrary, one-dimensional recognition was not measurably disturbed; but the patient knew by introspection that it was more difficult than over unaffected parts.

In civilian practice these cases occur so infrequently that it was impossible to investigate the problem systematically on these lines. But, as a consequence of the war, every neurologist has come across patients with injuries of the skull who have complained that one part of the hand "feels different" from the other. This may be a temporary phase on the road to recovery, or may remain almost unaltered for many months or years. I believe that these cases give the key to the part played by the cortex in the production of sensation, and enable us to guess at the topographical localisation of the various sensory activities which they reveal.

Twenty-one such cases have come under my observation, and I have fortunately been able to work them out fully, in spite of the considerable expenditure of time necessary in each instance to obtain a complete set of records.

§ 2.—An Illustrative Case

It will be well to begin with an account of one of these cases, so that the clinical phenomena they exhibit may be clear before we pass on to a more detailed examination of the sensory dissociation in each particular instance.

Case 17.—Private F. L., aged 29. On February 17, 1915, he was hit by a bullet which glanced from a sandbag and struck the left side of his head. He walked to the dressing station and was sent on to a field ambulance, arriving within three hours from the time of the wound. He suffered a good deal from pain in the head but did not vomit or feel sick. The right arm was weak, and, although he knew what he wanted to say, he had difficulty in finding words to express his meaning.

On February 19, he was operated upon by Captain Browne, who made the following notes: "Gunshot wound of head. Exit and entrance wounds over left motor area. Wounds joined up and extended. Gutter fracture of outer table; much fissuring of inner table; blood clot; dura incised: clot under dura with extensive pulping of cerebrum. Right arm, motor paralysis. Right facial paralysis and affection of speech. After operation, face and speech improved."

On March 3, he was transferred to London; his condition was carefully worked out by Dr. Fearnsides, who kindly arranged that I should see him. After some time spent at a convalescent home, he came under my care at the London Hospital in July, 1915. The following account is based upon records taken by myself during the first fortnight of that month.

At that time, four months after the wound, I found him an extremely intelligent, quiet Yorkshireman, who had left school at 12 years of age in the sixth standard, and held a second class Army certificate.

The wound had healed firmly and now consisted of a pulsating depressed scar covering a defect in the bone of an irregular diamond shape. This was situated 15·5 cm. behind the nasion and 1·5 cm. to the left of the middle line. The area of bony loss measured 8·5 cm. antero-posteriorly and 4 cm. across at the widest part. The nasion-inion measurement was 34·5 cm. and the inter-aural line cut it 14·5 cm. behind the root of the nose (Fig. 176).

Speech was entirely unaffected. He had not suffered from any form of convulsion or seizure. All headaches had disappeared several months before.

Vision was $\frac{6}{6}$ with either eye and the visual fields were normal. The discs showed no signs of past or present change. Hearing, smell and taste were unaffected.

The pupils reacted normally. Ptosis, nystagmus and ocular paralysis were absent. The face, tongue and palate moved well and equally.

The right wrist-jerk was slightly greater than the left, but both were brisk. Knee-jerks, ankle-jerks and plantar reflexes were absolutely normal. Both upper and the left lower abdominal reflexes were brisk; but that from the right iliac fossa was defective. Scratching the subumbilical area on the right side produced a contraction above the level of the umbilicus only.

The only defects in motion were to be found in the right hand; with this exception, even the movements of the right upper extremity were performed powerfully against resistance and showed no inco-ordination.

The grasp of the right hand was fairly strong, but clumsy and considerably weaker than that of the left; it did not relax materially when his eyes were closed. If his hands were held out in front of him, the fingers were out of alignment and, when made to close his eyes, they fell into irregular movements of flexion and extension. The contrast between the falling away of the fingers and the steadiness of the arm and forearm was exceedingly striking. Even with the eyes open he could not flex or extend the thumb without coincident irregular movements occurring in the fingers, and no isolated movements were possible in any of the digits of the right hand. Told to flex the index finger, he bent it at once, but at the same time considerable flexion occurred in all the other fingers and at the terminal joint of the thumb. When asked to straighten the right index, the thumb became extended together with the terminal joints of the middle, ring and little fingers, although the metacarpo-phalangeal joints continued somewhat flexed. If, however, he was told to open all his fingers, he did so rapidly, though the fingers remained out of alignment, owing to a diverse amount of flexion remaining at the metacarpo-phalangeal joints. The amount to which the fingers could be extended varied greatly from time to time, but the little finger was always in the worst position.

These difficulties in movement were distinctly exaggerated when his eyes were closed. No gross increase or decrease of tone could be discovered in the fingers or thumb of the right compared with those of the left hand.

Sensation

His only complaint on the sensory side was that his right hand "feels numb"; when he woke at night he knew he had a right hand, but it seemed stiff and dead.

Measured Movement.—No sensory changes could be discovered to any of the tests we use, either in the upper extremity above the wrist, or in the lower limb. All deviations from the normal, found in this case, lay in the right hand and were worked out finger by finger with the following result :—

Measured Movement.	*Right (affected).*	*Left (normal).*
Thumb	1°	1°
Index finger	5° to 10°	1° to 2°
Middle finger	10° to 20° (gross loss)	1°
Ring finger	10° to 20° (gross loss)	1°
Little finger	10° to 20° (gross foss)	1° to 2°

In every case, at least ten observations were made on each digit, and it is evident that on the normal hand the patient gave a perfect series of answers with a movement through an angle of less than 2°. But on the right hand, the records from the middle, ring and little fingers showed gross defects of appreciation; not only was it necessary for the movement to range through from 10° to 20°, but the answers were uncertain and the direction in which the finger had been moved was not infrequently misinterpreted. In the case of the index finger, there was no such error or uncertainty, but the threshold was raised; a movement through from 5° to 10° was necessary for appreciation, whilst on the normal side flexion or extension of from 1° to 2° was at once recognised. No difference could be discovered between the range of movement necessary for correct appreciation in the two thumbs.

Vibration of the tuning fork.—A tuning fork beating 128 vibrations per second (C°) was placed on the palmar aspect of the terminal phalanx of the right little finger and allowed to remain there until the patient said it had ceased. It was then transferred to the similar part of the left hand and the vibration was appreciated for from ten to fifteen seconds longer. But, when the converse experiment was tried, he failed entirely to recognise any vibration in the affected little finger, after it had apparently ceased on the normal side. This result was recorded as follows :—

From R. little finger to L.	+ 15 sec.	+ 10 sec.
From L. little finger to R.	+ 0 sec.	— 0 sec.

In the ring and middle fingers the records showed a less gross loss of sensation and in the index finger the loss was so slight as to be just perceptible only on the records.

From R. index finger to L. + 12 sec.		+ 11 sec.
From L. index finger to R.	+ 9 sec.	+ 8 sec.

There was no difference between the answers obtained from the two thumbs; evidently the right thumb was not affected to this test.

Simultaneous compass test—

	Right.	*Left.*
Thumb	Perfect at 1 cm.	Perfect at 1 cm.
Index	Perfect at 1 cm.	Perfect at 1 cm.
Middle	Gross loss at 3 cm.	Perfect at 1 cm.
Ring	Gross loss at 3 cm.	Perfect at 1 cm.
Little	Gross loss at 3 cm.	Perfect at 1 cm.

To this test the little, ring and middle fingers were affected, whilst the index and thumb gave perfect records when the points of the compasses were 1 cm. apart. This is the smallest distance that can be safely used in clinical work; if the patient is unusually intelligent, it may be possible to obtain a perfect record at 0·5 cm., but such accuracy cannot be expected in the general run of cases.

With regard to the records from the little, ring and middle fingers I have little doubt that the distance between the two points might have been considerably increased above 3 cm. without obtaining a threshold; for the patient did not show the slightest power of discrimination. But, when they are separated for much over 3 cm., one of the compass points is liable to fall over the basal phalanx, which, in some of these cases, may be in a more normal condition than the two terminal ones.

Localisation or "spot-finding."—There was distinct loss of the power to localise the spot stimulated, as shown by our modified Henri method, which avoids the fallacy of groping. Out of six tests applied to the palmar aspect of the right little finger, he made one erroneous localisation, referring a touch over the middle phalanx to the middle of the basal phalanx. Moreover, he showed some hesitation even with those stimuli which were correctly localised; this was not the case on the little finger of the normal hand. Elsewhere, even over the affected hand, he was astonishingly quick and accurate. Thus we must conclude that the power of localising correctly a single stimulus was somewhat disturbed on the right little finger, but was perfect elsewhere.

Measured tactile stimuli (the tactile hairs).—To this test the palmar aspect of the thumb, index and middle fingers of both right and left hands gave perfect readings with a hair of 21 grm./mm.^{2} But over the ring finger of the affected hand this hair was not uniformly appreciated and 23 grm./mm.^{2} was required before a perfect record could be obtained. That is to say, the threshold was here slightly raised.

On the right little finger the disturbance of sensibility was of a much grosser character, as shown by the following record :—

	Right (affected).	*Left (normal).*
21 grm./mm.^{2}		i i i i i i i i i i i i i i i i
21 grm./mm.^{2}	o i i o i i i o i i ⁞⁞ – o o o i o o	
23 grm./mm.^{2}	o o i o i o i i – o i i ⁞⁞ ⁞⁞ ⁞ – i i i – i i	
35 grm./mm.^{2}	o i i i i i i – i i i ⁞⁞ – i i i i i – i	
70 grm./mm.^{2}	i i i i – i i i – i i i i i i – i i i	
21 grm./mm.^{2}	i i i ⁞ – i ⁞⁞ – o i i i – o o o i – o o o o	
21 grm./mm.^{2}		i i i i i i i i i i i i i i i i

(An "i" signifies that he responded to the contact of a tactile hair of a strength given in the left hand column. An "o" records an absence of reply, whilst a dotted line represents an hallucinatory answer. The horizontal lines correspond to pauses of 5 sec. or more, interpolated either after a series of hallucinations, or in order to test the possibility that the previous answers might have been hallucinatory.)

Here the threshold was raised to 70 grm./mm.^{2} With all lighter stimuli, hallucinations and gross defects of response made their appearance.

Temperature.—It is always extremely difficult in cases of cortical lesions to obtain a trustworthy series of temperature records; for a large number of observations are necessary, comparing the behaviour of the two hands to the same temperature. This is impossible with a stupid patient and fatiguing to one who is intelligent, if it forms part of a long examination. In this case, therefore, I was satisfied with a careful exploration of the condition of the little finger of the right hand compared with that of the left.

For both hands the point at which he ceased to recognise the silver tube as cold was 27° C., whilst the threshold for heat was 30° C., the external temperature being 19° C. throughout these observations.

He made no mistakes in the relative warmth of silver tubes containing water at 35° C. and 45° C. throughout a series of tests on both little fingers.

In fact, were it not that he said, "It is never so clear on the right little finger as on the left," no abnormality could have been detected. Here there was evidently a diminution of sensory acuity so slight that it could not be measured, though it was evident to the patient himself. This I shall call an "introspective" difference.

Prick.—There was no difference between the two hands in the sensitiveness to a measured prick, tested finger by finger, and introspectively the patient was not aware of any abnormal sensations.

Weight.—The best method for testing the power of recognising differences in weight in the five digits is to add and subtract leaden discs of the same surface area, but of different thickness. The hand is laid palm upwards on a pillow, in such a way that it is fully supported; a cork disc of negligible weight is laid on the palmar aspect of the finger under examination. To this, progressively heavier weights are added, and then removed until the cork alone remains on the finger.

These weights are not added or removed in unbroken sequence, first up the scale and then down, but irregularly, and the patient is asked to indicate when any change occurs. He is required to say "on" or "off" only, or, if he prefers not to do so, may answer "heavier" or "lighter." He is not allowed to raise the finger from its basis on the pillow so as to "weigh" the test object.

This test applied to the two little fingers gave the following records :—

Weight added or subtracted.	*Right (affected).*	*Left (normal).*
+ 20 grm.	No reply	On
+ 40 „	On	On
— 40 „	On	Off
+ 40 „	On	On
+ 80 „	On	On
— 80 „	No reply	Off
+ 80 „	Off	On
+ 100 „	Off	Off
— 100 „	No reply	Off
— 80 „	No reply	Off
— 40 „	No reply	Off
— 20 „	No reply	Off
	Asked if any weight was on the hand he replied that it was still there	He then added "All gone."

A similar series of records was obtained from the right ring finger, whilst from the right index he gave a perfect series of answers.

Texture.—The test object, *e.g.*, a piece of velvet, was passed round the top of each digit and then moved from side to side across the palmar aspect of the terminal phalanx. With the little finger of the left hand he recognised velvet, silk, cotton and flannel without difficulty, but failed entirely with the right; to each he said, "I don't know," or "I've no idea."

With the thumb and with the index finger of each hand he gave equally perfect answers.

The sensory condition of the various digits of the right hand revealed by these tests can be summarised in the following table :—

	Little.	Ring.	Middle.	Index.	Thumb.
Measured movement	Gross loss	Gross loss	Gross loss	5° to 10°	Normal
Vibration	Gross loss	Affected	Affected	Slight loss	Normal
Compass test	Gross loss	Gross loss	Gross loss	Normal	Normal
Localisation	Uncertain	Normal	Normal	Normal	Normal
Tactile hairs	Gross loss	Raised threshold	Normal	Normal	Normal
Temperature	Introspective	Normal	—	Normal	Normal
Prick	Normal	Normal	—	Normal	Normal
Weight	Gross loss	Gross loss	—	Normal	—
Texture	Loss	—	—	No loss	No loss

CHAPTER IV

THE FORMS ASSUMED BY DISTURBANCES OF SENSATION DUE TO LESIONS OF THE CORTEX

§ 1.—INTRODUCTORY

BEFORE we pass on to consider the significance of this regional dissociation of sensibility, it will be well to summarise the conclusions which can be drawn from the case I have just described.

(1) Sensation as a whole may be affected by a cortical lesion to a different degree in the various digits. In this instance, the thumb was normal; but there was a steady deterioration in the sensory condition on passing towards the post-axial border of the hand, culminating in gross loss over the little finger.

(2) A similar tendency to graduated loss of sensibility was shown in the records of each individual test. Thus, the patient could appreciate passive movement equally well on both thumbs; but a range of 5° to 10° was required in the index finger, and gross loss was evident in the three other digits.

(3) Tests which appeal to fundamentally different aspects of sensation may not be affected over the same number of digits. In the case already described, appreciation of passive movement was defective in the index, middle, ring and little fingers, whilst the tactile hairs, a most delicate test, revealed loss of sensibility in the ring and little fingers only. This dissociation, as I shall show later, can go so far that one form of sensibility may be grossly defective whilst another may show little or no change.

(4) Even those tests which belong to the same sensory order may not be affected over the same number of digits. Thus, measured movement, the compass test and "spot-finding," are all methods of exploring the spacial aspects of sensation. But, in the example I have chosen, recognition of movement was disturbed in four digits, tactile discrimination in three, and topical localisation in one only.

Before we can draw any general conclusions from the detailed examination of these cases of dissociation, it is necessary to consider the nature of the sensory tests on which our results are based. None of them were invented as a special means of exploring the defects produced by a lesion of the cortex, and the majority excite to activity both the essential organ of the optic thalamus and the cortical centres. If we call to mind the various aspects of sensation which depend on the physiological activities of these two cerebral end-stations, we recognise that, whereas the optic thalamus deals with crude awareness to contact, heat, cold and pain, the sensory cortex endows these basic functions with spacial qualities, intensity and relativity.

When we pass in review, according to this conception, the sensory tests we habitually use, it is evident that recognition of passive movement, discrimination of two compass points and our method of testing localisation appeal to those elements in cortical activity underlying recognition of relations in space. Thus measurement of the angle through which any part of the limb must be moved, in order that such change in posture may be appreciated, is an exploration in three-dimensional space. The power of discriminating two points of the compasses, applied exactly at the same moment, reveals the capacity for recognising two-dimensional space, whilst "spot-finding" is an exercise in one-dimensional localisation.

Further analysis on these lines shows that our methods for examining sensibility to touch, temperature and pain can be combined into another group from the point of view of the sensory cortex. For, although the basic response to all these tests is due to the activity of the optic thalamus, the power of recognising differences of intensity in the sensation evoked is a function of the cortex. All the methods we use presuppose that an increase in strength of the physical stimulus will result in a sensation of greater intensity, in some more or less graduated proportion; on this principle depends the determination of a threshold, which plays so important a part in all our sensory examinations. But one of the signs of cortical disturbance is inability to obtain a threshold. The answers are uncertain, even to stimuli of the same strength applied in an exactly similar manner, and, although a response may be evoked, it is not of necessity in proportion to the degree of stimulation.

Of the remaining tests, weight is the only one applicable to the fingers which can be strictly graduated. As I have applied this test, it makes an appeal to another sensory faculty, the power of appreciating similarity and difference. At first it might appear to be only another means of gauging the recognition of intensity. But, if the methods of using the tactile hairs and graduated weights are compared, we see that the measure of tactility is given by the bending strain of the hair to which the patient responds; he is touched with one hair and gives uncertain answers, whilst a stronger hair may evoke constant recognition of a series of contacts. But, in testing with weights, one after another is placed on the hand, and he is then asked to say when a difference occurs; sometimes the load is made heavier by addition, sometimes lighter by subtraction. When this test is carelessly carried out, the act of removing or replacing a weight may arouse the patient's awareness and he at once responds; but he cannot tell with certainty whether the weight on his hand is lighter or heavier than it was before he received the sensation of "something happening." We are not dealing with his capacity to appreciate a contact of a certain intensity, but with his power of recognising difference.

Yet, even after we have grouped our tests according to the particular aspect of cortical sensibility, which they reveal, it is necessary to remember that they differ greatly in the severity of the task they set to the patient, and in the accuracy of the answers they demand. It is far more difficult to recognise a minute range of passive movement in one of the fingers than to indicate, within necessarily wide limits, the situation of the spot stimulated. Similarly, a series of perfect answers to the contact of graduated hairs requires a more perfect reaction to differences in intensity than the crude comparison which is alone possible with a series of pricks.

For the sake of simplicity let us then select from each group of tests the one which gives the widest possible range of measured difference. The power of recognising passive movement may be taken as the representative of the spacial aspect of sensibility; in the same way, the tactile hairs form the best measure for the faculty of appreciating graduated differences in intensity, whilst the addition and subtraction of weights can be taken as an indication of the ability to recognise similarity and difference in stimuli of the same sensory quality.

Case.	Measured movement.	Tactile hairs.	Weights.
No. 18	0	Affected (5 digits) ...	Affected (2 digits).
No. 3	Affected (5 digits) ...	0	,, (2 digits).
No. 21	Whole hand affected ...	0	Defective.
No. 16	,, ,, ,, ...	0	Gross loss over whole hand.
No. 2	Affected (4 digits) ...	0 (or introspectively) ...	Introspective (1 digit).
No. 19	,, (5 ,,) ...	Slightly affected (3 digits)	0
No. 13	,, (4 ,,) ...	Affected (5 digits) ...	0
No. 22	,, (5 ,,) ...	Introspective (3 digits) ...	0
No. 14	,, (2 ,,) ...	Threshold raised (2 digits)	0

The cases collected in the above table show that it is possible for one or more of these representative tests to remain entirely unaffected, although a profound disturbance of sensation may be revealed by the remainder. Thus, in No. 18, recognition of passive movement was not affected in any of the digits in spite of a grave disturbance of tactility and of the power of responding to differences in weight. No. 3 showed no loss of tactile sensibility, and yet there was extensive want of appreciation of passive movement and of relative weights. No. 22 showed a profound loss to the tests for measured movement and an introspective defect to tactile stimuli, but perfectly appreciated the addition and subtraction of weights on all the fingers.

It is, therefore, probable that these three aspects of sensibility are due to distinct physiological activities, which are not uniformly distributed throughout the so-called sensory cortex; some are more intensely represented at one part, some at another. Otherwise it would be difficult to understand how one aspect of sensation could be gravely disturbed by a cortical lesion, whilst some other form escaped entirely; and yet in another case this relation may be completely reversed.

Many attempts have been made to determine the topographical localisation of the sensory activities of the cortex, but they have all failed, because the nature of its functions was unknown. So long as investigators continued to think of the sensory cortex as the seat of processes underlying the full appreciation of touch, pain, heat, and cold, they were bound to find the clinical facts inexplicable. But as soon as it was evident that crude qualitative appreciation of these modes of sensation was due to the activity of the optic thalamus, it became possible to study the phenomena of sensory loss with some hope of discovering the part played by the cortex. Once we had determined that the physiological activity of the cortex was responsible for the recognition of spacial relations, intensity and relativity, it became possible to group the physiological processes which underlie sensation. But, before we can formulate any coherent conception of these cortical activities, it will be necessary to examine in detail the manner in which they are affected, as shown by the various tests belonging to the same order of sensation.

§ 2.—Spacial Recognition

Some loss of power to recognise passive movements of the affected part forms one of the most frequent consequences of injury to the sensory cortex. In fact, it may be accepted for clinical purposes as a leading sign in the syndrome of cortical disease. It is, however, only one of the methods of discovering whether the spacial aspect of sensation is disturbed; the compass test and "spot-finding," as we have employed them, are also explorations in spacial recognition.

But these three tests are not equally affected by a lesion of the cortex. The most delicate of them and the most susceptible of change is the power of appreciating a measured movement made passively. Next in order comes discrimination of the two compass points applied strictly simultaneously.[1] Finally, topical localisation or "spot-finding" is affected to the smallest degree of all the three spacial tests: for not only is it scientifically less precise, but the problem it presents to the patient is easier than with either of the other methods of research.[2]

This graduated relation between the disturbance of sensibility revealed by the three spacial tests, is evident from whatever point of view the records are examined. Thus, if the injury is a slight one, the only loss may be in the power of appreciating passive movement. A somewhat more severe disturbance affects discrimination of the compass points, and finally "spot-finding" may also be defective.

The same law is manifest if we judge, not by the frequency with which

[1] The compass test cannot be used to measure the power of discriminating two contacts in cases where tactile sensibility is grossly disturbed. It presupposes that the patient is capable of recognising touches with some approach to uniformity. Throughout this chapter I have carefully excluded this source of error, but have postponed its more detailed consideration to p. 696.

[2] Our method of testing the power of topical localisation also depends somewhat on the condition of tactile sensibility. This association has been fully investigated and described by Graham Brown and Stewart [13], and is considered on p. 698.

any one of these three aspects of spacial recognition is affected over a series of cases, but by the number of digits which show disordered sensibility to each test in turn. Three-dimensional loss (appreciation of measured movement) occupies the largest number of fingers, two-dimensional loss is found to extend either to the same or to a smaller number of digits, and localisation is disturbed over a still less extensive area.

I have summarised in the following table the records of twelve cases where spacial recognition was not uniformly disturbed over the whole hand. The numerals correspond to the number of digits found to be affected to each of the three tests. It is at once obvious that the widest loss of sensibility is shown by the range of passive movement necessary to excite appreciation, whilst the power of discovering the position of the stimulated spot is least extensively affected.

Case.	Measured movement.	Compass test.	Localisation.
No. 10	5	4 + 1 introspective	3
No. 22	5	4 + 1 introspective	2
No. 4	5	4 + 1 introspective	2
No. 20	5	3	1
No. 19	5	2 + 1 introspective	1 + 1 introspective
No. 3	4 + 1 introspective	2	2
No. 7	5	1 + 1 slightly	0
No. 1	5	2	0
No. 17	4	3	1
No. 2	4	1	0
No. 12	3	2	0
No. 14	2	2	0

This graduated relation between the amount and the extent of the loss discovered by the three spacial tests comes out clearly in the following example (No. 3). Fortunately, tactile sensibility was not affected in this case, and the readings are therefore free from this troublesome source of fallacy.

	Measured movement.	Compass test.	Localisation.
Thumb ...	1°, but direction not always accurate ...	Perfect at 1 cm.	Perfect
Index finger ...	Between 2° to 3°, but slow	,, 1 ,,	,,
Middle finger	2° to 3°	,, 1 ,,	,,
Ring finger ...	Gross loss	Gross loss at 5 cm.	Slightly affected
Little finger ...	Gross loss. Cannot even recognise posture of finger	All called "one" at 5 cm.	Definite, but slight loss

Here three-dimensional loss was so great over the little finger that the patient could not even recognise its position, when it had been moved passively into the extremes of flexion and extension. In the ring finger the disturbance was considerable but not so complete, whilst in the middle and index fingers a movement of from 2° to 3° was recognised slowly. The range of movement actually appreciated in the two thumbs was the same, but the answers from the affected hand were less prompt and the direction was not always indicated correctly.

The compass test was affected over the ring and little fingers only, but over the latter the loss of discrimination was absolute when the points were 5 cm. apart.

Topical localisation was slightly disturbed on the ring finger and the patient was less certain in his answers, but over the little finger the change was more definite. Out of five observations he made two mistakes, and at the same time complained that the test was more difficult than elsewhere over the hand.

Here, then, both the degree of sensory change and the extent of the loss, measured by the number of digits affected, obeyed the law laid down at the beginning of this section. The earliest disturbance of sensibility is revealed by a test in three-dimensional recognition, whilst "spot-finding" is both last and least affected.

So far, I have spoken of the extent to which recognition in space was disturbed as if it was determined by measurement only. This is, however, not the case. For the first sign that any one of these varieties of spacial recognition is affected is the statement of the patient himself, that the tests are less easy on the abnormal digit. Even though the compass test may give a threshold within normal limits, he is slower in his answers and finds greater difficulty in making up his mind as to whether he has been touched by one or two points. A similar state of uncertainty may be the first sign that localisation is disturbed, although finally he may indicate correctly the spot touched. In all these instances, the change would be recorded as an "introspective" one. With intelligent patients, this introspective difference between similar parts of the two hands is a most valuable indication that a change in sensibility exists, even though it is too slight to become apparent by our somewhat coarse methods of measurement.

A more advanced affection is shown by a raising of the threshold; there may be no difficulty in obtaining perfect appreciation of passive movement and of the compass test, but the angle through which the affected part must be moved may be five to ten times greater than normal, and the two points have to be separated to a distance far in excess of that necessary on the unaffected hand. In such cases correct recognition and discrimination are possible, provided the task is made easier.

The next stage of dissolution is shown by the absence of a threshold; movements to the extreme distance possible in any direction may not be recognised. The records are marred by uncertainty, guessing and hallucinations. The patient may describe movements, indicating their direction, although the part has remained rigidly in the same position; contact stimuli are particularly liable to be translated into sensations of movement. In the same way, the maximum separation of the compass points possible over the affected part fails to lead to correct discrimination and the records may show uncertainty and guessing, even when one point only has been applied to the skin. An analogous tendency appears when the power of localisation has been profoundly disturbed; the patient not only indicates erroneously the spot touched, but may give up all attempt to determine its position, saying, "I have no idea where you are touching me."

These various grades of defective recognition are well shown in the following case (No. 2), where all the fingers were in a different condition:—

	Measured movement.	Compass test.	Localisation.
Thumb	Normal (1°)	Threshold 1 cm.	Perfect
Index finger ...	Threshold raised (3° to 6°)	,, 1 ,, ...	,,
Middle finger ...	,, ,, (6° to 10°)	,, 1 ,, ...	,,
Ring finger ...	,, ,, (5° to 8°)	,, 1 ,, ...	,,
Little finger ...	Gross loss of threshold and confusion	,, 1·5 cm., with some uncertainty of response	,,

Here there was no difference between the sensory condition of the two thumbs; it was as easy for him to give correct answers to the three tests on the affected as on the normal hand. The first change appeared when he attempted to describe passive movements of the index finger; his answers were slower and a range of from 3° to 6° was required before he could appreciate the direction correctly. With the middle and ring fingers, the movement had to be made through an angle of from 6° to 10°, whilst in the little finger the loss was even greater. For he not only required movements of from 15° to 20° before he could recognise that some change of posture had occurred, but its direction was sometimes wrongly interpreted even at 25°.

In spite of this extensive disturbance in the recognition of passive movement, the only change to the compass test was found on the little finger of the affected hand. Not only was it necessary to separate the two points to a distance of 1·5 cm., but he gave the following account of his sensations in this digit. "The thing that puzzles me on the little finger is that it seems like an echo. I don't know whether it is two, or one with an echo. When they are close together, I can't tell whether it is one point, which influences the part around, or two points. When they are wide apart, the second point falls outside this part influenced, and I know it is two."

Even when we consider the state of any one digit, we can frequently discover a similar graduated relation between the extent to which the three spacial tests are affected. Take for example the sensory records from the little finger in No. 2. Recognition of passive movement showed the profoundest disturbance; it was impossible to obtain a definite threshold, even with a wide range of alteration in posture, and the patient's answers were confused. Yet the compass test revealed a threshold, with the points separated to a distance of 1·5 cm., and localisation was entirely unaffected.

Whenever, therefore, spacial recognition is diminished as the result of a cortical lesion, appreciation of passive movement will be disturbed. Moreover, in any such case, this aspect of sensation shows the most extensive and also the most intense changes.

Next in order comes two-dimensional discrimination, as shown by the power of recognising the two compass points applied simultaneously.

Localisation, or the capacity to determine the position of the stimulated spot, is affected less often, less extensively, and to a smaller degree than any of the other spacial tests.

This is an excellent example of the law, laid down by Hughlings Jackson, that the higher and most specific aspect of any function is affected before the lower. Sensory disturbances associated with lesions of the cerebral cortex are psychical manifestations, rather than the result of mechanical interference with conduction of afferent impulses. The physiological activities, which directly underlie sensation, are struck in the centre of their production. We have no longer to deal, as on lower levels, with loss of sensation caused by the cutting off of afferent impulses from a normal receptive centre. All such expressions as "joint-sense," "proprioceptive impulses," "epicritic and deep sensibility," adequate terms at certain other sensory levels, cease entirely to have validity when we are considering the disturbances in spacial recognition associated with a cortical lesion.

Such a lesion, when it interferes with spacial recognition, first disturbs that function which is psychically most difficult, and then in order those of less complexity. We are so near the psychical act of sensation that we must now classify disturbances of sensibility under categories we can recognise introspectively, and we are not compelled to group them according to their local origin, phylogenetic qualities, or physiological history, as was the case with lesions at lower levels of the nervous system.

§ 3.—Intensity

Touch, pain, heat, and cold form a natural group with certain features in common. Each of these aspects of sensation depends on the action of measurable physical stimuli; the impulses generated are specific and, on the physiological levels of the nervous system, they are gathered together into separate afferent streams, which can be interrupted independently of one another.

But a cortical lesion never completely abolishes sensibility to touch, pain, heat, or cold. Even when the whole sensory cortex is thrown out of action, contact, especially of an object moving over hair-clad parts, may produce a definite tactile response. Under such conditions, contact-stimuli produce a vague sensation of "something happening" within the body, without immediate appreciation of variations in intensity. In the same way, heat and cold may be correctly discriminated, although the patient cannot recognise differences in the degree of thermal stimulation. The sensation evoked by a prick may not seem so "sharp" or so "clear" as over normal parts, but the discomfort it produces may be greatly increased.

The power of recognising contact, especially of a moving object, and appreciation of the qualitative aspects of thermal and painful stimuli, are functions of the optic thalamus; the activity of the cortex endows us with the capacity to estimate the relative intensity of such stimuli. It is obvious, therefore, that all these forms of sensibility must be affected in a similar way by a cortical lesion. Their qualitative appreciation is already provided for elsewhere; but the clarity and definiteness of the sensation and the stability of the response to repeated stimuli are a function of cortical activity.

Now, from the cortical aspect our tests for measuring sensibility to touch, temperature, and pain are not of equivalent value. The tactile hairs demand a high degree of constancy and graduated response to stimulation; this test, therefore, shows the greatest change amongst the group we are now considering.

Appreciation of heat and cold, as we are forced to examine it clinically, depends comparatively little on cortical activity. For, whilst it is easy to say whether an object is hot or cold, it requires an intelligent patient and unusually favourable conditions to test the relation of two warm stimuli to one anothe , or to determine the threshold for heat and cold with approximate accuracy.

These difficulties are multiplied a hundredfold in the case of pain. A prick is the only effective means of applying a measurable painful stimulus to the skin, and any sharp object, such as a needle, produces first of all a recognition that the stimulus is pointed; further pressure adds to this a sensation of pain. It is almost impossible to prevent the patient from saying that he is pricked, whenever he appreciates that the stimulus is a sharp point, and, if he is told to wait until he obtains a distinct sensation of pain, we run the risk of placing the threshold too high. In the vast majority of cortical disturbances, the threshold for prick is the same on the two sides. But in rare instances it would seem as if the threshold were raised somewhat over the affected parts, and the patient complains that the "feeling" is different. How far this is due to a profound change, not uncommonly present, in the sensation produced by the point apart from pain, and how far it may be caused by a slight raising of the pain-threshold, is dealt with in Chapter VI (p. 708). Whatever the true significance of this phenomenon, appreciation of a prick is affected less often than any other form of sensation.

Whenever the power to appreciate touch, pain, heat, or cold is disturbed, in consequence of a cortical lesion, measurements with hairs of graduated strength invariably reveal some loss of tactile sensibility. Out of eleven cases where one or more of these qualities of sensation showed some defect on the hand, tactile appreciation was disturbed in all; five showed some loss of thermal sensibility, whilst measured prick was defective in one case only.

If these eleven cases are gathered together to form a table, it will be seen that tactile sensibility is most often affected, but the loss is invariably greater in amount than that of either of the two other forms. Similarly the defects shown by the thermal tests are greater than those which appear in the records of measured prick.

Case.	Tactile hairs.	Thermal tests.	Prick.
No. 5	Gross loss	Affected	Threshold raised
No. 10	" "	"	Normal
No. 17	" "	Introspective	"
No. 4	" "	"	"
No. 18	" "	Slightly affected	"
No. 14	Threshold raised	Normal	"
No. 13	" "	"	"
No. 20	" "	"	"
No. 12	" "	"	"
No. 1	Threshold slightly raised ...	"	"
No. 7	" " " ...	"	"

A similar relation is evident, if we judge by the number of digits affected in each particular instance. The following table shows that the extent of the loss to graduated tactile stimuli exceeds, or is as great as, that of any other form of sensibility belonging to this group. Next in order comes the number of fingers which exhibit some lack of thermal appreciation, whilst in most cases prick is not affected anywhere.

Case.	Tactile hairs.	Thermal tests.	Prick.
No. 5	5	2 + 2 introspective ...	3
No. 10	5	3	0
No. 13	5 threshold slightly raised	0	0
No. 4	3 + 2 introspective ...	3 introspective	0
No. 20	1 + 4	0	0
No. 17	2	1 introspective	0
No. 14	2	0	0
No. 1	2	0	0
No. 12	1 + 1 introspective ...	0	0
No. 7	1 + 1	0	0

In all attempts to record the amount or the extent to which these forms of sensibility are affected we cannot depend entirely on measurement. Introspective differences, irregularity of response and hallucinations must all be carefully taken into account.

It is more particularly in this group of tests, dealing with response to stimuli of different intensity, that introspection is of the greatest value. The patient insists that the impression he receives is "less plain," "less certain," over affected parts; the threshold may be slightly raised only, or it may be impossible to say that there is any measurable difference between similar parts of the normal and affected hands, and yet he insists "the two hands are different." "It is harder for me on the affected hand;

I can't be certain that I am right, but it's easy enough on the normal hand."

No. 2 was a splendid example of this degree of sensory affection. For, as far as touch, temperature and pain were concerned, the little finger showed a disturbance of sensibility which, though not apparent to our rough tests, was obvious to the patient. He gave a perfect series of answers on the right and left little fingers even with a hair of 14 grm./mm.^{2}, but the response was slower from the right than from the left. He said, "The first two or three touches were fairly clear; then it seemed to become more difficult and I wasn't so certain. I was doing it with an effort on the affected hand (right) instead of not thinking about it." With the same hair on the two thumbs he said, "That is quite easy; there is no effort on either side."

The threshold for the appreciation of heat and cold did not differ materially on the two little fingers; but he asserted that the impression he received was not the same. "There is a difference in the left hand (normal); it is immediate, whilst in the right it seems to change gradually. The ultimate sensation is the same, but it is quicker in the left hand."

On testing this patient with measured pricks, it was difficult to be certain whether the threshold was raised or not; but he never doubted for a moment that he received a different impression from the two little fingers, whilst the sensation evoked from the two ring fingers by the same stimulus was identical. If the algesimeter was set at 3·5 grm., it was said to "prick" on both little fingers; on the affected hand, however, it was "not so plain" as on the normal one.

Here, then, is an instance where, as far as the intensity of tactile, thermal and painful stimuli is concerned, no measurable abnormality could be discovered: and yet, in every case, the patient was certain that the sensation from the two hands was different.

When sensation is more gravely disturbed, the threshold rises over the affected part; it may still be possible to obtain a perfect series of answers, but a stronger stimulus is required. The normal hand may respond perfectly to a hair of 14 grm./mm.^{2}, whilst imperfect records may be obtained on a similar part of the other hand, until we employ a hair of considerably greater strength. In such cases, the patient is usually conscious that the sensation evoked is different, and hallucinations are liable to appear, especially if the testing has continued for an unduly long period. In the same way, although crude recognition of heat and cold may show no confusion, the patient may not be able to appreciate heat below about 35° C., or cold above about 26° C., whereas on normal parts the thresholds are respectively about 30° C. and 28° C.

In many cases, a further stage is reached in sensory dissolution. No threshold can then be obtained by increasing the stimulus within certain limits. Normally a hair of 14 grm./mm.^{2}, or at any rate one of 21 grm./mm.^{2}, evokes a perfect series of answers from the palmar aspects of the tips of the fingers. When, however, we speak of the threshold as unobtainable, we mean that even a hair of 100 grm./mm.^{2} does not necessarily or materially increase the accuracy of the response. It is not safe to employ hairs of greater bending strain, as they are liable to produce a sensation of pricking; even those between 70 or 80 grm./mm.^{2} may occasionally seem to prick, over the tips of the fingers.

With the disappearance of a threshold, hallucinations frequently mar the records; the patient responds when he has not been stimulated, and often insists that the hair has not been removed, but still presses on the surface. At other times, it seems to him as if the hair was being dragged along the skin, instead of being applied to one spot and then removed. This translation of contact into a sensation of movement is one of the most striking consequences of some disturbance in the sensory cortex.

Case 5 was an excellent example of such changes in the appreciation of touch, heat, cold and pain.

	Tactile hairs.	Thermal tests.	Prick.
Index finger ...	Threshold destroyed; 23 and 100 grm./mm.^{2} gave the same number of correct answers. Irregular response. Contact thought to be movement across the surface	No certain appreciation between about 26° and 40° C.	8 grm. or more.
Middle finger ...	Threshold raised 23 grm./mm.^{2} ...	Unable to distinguish 35° and 40° C.	8 grm.
Ring finger ...	,, ,, 23 ,, ...	Threshold for cold 27° C., for heat 34° C.	8 ,,
Little finger ...	Much introspective difference; threshold slightly raised	Introspective change only	4 grm.; same as normal little finger.

On the normal hand, the threshold for measured touch was in every case below 21 grm./mm.^{2}; that is to say, that with a hair of this bending strain, a uniform series of replies could be obtained from all his digits. With an external temperature of 18° C., it was found that the threshold for heat, on the fingers of the normal hand, was about 30° C., that for cold was about 27° C. He had no difficulty in recognising the difference between a silver tube containing water at 35° C., and one at 40° C., presented in different order and irregular sequence. Prick was distinctly appreciated on all the normal fingers, when our spring algesimeter registered 4 grm.

Let us examine more in detail the condition of the index finger of the affected hand, as compared with that of the normal side.

A series of observations with the tactile hairs, carried out in the usual way, yielded the following readings. Each unit represents appreciation of a contact of measured force indicated in grm./mm.^{2}, whilst a nought signified that the touch was not perceived. It is evident that no true threshold could be obtained to touches of this order, for the number of correct answers with a hair of 23 grm./mm.^{2} is the same as that to a hair of more than four times the bending strain.

	Right (affected).	*Left (normal).*
21 grm./mm.^{2}	—	i i i i i i i i i i i i i i
21 grm./mm.^{2}	o o o o o o o o o o o o o o o o o o	
23 grm./mm.^{2}	i o o i o o i o o o o o i i o o	
35 grm./mm.^{2}	i o i i o i o o i o o o o i o i	
70 grm./mm.^{2}	i i i i i i o o i i i i i o o o	
100 grm./mm.^{2}	o o i o o i i o o o i i o o o o	
23 grm./mm.^{2}	o o o o o o o o i o i o o o o i	
21 grm./mm.^{2}	—	i i i i i i i i i i i i i i i

This bald record, however, gives an incomplete idea of the sensory disturbance. The patient said, "On the left (normal) side I felt as if you were putting on and taking off a fine wire point. On the right hand, it was exactly as if a mosquito drew its leg along the surface. I never felt a distinct pressing on. Sometimes I felt it vaguely as if it was still there, and I wanted you to press it and take it away again, so that I might be certain if it was there or not."

On the affected index finger, he could not appreciate heat or cold with certainty between about 26° C. and 40° C., whereas on a bright spring-like day, the temperature of the room being 18° C., the indeterminate zone lay between about 26° C. and 30° C. over the normal hand.

This extension of the indeterminate zone on the affected hand is one of the characteristic features of thermal sensibility, when it is disturbed from a lesion of the cortex. An even more striking defect is inability to distinguish two stimuli of the same thermal quality but of different intensity. I have seldom examined a more complete example of the defect.

Index finger.	Right (affected).	Left (normal).
Compared—		
35° and 40° C.	"No difference"	"The second was much hotter"
40° and 35° C.	"No difference"	"The first was hotter"
35° and 40° C.	"No difference"	"The second was hotter"
35° and 45° C.	"Both hot; the last hotter" ...	"The last was hotter"
45° and 35° C.	"No difference"	"The first was hotter"
35° and 45° C.	"No difference"	"The last was hotter"
45° and 35° C.	"First hotter; the second was cold, or nearly so"	"The first was hotter"
25° and 20° C.	"Cold; no difference"	"Neutral and cold"
20° and 25° C.	"The same; just about cold" ...	"Cold and neutral"
25° and 20° C.	"The same; they are not neutral"	"On the cold side and distinctly cold"
20° and 25° C.	"Both are ice cold"	"First much colder; the second just on the cold side of neutral"

When tested with the warm and cold tubes, he said: "There is a great difference between the two fingers: the right never changes its mind, whereas with the left (normal) the temperature seems to grow upon it; with hot I feel it growing hotter, until it reaches a certain stage and then stops. Cold does the same thing. I was baffled on the right hand; I don't know how to describe it. It sometimes seemed ice-cold and sometimes nothing at all; but there was never any difference between the two tubes." He was first tested with the cold tubes on the affected hand, and as soon as the change was made to the normal hand, he burst into laughter, saying, "I could not have believed that the difference could be so great. Here I never had a moment's doubt; the first was just off tepid and the second was colder still, or vice versa as the case might be."

To prick, the threshold was decidedly raised, and although 4 grm. was sufficient on the normal index finger to evoke the sensation of pricking, 8 grm. or more was required on the right hand. Moreover, he said, "I feel it more on the left hand: it is quite soft on the right."

Thus, we can sum up the results reached in this section as follows :—

(1) Sensibility to touch, heat, cold and pain is never abolished as the result of a true cortical lesion, provided the period of shock has passed off and epileptiform attacks are absent.

(2) Sensibility may, however, be profoundly modified. This change shows itself first in the patient's introspective recognition that the sensation obtained from the normal and affected parts is not similar. Next, this difference may become manifest in a raised threshold. A still graver disturbance is shown by inability to obtain a threshold within reasonable limits; such records are liable to be disturbed by hallucinations and other irregularities of response. At this stage of dissolution, the patient may not be able to appreciate with certainty temperatures between about 26° C. and 40° C., nor to discriminate between two hot or two cold stimuli, easily recognisable on the normal hand.

(3) Whenever the graduated tests for touch, heat, cold or prick demonstrate that sensibility is changed, the tactile hairs always discover the gravest disturbance, heat and cold are less and prick least affected. By this I mean, not only that the loss is more intense over any one part, but also that it extends to a larger number of digits on the hand.

(4) This is probably due in part to the more delicate and complex appreciation required by the test of the tactile hairs, compared with the crudity of those we can apply clinically for heat, cold and especially for prick. But it also depends on the relative extent to which these stimuli appeal to the activity of the optic thalamus. A prick, as far as its painful element is concerned, depends for recognition almost entirely on this organ, whilst the "pointedness," "clearness," "sharpness" are the result of cortical activity. On the other hand, the graduated hairs require for their appreciation a reaction to different intensities; this reaction must be constant and correspond relatively to the strength of stimulation. When once the maximum threshold has been exceeded, the answers must be free from gross irregularities. All these factors in contact sensibility depend on the sensory cortex and are

therefore most disturbed in consequence of such lesions as I have dealt with in this paper.

(5) All these changes in sensibility can be grouped together under the heading of defective appreciation of intensity; for, at bottom, they depend on an inconstant reaction to graduated stimuli. This tends to produce that characteristic confusion and want of definition, which are manifest throughout the records of touch, pain, heat and cold in many cases of cortical injury.

§ 4.—Recognition of Similarity and Difference

Appreciation of the shape, relative size, and nature of common objects is frequently disturbed in cases of cortical lesion, and has been erected into one function under the name "stereognosis." But this term is a bad one, because it applies strictly to recognition of form only; it cannot possibly be made to include the relative appreciation of weights, the most easily measurable member of this group of tests. Nor can it comprise the many other means of examining the patient's power of recognising the similarity or difference of two objects placed in the hand, all of which may be more or less simultaneously affected by a lesion of the cerebral cortex.

When we were dealing with the consequences of destruction at subcortical levels of the nervous system, the success or failure of all the tests of this group depended on more than one stream of impulses; the patient might fail if the test was carried out in one way, but make a good record by another procedure. Thus, when the interference with conduction is subcortical, the power of appreciating differences in weights depends on two separate streams of afferent impulses, one concerned with tactile impressions, and the other with recognition of passive movements. If the hand is fully supported, addition and removal of weights can be correctly appreciated only when tactile sensibility is perfect; subcortically, this test is another method of discovering whether touch is or is not affected. When, however, the hand moves freely in space, and the patient is told to "weigh" the objects placed upon the palm, his power of estimating weight depends on the integrity of spacial recognition. It is, in fact, another indirect test for the appreciation of movement.

As soon, however, as we come to deal with disturbances of cortical origin, we are face to face, not with an interference with conduction to an intact centre, but with destruction of the activities of that centre itself. The power of estimating weights is now a primary, and not a secondary function; and, if it is disturbed by a cortical lesion, all aspects of the tests are more or less affected.

The power of appreciating differences in weight is no longer linked up directly with postural recognition, or with tactile sensibility. These functions may be entirely dissociated. Thus, in No. 18, measured movement was in no way defective, and tactile sensibility was disturbed to a scarcely perceptible degree, and yet the power of appreciating differences of weight was gravely affected. Conversely, in No. 13, the patient was able to discriminate differences in weight, and yet recognition of movement and tactile sensibility were considerably disturbed.

Again, it may happen that perfect appreciation of graduated contacts is accompanied by loss of power to estimate weight. In two cases (No. 16 and No. 21), where this condition was present over the whole of the affected hand, it was associated with inability to recognise passive movement in all five digits. At first sight it might be supposed that the two lost functions were bound up together, were it not for another group of cases (Nos. 13, 19, 22), where the records of measured movement showed the grossest defects, but the relation between two weights could be correctly appreciated.

Thus it is evident that the power to recognise differences of weight is a function of the cortex, independent of tactile sensibility, or of the appreciation of measured movement and posture of the affected parts. At all levels of the nervous system below the cortex, discrimination of weights depends on the manner in which the test is applied. If tactile sensibility is diminished, the patient is no longer able to recognise the relation of two weights placed on the hand when fully supported, whereas a proper appreciation of movement is required for the due recognition of weights laid on a hand that is moving freely in space. But, from the point of view of cortical activity, discrimination of weight is a function independent of either postural or tactile recognition.

The faculty of recognising the shape of objects placed in the hand is a closely allied function, as far as the sensory activities of the cortex are concerned. But, whereas graduated weights can be applied to each separate finger, it is impossible to use the tests for appreciating shape in this way. In order to prove that these tests fall into the same sensory group as those for weight, from the point of view of cortical activity, we are compelled to fall back upon cases where, at any rate, a considerable part of the palm is affected as well as the digits. The patient is then allowed to roll the solid objects of different shape between the fingers and the palm.

On running through the records of my series of cases, it is at once apparent that recognition of form in three-dimensions rises and falls *pari passu* with the power of appreciating the relation of two weights; when the one aspect of sensory discrimination is disturbed, the other is also affected. Thus, No. 18 had lost all power to recognise the shape of solid objects rolled between his thumb, index, and palm, and could not recognise addition or subtraction of weights, although appreciation of passive movement was not affected, and the tactile threshold was but slightly raised. Conversely, in No. 14, recognition of form and weight was perfect, although the power of appreciating measured movement and the tactile hairs was obviously defective.

Throughout this research, I have used wooden figures cut to scale, and of six different geometrical shapes. Their size was such that they could be easily recognised in the normal hand, if the patient were sensitive and intelligent, even when rolled over the palmar aspect of the fingers.

It is unfortunately impossible, clinically, to use several sets of solid figures of different sizes in order to test appreciation of form; for the time required to make so long a series of observations would be too great, and in most cases they would end in confusion on the part of the patient: this must be avoided even at the cost of reducing the measurable aspect of the test. Should this faculty of recognising the form of objects be diminished, but not entirely lost, our method does not enable us to work out a threshold, as was the case with weights; the results are purely relative, and cannot be expressed numerically. But when the disturbance is extreme, the patient not only says he has no idea of the form of the geometrical figures we habitually use, but he may also fail to recognise the shape and nature of common objects such as a knife, coin, or pencil placed in his hand. This is the well-known condition usually called "astereognosis."

The power of recognising stuffs by their difference in texture also belongs primarily to this group; it is closely associated with ability to appreciate differences in weight and form. But this aspect of the test presupposes perfect tactile sensibility. If touch is vague and uncertain, it is obvious that the patient will not be able to recognise the characteristics of the stuff beneath his fingers as readily as with the normal hand, and so will fall into mistakes that have nothing to do with the power of appreciating similarity or difference. The relation of this test to those for the recognition of weight and form can only be established in cases where tactile sensibility is perfect.

Fortunately I have examined one such instance of this dissociation in an extreme form (No. 16). Touch was nowhere disturbed, but the patient was unable to distinguish velvet, silk, flannel or cotton anywhere over the affected hand. He had also lost the power of recognising differences in weight, whether the hand was supported or free to move, and had no idea of the shape even of common objects placed in the palm. Thus, provided tactile sensibility is normal, it is possible to show that the recognition of differences in weight, form and texture is the expression of one aspect of cortical activity.

A striking example of this law is seen in the case of No. 3, where all the digits were not in the same condition (*vide* table). Tactile sensibility was everywhere normal, but the three tests, weight, form and texture, showed considerable loss over the little, ring and middle fingers. Appreciation of measured movement was disturbed to a greater or less extent over the whole hand.

	Weight.	Texture.	Form.	Tactile hairs.	Measured movement.
Thumb ...	Perfect ...	Perfect ...	...	Perfect ...	Introspective (1° perfectly)
Index ...	,, ...	,, ...	Normal ...	,, ...	Affected (2°–3°)
Middle ...	Defective	Defective	,, ...	,, ...	,, (2°–3°)
Ring ...	Gross loss	Gross loss	Complete loss	,, ...	,, (3° badly)
Little ...	,, ,,	,, ,,	,, ,,	,, ...	,, (not under 5°)

The tests we have considered in this section show that the power of discriminating differences in external objects, apart from the intensity or spacial attributes of the sensations they evoke, is a fundamental function. It is not secondary to the due appreciation of some other sensory quality, such as touch or spacial projection. This is strictly true of the discrimination of weight and form, but full recognition of differences of texture is only possible, when tactile sensibility is also unaffected.

All these tests, the weights, the different shapes in three dimensions and stuffs of various textures, demand the same power of discrimination. Some offer a more difficult task than others, but they do not stand to one another in a graduated scale of difficulty like the three tests for spacial recognition, or the tactile, thermal and painful stimuli we have employed in this work. In cases where they can all be employed in consequence of the whole hand being affected, they are usually found to fail together. Tests capable of measurement, such as those for weight, obviously reveal a slighter degree of change than those which consist in the recognition of certain fixed shapes or textures; for, in this latter group, the patient has simply to appreciate the nature of an object whose character cannot be varied.

In conclusion, there can be little doubt that the faculty of recognising the similarity and differences of objects brought into contact with the body depends upon one of the fundamental activities of the sensory cortex. It can be disturbed apart from the power of appreciating spacial relations and independently of the reaction to stimuli of varied intensity, or it may be preserved, when these two functions are grossly defective.

§ 5.—Analysis of the Tests which depend upon more than one of these three Cortical Activities

So far, I have treated each of these sensory tests as if it made a specific appeal to one of the three aspects of cortical activity. This is manifestly an incomplete statement of the case. For, if the physiological workings of the cortex endow sensibility with relations in space, intensity, and individual character, it is obvious that these functions will be exercised on all afferent materials presented to its action.

There are but few tests which do not depend in some way on the appreciation of contact, and wherever tactility comes into action the question of its spacial relations, intensity or characteristics must of necessity arise. But, in the preceding sections of this chapter, I have attempted so to select my instances that the particular test in question shall give, as far as possible, an uncomplicated answer. Thus, when discussing spacial sensibility, I have chosen cases where the power of appreciating graduated intensity was little affected. In the same way, the capacity to recognise various stuffs by their texture was treated as if the condition of tactile sensibility played no part in the test.

It was necessary to adopt this deliberately partial standpoint in order to elucidate the nature of the sensory activity of the cortex. For it is obvious that the simultaneous compass test depends on the integrity of tactile sensibility; at lower levels of the nervous system it is often impossible to apply this test, because the patient cannot appreciate any tactile stimulus, however intense. Even with a less complete interference, the impression made by contact may be so feeble that the patient does not receive the afferent materials necessary for discrimination. Under such conditions the compass records would show little more than the effect of the loss of touch. But we have many better methods for measuring defects in tactile sensibility, and the true value of the compass test lies in the fact that it is the best means at our disposal for exploring two-dimensional discrimination.

By careful selection of cases it is possible to find specific instances where each of the tests we have used exhibits the changes in one only of the cortical activities on which it depends. But, from the point of view of the general facts presented by cerebral lesions, such exclusion is wasteful and inconvenient. It behoves us, therefore, to discover, if possible, some peculiar feature of the records of each of these tests which will reveal the particular activity at fault. In many cases two or even three of these activities may be defective; here the records will show the profoundest changes, but they are useless for that analysis upon which we are intent in the present section.

In a recent paper, Graham Brown and Stewart [13] put forward their views on disturbances of localisation and discrimination in cases of cerebral lesions; their results were based on a long series of observations mainly on one patient, but the conclusions to which they arrived are of the greatest interest. They believe that a sensation of touch has three attributes—its character, individuality and position. Every sensory effect produced by a touch must evoke a state different from that conditioned by all other tactile stimuli; this is its "character." But each sensation of touch must resemble all those arising from stimulation of the same spot, and this is what they call its "individuality." But, apart from this individual similarity to others that have preceded it, a touch has definite "position." The two authors then analyse along these lines their experiments on topical localisation and discrimination of the compass points.

My observations are not extensive enough, and the tests I have used are relatively too coarse, to permit any criticism of their results. My method of attacking the problem differs from that by which they reached their results. I have attempted, by ranging widely over a number of suitably selected cases, to discover conditions where the various factors in cortical activity were dissociated; thus I have been able to observe the behaviour of the patient under simultaneous application of the compass points, when other spacial tests were affected, but tactile sensibility was perfect. Conversely, these results were compared with the compass records obtained when spacial recognition was normal, but there was grave want of response to tests of graduated intensity. In this way, certain general rules have emerged, which I shall proceed to consider more in detail under the heading of each separate test.

(*a*) *The compass test.*—This test above all others is liable to be disturbed by inequalities of tactile appreciation. It is essentially a measure of the power of discriminating two points applied simultaneously. If, however, the two contacts evoke sensations of different and inconstant intensity, in spite of the most careful application, the patient will have difficulty in making up his mind as to whether he has been touched with one or two points, and yet from other tests it may be unlikely that the spacial aspect of sensation is disturbed.

From the records of selected instances, where in the one case spacial recognition was affected, but tactile sensibility was perfect, and in the other the condition was reversed, I think it is possible to enunciate the following general rule. So long as the power of reacting uniformly to touches of graduated intensity is not impaired, defects in two-dimensional discrimination show themselves in a tendency to speak of both single and double contacts with the compass points as "one." Thus, according to the method we use for recording the results of this test, errors will be plentiful in the lower line, because many "twos" are called "one," whilst the upper line will be almost clear, because there is an habitual tendency to call all contacts "one."

On the contrary, if the appreciation of tactile stimuli is inconstant, as shown by the answers obtained to the tactile hairs, the compass records will have a different appearance, provided spacial recognition is not affected. Just as many errors may appear in the upper as in the lower line; one contact is called "two," and two are said to be "one" with almost equal frequency. Moreover, a considerable increase in the distance between the points may make little difference in the number and proportion of these mistaken answers.

Let us first of all consider the case where the appreciation of tactile intensity was not disturbed. No. 3 is a good example of such a condition. The left hand was alone affected and all five digits showed some want of recognition of passive movement. Tactile sensibility was, however, remarkably good; a hair of 21 grm./mm.^{2} gave perfect records over the palmar aspect of all the terminal phalanges and the patient could discover no difference in the sensation evoked from the two hands. It was obvious, therefore, that if discrimination of the compass points was defective the disturbance must have been mainly due to want of spacial recognition in two dimensions. The compass records were perfect over the thumb, index, and middle fingers; but over both ring and little fingers every application, whether of one or two points, was called "one," even when they were separated by a distance of 5 cm. Moreover, the patient added, "I feel the pressure but I can't be certain that it is two. It doesn't feel like it does on the other fingers."

The progressively increasing disturbance of the compass records over the little, ring and middle fingers in No. 22 is another striking example of the loss of two-dimensional discrimination. All the digits reacted constantly to a hair of 21 grm./mm.^{2}, as on the normal hand; the only change on the middle and ring fingers was an introspective one, and even this abnormality was absent from the little finger. Here the two hands reacted alike to a hair of this bending strain. The records of the compass test worked out as follows on the three fingers :—

Little finger—				
	0·5 cm.	1	10 Right.	0 Wrong
		2	7 Right.	3 Wrong
	1 cm.	1	10 Right.	0 Wrong
		2	10 Right.	0 Wrong
Ring finger—				
	2 cm.	All called "one."		
	3 cm.	1	10 Right.	0 Wrong
		2	7 Right.	3 Wrong
	4 cm.	1	10 Right.	0 Wrong
		2	10 Right.	0 Wrong
Middle finger—				
	3 cm.	All called "one"		
	4 cm.	1	10 Right.	0 Wrong
		2	2 Right.	8 Wrong
	5 cm.	1	10 Right.	0 Wrong
		2	3 Right.	7 Wrong

Here we see a steadily increasing tendency to call all the contacts "one" at wider distances, as we pass from finger to finger towards the centre of the disturbance.

The account obtained from intelligent patients confirms the conclusions drawn from examining the records. They complain that they cannot feel the difference between one and two points. "I don't feel two as I do on the other fingers," said one of them in whom tactile sensibility was little, if at all, disturbed. "I have to stop and think how big the feeling is; sometimes it seems over a larger area, and then I say 'two.' I don't really know at all." This is the secret of this form of change; it is an "agnosia" of greater or less intensity.

When, on the contrary, the records of the compass test are disturbed by a defective and inconstant reaction to graduated tactile stimuli, the records exhibit a constant confusion. As many single touches may be said to be "two" as double contacts are recorded as "one." For example, in No. 18, passive movements were perfectly appreciated in all the digits, but the compass test yielded defective records over the thumb, index, and middle fingers. This coincided exactly with the extent of the disturbance of tactile sensibility; for, over the thumb, he did not give a perfect series of answers with any hairs of less bending strain than 35 grm./mm.^{2}, whilst over the index finger even 100 grm./mm.^{2} yielded a series in which he failed to appreciate six out of sixteen consecutive contacts. Over the middle finger, the condition was somewhat better, and he responded to 23 grm./mm.^{2}, which is still considerably above the pressure to which he reacted well on the similar digit of the normal hand.

Bearing in mind this defective reaction to contacts and the complete absence of any loss of spacial recognition, the following compass records form a pronounced contrast to those given in detail above.

Thumb—				
	1 cm.		All called "one"	
	3 cm.	1	6 Right.	4 Wrong
		2	6 Right.	4 Wrong
Index finger—				
	1 cm.	1	5 Right.	5 Wrong
		2	4 Right.	6 Wrong
	3 cm.	1	4 Right.	6 Wrong
		2	8 Right.	2 Wrong
Middle finger—				
	1 cm.	1	7 Right.	3 Wrong
		2	6 Right.	4 Wrong
	3 cm.	1	6 Right.	4 Wrong
		2	6 Right.	4 Wrong
Ring finger—				
	1 cm.		Perfect record	

No. 15 gave a striking demonstration of the same sort of defect. By a remarkable chance, a wound of the vertex had disturbed the power of recognising passive movement in the left foot, and here also two-dimensional discrimination was somewhat defective. Touch was in every way normal. Conversely, over the right foot tactile sensibility was grossly affected, but passive movements were perfectly appreciated. The contrast between the compass records on the two feet is most instructive.

Right Sole (tactile loss).

3 cm.	1	6 Right.	4 Wrong
	2	5 Right.	5 Wrong
4 cm.	1	6 Right.	4 Wrong
	2	5 Right.	5 Wrong
6 cm.	1	7 Right.	3 Wrong
	2	4 Right.	6 Wrong
10 cm.	1	10 Right.	0 Wrong
	2	10 Right.	0 Wrong

Left Sole (spacial loss).

3 cm.	1	10 Right.	0 Wrong
	2	6 Right.	4 Wrong
4 cm.	1	10 Right.	0 Wrong
	2	9 Right.	1 Wrong

The patient complained that on the right sole he found great difficulty, "because they all seem to run into one another. The touch seems to linger on here; it is difficult to find out if it is the one you put on last, or if it is two together."

Here a slight defect in two-dimensional discrimination on the left foot led to some double contacts being mistaken for single ones, whilst on the right sole the tactile loss resulted in confusion, evident in the records both of one and of two touches.

(*b*) *Topical localisation* ("spot-finding").—The method we have used for testing the power of one-dimensional localisation is a comparatively coarse test, and allows a considerable margin of possible error. Moreover, the results cannot be expressed numerically. The patient is told that he will be touched over the various digits between the joints and that he is to indicate the exact spot on the hand of an assistant. The normal hand is first tested, so that he may understand what is required of him. This also enables us to judge of his natural aptitude and trustworthiness, before undertaking exploration of the affected parts. Any answer that lies over the correct phalanx is recorded as a successful response, and thus the margin of error may be nearly a centimetre distal or proximal to the spot actually touched.

Then, too, in contrast with the long series of experiments of Graham Brown and Stewart, I have as a rule made no more than six observations on any one finger, a number utterly insufficient for any conclusion, except that topical localisation was or was not affected. Each digit was then carefully re-tested for the appreciation of two points applied consecutively, which has been shown elsewhere to be a closely analogous function.

But, by selecting cases in which the various sensory activities of the cortex were dissociated, it has been possible to reach a definite conclusion. In this I have been greatly aided by the patient's own account of his difficulties.

In No. 3, the reaction to graduated tactile stimuli was perfect, but the three-dimensional aspect of sensation was disturbed in all five digits, reaching a maximum in the ring finger. I therefore chose the palmar aspect of the four post-axial digits for a more extended series of observations on topical localisation. A tactile stimulus was planted on each phalanx in irregular order and the patient indicated on the hand of an assistant the position of the spot touched. Twelve contacts were made, first on the normal and then on the affected side; this was repeated three times on each hand to the number of seventy-two observations in all. Every touch on the normal hand was correctly localised, but the answers from the fingers of the affected side showed a defect increasing in the post-axial direction. Thus, whilst all nine stimuli were correctly localised over the left index, he made one mistake over the middle, two over the ring and six over the little finger. Of these six errors, one was placed on the wrong digit, three were more or less distal, and two were proximal to the spot stimulated. Two out of three mistakes on the middle and ring fingers consisted in choice of the wrong digit.

This inability to decide which digit had been touched was strikingly evident in No. 22. The maximum point of the sensory disturbance was the middle finger, but in the thumb, index, ring, and to a slighter degree the little finger, he had difficulty in appreciating passive movement. Now, whenever he was asked to localise a touch over the three middle digits, his answers were slow and hesitating. He moved them backwards and forwards as if he was playing the piano, and then indicated the spot on my assistant's hand which he imagined I had touched on his own, lying hidden from his sight. He said, "I couldn't tell which of the three fingers it was accurately: but, when I moved them, then I could tell." As a matter of fact, he was not always accurate, even in his selection of the finger that had been touched.

In another patient (No. 19), there was some loss of appreciation of passive movement in all five digits, reaching a maximum over the little finger. The tactile threshold was just perceptibly raised over the ring and little fingers; but the defect was extremely slight, and would not have been measurable, had he not been unusually sensitive over similar normal parts. But his power of localising a touch was obviously defective. His answers were slow, and the tone of his voice gave a better idea of his state of doubt than the actual records. He said, "I have difficulty in making up my mind whether you are touching me on the little or ring finger." Out of eight contacts, two were wrongly placed, and, with two others, he said he did not know on which finger they lay, though he finally chose correctly. When the compasses were applied consecutively with the points separated by a distance of 0·5 cm., he gave one false and one doubtful answer out of ten double contacts on the little finger: on the ring finger, he found "it was a great effort to decide whether it was one or two," although he ultimately made no mistakes.

Thus it would seem that, when localisation is defective, because the spacial element in contact sensibility is disturbed, the error takes the form of inability to decide on what finger, or on what part of it, the touch has fallen.

This is a great contrast to the condition discovered in the thumb of No. 9. I have chosen this digit, because here the power of recognising passive movements was not affected, as it was in the index and middle fingers. The tactile threshold was raised, so that he did not give a perfect series of answers to any hair under 100 grm./mm.^{2}. He had no doubt which digit had been touched; but he passed his indicating finger up and down, saying, "It was somewhere on the thumb. I can't say where." The thumb, the index or the middle finger were at once named correctly as the site of the stimulus, but he indicated vaguely the situation of the contact by rubbing his finger along the assistant's hand, or in four out of eight observations brought it to rest at some more proximal point. Some of these patients say, "The spot seems to be spread out, so that I can't exactly say what part of it you have touched."

Such a condition is in exact harmony with the change in contact sensibility discovered by testing with the graduated hairs. Not only does the touch seem to persist long after the hair has been removed, but it seems as if "something was being dragged across the hand; as if a mosquito was dragging its leg along, not in the least as if you were touching me at one point only." This is the type of disturbance discovered when localisation is disordered by a defective reaction of the part to contact stimuli. The touch seems to be spread out, and may be translated into a sensation of movement across the surface.

(c) *Texture.*—The power of recognising various stuffs by feeling them with the fingers is obviously dependent on the accuracy of tactile impressions. But there is another aspect of this test, which demands the same faculty of appreciating essential similarity and difference underlying the recognition of weight and form. This appeal to two sides of cortical activity can be demonstrated by choosing suitable cases of sensory dissociation. If tactile sensibility is perfect, whilst the tests with various weights and shapes are manifestly affected, the power of recognising stuffs by their texture will be disturbed in one direction; another sort of defect is found where touch is impaired, and weight and shape can be appreciated without fail.

No. 16 was a characteristic example of the first condition, the more striking because the whole hand exhibited this form of dissociation. Here, then, was none of that difficulty so often experienced when some fingers are affected, and others are not; the various stuffs could be frankly placed in his hands, and he could handle them freely in the natural manner. The index and little fingers of the two hands responded to a hair of 14 grm./mm.^{2}, and the palms to one of 21 grm./mm.^{2}, showing that tactile sensibility was in no way defective. He was allowed to take each of the following stuffs into his affected hand and to palpate it as he might desire. It was then transferred to the normal hand. Flannel in the left (affected) hand was said to be "something rough," but was recognised at once on the other side. Silk was said to be "smooth, silky," but was called silk in the normal hand; corded velvet and cotton were thought to be "something rough" on the affected side, though recognised as "corded stuff" and "cotton" over normal parts. When a piece of corded velvet was placed in the two hands at the same time, he said: "They are quite different stuff. The piece in the right (normal) hand is corded; it feels rougher and thicker. The piece in the left hand seems smoother and more like calico: I don't think it is silk."

It was not, however, the smoothness and roughness that were not appreciated, but the essential difference which enables us to give each textile material its specific name. It was, in fact, an "agnosia." This view is borne out by the character of his answers to the tests for the recognition of form and of common objects. In every case, with the wooden blocks in the left (affected) hand, he said, "I don't know," though they were perfectly recognised on the normal side. He had no difficulty in naming correctly a knife, penny, sixpence, and scissors in the right palm, but said, "I don't know," when the same objects were placed in the left.

In No. 3, the perfect retention of tactile sensibility made it possible to show how the loss of recognition of weights and textures runs parallel in the three affected fingers.

	Addition and subtraction of weight.	Texture.
Thumb	Perfect. (No mistakes in 12 tests) ...	Perfect recognition.
Index	Perfect. (No mistakes in 12 tests) ...	Perfect recognition.
Middle	7 right and 5 defective answers ...	2 wrong out of 4. Velvet called "calico," cotton called "flannel."
Ring	5 right and 7 defective answers ...	3 "don't know." Flannel named correctly.
Little	Gross loss. Inability to tell if there was weight on the hand or not.	Gross loss. "Something rough; I can't determine what it is," was his answer to each of the 4 stuffs.

Contrast this progressive agnosia with the series of answers given by No. 13. In this case, there was no difficulty in appreciating the relation between weights, but tactile sensibility was distinctly affected in the same fingers where recognition of texture was disturbed.

	Tactile hairs.	Texture.
Thumb	Perfect record with 21 grm. mm.² R. and L. Not quite perfect in either thumb with 14 grm. mm.².	Perfect answers. No difference between the two hands.
Index	Perfect record with 14 grm./mm.² R. and L.	Perfect answers. No difference.
Middle	Perfect record on the normal hand with 14 grm. mm.²; imperfect record on affected hand. With 21 grm. mm.² he gave a perfect record R. and L. but said it was "clearer" on the normal side.	All answers correct, but he said, "It is more difficult on R. (affected), because it is not so sharp, it is duller."
Ring	Perfect record on the normal hand with 14 grm. mm.² Defective answers on the right hand with all hairs of less than 23 grm./mm.². He said, "It doesn't feel like a sharp point at all. It is as if you were touching me with your finger."	None of his answers were quite correct. He said, "I can tell it's a bit of cloth, but can't tell if it is rough or smooth in the R. hand so well as in the L."

Patients, in whom the loss of recognition of texture belongs to this class and is associated with want of tactile sensibility, usually attempt to name the stuff placed in their hands; but they frequently add some explanation of the difficulty they recognise in determining the character of the material. They say, for instance, "That is cotton, I think, but I can't feel it so well as in the other hand." "I can always feel the silk, but it is with the rougher materials that I have difficulty."

I think, therefore, that we are justified in concluding that the test for the recognition of various stuffs by their texture depends on two factors in cortical activity: firstly, on the power of appreciating similarity and difference, and, secondly, on an orderly response to contacts of graduated intensity. In the one case, the patient's answer approximates more or less to, "I don't know what it is," whilst in the other he has a greater tendency to hesitate and to be puzzled by the curious sensory differences in the two hands; generally, however, he makes a guess, which would be recorded as a normal answer were it not for the explanation with which it is so frequently qualified.

CHAPTER V

SUBCORTICAL LESIONS

We have analysed elsewhere the effect produced by a subcortical lesion on sensation (p. 594), and such conditions do not materially concern the aims of the present paper. But it is obvious that many gunshot wounds of the brain must injure, more or less severely, other parts than the cortex; some of the signs which appear, even in such carefully selected cases as those I have chosen for my examples of cortical interference, may be due to disturbance of deeper structures. It is necessary, therefore, to consider shortly those differences in response to the various sensory tests which point to subcortical interference with afferent impulses. Then only will it be possible to determine, in any particular case, the extent to which the disturbance of sensation is due to more superficial or deeper destruction.

The following general rule can be laid down from a study of undoubted subcortical injuries, which have spared both the receptive and essential organs of the optic thalamus. Whenever a stimulus can be appreciated, a threshold can be obtained. For we are dealing with the results produced by interference with incoming impulses, and not with destruction of their receptive centre.

The closer the lesion lies to the internal capsule, the more extensive is usually the loss of sensation, and the more certainly does it tend to assume a hemiplegic distribution. Face, arm and leg are all more or less affected, although one part, such as the hand or foot, may be more gravely disordered than the rest of that half of the body. Thus, although we cannot attribute such cases as I have described in this paper, in every instance, to uncomplicated cortical lesions, we can be certain that they are not due to injury of the afferent fibres of the capsule.

Secondly, the loss of sensation is extremely severe, compared with that caused by more superficial injuries. Stimulation with cotton wool can be appreciated over hair-clad parts, but not over the palm of the hand, or the sole of the foot; for it must be remembered that movement of the hairs makes a potent thalamic appeal. Should either of these parts retain some sensibility to measured tactile stimuli, there is none of that uncertainty seen in cortical cases; the patient does not respond to contact of the lighter test-hairs, and each increase in strength is associated with a progressively larger number of correct answers.

The loss of appreciation of posture and movement is often so severe, that the patient not infrequently fails entirely to recognise the position into which the limb may have been moved passively. When he wakes at night, he has no idea where to find the affected parts, although he is still conscious of the existence of his hand or his foot. Should the disturbance be less severe, the threshold will be raised, but the range of movement required to excite a response can be measured with greater accuracy than is the case with a cortical lesion. Thus, from 15° to 20° may be required before a movement is appreciated, instead of 1° as on the normal side; but all the ten measurements may fall between these limits, instead of ranging widely from 10° to 45°, accompanied by errors of direction and hallucinations, as is so common with injuries of the cortex.

The compass test usually suffers severely from the coincident disturbance of spacial and tactile impulses. Even when the points are separated to the widest extent possible within one segment of the limb, every application is said to be "just a touch: they are all the same." Contact is appreciated, but contains no element of "oneness" or "twoness."

Topical localisation is gravely defective, as might have been expected from the other aspects assumed by the sensory loss. Here I believe there is a definite tendency to indicate the site of the stimulated spot, not only on wrong digits, but proximally to its true situation. In one case, out of fourteen contacts on various parts of the fingers and thumb, one only was correctly localised; all the others were referred too low upon the digits or to some spot on the dorsum of the hand.

Ice and water at 50° C. can be appreciated without fail in uncomplicated cases of capsular injury, but, not uncommonly, are thought to be "colder" or "hotter" on the affected side. There is, however, no widespread over-reaction so characteristic of lesions that have entirely freed the thalamic centre from cortical control. The loss of thermal sensibility is shown by the want of response to such temperatures as 24° C. and 38° C., and all that lie between them. Upper and lower limits vary in each case, but it is the central portions of the thermal scale that are affected.

The threshold for measured prick is not infrequently somewhat raised; even if it happens to be the same on the two sides, the stimulus is said to be "less sharp" or "blunter" over the affected than over normal parts.

All such faculties as the power of appreciating weight, form, size and texture are lost. The patient can tell when a weight has been added or removed carelessly, so as to produce a jarring contact; but he cannot tell if the remaining pile is lighter or heavier in consequence of the manipulation. He is also conscious that some of the blocks, used in exploring his appreciation of form, have sharp edges and some have none; but he is unable to recognise that they have any shape. Occasionally he knows that some of the tests for texture are rougher, and some are smoother, but he has no idea of their nature.

Here we see the effects of interrupting afferent impulses on their way to the cortex after the point at which they can influence the essential organ of the optic thalamus. In such cases, there is almost always a coincident affection of the pyramidal tract, usually accompanied, at any rate, in the later stages, by some spastic rigidity.

Such a clinical picture differs profoundly from that of the cases on which this paper has been based, both in the character and distribution of the loss of sensation. But it helps us to understand the form assumed by the sensory disturbance when subcortical tissues are affected by the injury, with or without destruction of the grey matter on the surface.

Now it sometimes happens, that a gunshot wound of the skull strikes some part of the brain, outside the primary motor and sensory centres and passes backwards or forwards amongst subcortical structures. Provided the destruction of tissue is limited, and the wound heals well without the formation of a cerebral hernia, it may be possible for the sensory disturbances on the hand to be unequally distributed over the various digits; and yet the character of the reaction to the various tests shows, that the cortical centres have not been destroyed. The character of the loss of sensation is still that which we have learnt to associate with blocking of afferent impulses.

No. 6 was a superb example of this condition. He was wounded on July 3, 1916, in the frontal region well in front of the motor area. I saw him first a fortnight later; but it was in March, 1918, that I had the opportunity of making the extensive series of observations on which are based the following conclusions. At that time, the various digits of his right hand reacted to the measured sensory tests in the following manner:—

	Little finger.	Ring finger.	Middle finger.	Index finger.	Thumb.
Measured movement ...	15° to 20° ...	10° to 20° ...	7° to 10° ...	5° to 10° ...	2° to 3°
Compass test ...	1 cm.	1 cm.	1 cm.	0.5 cm. slower	0.5 cm. "Not so sharp."
Localisation ...	Not affected ...	Not affected ...	Not affected ...	Not affected	Not affected.
Tactile hairs ...	Defective series, even with 110 gr./mm.²	Threshold 110 gr./mm.²	Threshold 70 gr./mm.²	Threshold 35 gr./mm.²	Threshold 35 gr. mm.²
Thermal ...	Total want of discrimination	3 out of 4 wrong	2 out of 4 wrong	Perfect ...	Perfect.
Prick	9 grm.	7 grm.	7 grm.	6 grm. ...	3 grm. Normal.
Weight ...	7 out of 12 not appreciated	5 out of 12 not appreciated	Affected ...	Affected ...	Normal.
Form	Defective ...	Defective ...	Hesitation; named correctly	Good ...	Good.
Texture ...	Complete want of appreciation	3 out of 4 not appreciated	Introspective change	Introspective change	Introspective change.

Sensory Condition of the Right Hand in a case of Subcortical Lesion (No. 6).

From this table it is obvious, that the sensory disturbance became steadily worse on passing from the thumb in the direction of the little finger. But it is to the character of the reactions, rather than to the distribution of the defective sensibility, to which I am anxious to call attention. On any one finger, the highest and lowest number of degrees necessary for the appreciation of passive movement lay much closer to one another than is the case in pure cortical lesions. It was possible to obtain a true threshold in each digit, unhindered by those inconsequent irregularities and hallucinations of movement which so frequently mar the records in most of the examples illustrating this paper. Throughout the whole series of fifty observations on the various digits, there was but one instance of wrongly named direction; whereas, in cortical cases this is one of the most frequent errors.

Perhaps the most striking difference between the reactions of this patient and those we have noticed in cortical cases was exhibited by the tactile hairs. Not only did the loss of sensibility increase digit by digit with strictly measurable increments, but in every case it was possible to obtain a threshold. Compare such a record as that from the index, ring, or little finger with those obtained in No. 17 (p. 675). To the lighter hairs he made no response; then, as the strength of the stimulus was increased, he began to appreciate the contact, until, with some one of the hairs of sufficient bending strain, a complete series of answers was obtained. We had then passed the maximum threshold. Even on the little finger, where the response was imperfect to the strongest hair that can justifiably be employed, we can trace the steady improvement in the record with each increase of intensity.

	Right (affected).	*Left (normal).*
Index finger—		
14 gr. mm.^{2}	—	i i i i i i i i i i i i i i i i
14 ..	No response	
21 ..	o o o o o o o i o o o o o i o o	
23 ..	o o i o i i i i i i i i i i i i	
35 ..	i i i i i i i i i i i i i i i i	
Ring finger—		
14 gr. mm.^{2}		i i i i i i i i i i i i i i i i
14 ..	No response	
21 ..	..	
23 ,,	o o o o o o o o o i o o o o o o	
35 ,,	o o o o o i o o i o o i o i o o	
70 ..	i i i o o i i i o o i o o i i i	
110 ,,	i i i i i i i i i i i i i i i i	
Little finger—		
14 gr. mm.^{2}		i i i i i i i i i i i i i i i i
14 ,,	No response	
21 ..	..	
23 ..	..	
35 ..	o o o i o o i o o o o o o o o o	
70 ..	o o o o o i o i o o i o o i o o	
110 ,,	o i i i o i i o o o i o o i o o	

The records of the tests for appreciation of weight, form, and texture also differed fundamentally from those to which we are accustomed in cases of uncomplicated cortical lesions. When weights were added or subtracted in irregular series, he first complained that it was "not so easy" on the affected finger; then a greater defect was shown by a tendency to miss the removal of a weight, although he did not fail to recognise its addition to the pile. Finally, on the little finger he did not respond to seven out of the twelve additions and subtractions.

The appreciation of texture ran *pari passu* with tactile sensibility, and all the statements of the patient pointed to a strict relation between the two defects.

Recognition of form was, however, perfect in the thumb and index finger; it nowhere showed the gross loss that would have accompanied so considerable a disturbance of the appreciation of weight, had the lesion been cortical.

One of the most striking features was the steadily rising threshold for measured prick, on passing from the thumb towards the little finger. This phenomenon is dealt with in the next chapter.

Another significant aspect of this case, was the affection of the foot. Had the patient suffered from an uncomplicated cortical lesion producing the graded loss of sensibility on the hand, it is unlikely that the lower extremity would have suffered; or it would have formed the central focus of the disturbance to which the condition of the hand was an insignificant accessory. The wide extent of the affection of sensibility, eighteen months after the wound was healed, associated with the comparative slightness of the disturbance at any one part of the field, point to an interference with afferent impulses on their way to the cortex, rather than the destruction of cortical centres.

These records prove that the permanent effect of a high subcortical lesion on sensation is shown by straightforward raising of the threshold rather than by irregular, inconsequent, and uncertain responses. Impulses, which can pass the block, give rise to normal sensations; the patient reacts to the graduated intensity or changing character of the stimulus, whatever its nature.

The closer a subcortical injury lies to the surface of the brain, the more nearly does the character of the sensory loss approximate to that produced by lesions of the grey matter. But the grouping of the disturbed sensibility always tends to diverge more or less from the three categories: recognition of spacial relations, reaction to graduated intensity, and appreciation of the character of the stimulating object. For afferent impulses still remain grouped according to their sensory quality, until they have been subjected to the transforming activities of the cortex.

In each instance of a superficial lesion of the brain, we must analyse the defects of sensation according to these criteria; a definite and orderly progression from complete insensibility to a clear supraliminal response points to subcortical interference with afferent impulses. Irregular answers, inability to come to a conclusion, hallucinations whether of contact or movement, show that the disorder is due mainly to sensory centres. In many cases, the disturbance of sensation shows both these characteristics, a high threshold and irregular response; and there is little doubt that many gunshot wounds of the brain produce their effects by destroying both cortical and subcortical tissues.

CHAPTER VI

TESTS WHICH APPEAL TO THE CORTEX AND TO THE OPTIC THALAMUS

§ 1.—Measured Prick

No test is more difficult to devise than a measurable painful stimulus. Pressure is too coarse, and is liable to harm the delicate structures of the skin. Electrical methods are too uncertain and variable in their effect, changing with conditions over which we have no control, such as the conductivity of the superficial tissues. A prick is the only effective means of applying a measurable painful stimulus.

There are, however, several reasons why it is far more untrustworthy and uncertain in its effect than any other measured test amongst those we have habitually employed. I pointed out above, when we were considering the phenomena of punctate sensibility, that the reaction of the pain-spots was extremely variable. The fact that the stimulus, to be effective, must actually puncture the skin makes a long series of observations impossible. After systematic exploration with the point of a sharp needle, the surface structures are injured. This is not the case with heat- and cold-spots, provided suitable temperatures are used in the examination.

A second difficulty arises from the fact that the first effect produced by pricking with a sharp needle is recognition of an acutely pointed object; further pressure adds to this a sensation of pain. It is almost impossible to prevent the patient from saying he is pricked, whenever he appreciates that the stimulus is a sharp point, and, if he is told to wait until he obtains a distinct sensation of pain, we run the risk of placing the threshold too high.

Now this appreciation of the pointed nature of the stimulus is a discriminative faculty which, on the lowest level, is associated with epicritic sensibility. It is bound up with the processes underlying recognition of the size and spacial extent of objects in contact with the surface, and is one of the most potent factors in controlling the diffuse and radiating responses of the protopathic stage of recovery. Thus, from its inception at the periphery, the effect produced by a prick makes a double appeal. On the one hand, the pain it evokes is a function of thalamic activity, whilst the discriminative aspect, the "sense of a point," is the product of cortical centres.

This is evident in cases where the optic thalamus has been freed from cortical control: the threshold for the discomfort produced by pressure is almost always lowered, under favourable conditions, on the affected side.

But the threshold for prick is usually somewhat raised, in spite of the great increase in the vividness of the reaction, once it is evoked. The strength of the stimulus may have to be raised from three to eight grammes; when, however, it is increased sufficiently to produce a sensation, the pain and general reaction is enormously greater on the affected side. Evidently something has been lost in acuteness of sensibility by the removal of the activity of the cortex. This is not only that "sense of the point," which has nothing to do even introspectively with pain, but consists of a certain blunting to pain itself. The threshold is raised even to the painful aspect of a prick, whilst it is lowered to the more direct discomfort of excessive pressure.

Evidently, then, the sensory effect produced by a prick owes something to the physiological activity of the cortex. But this is so small, compared with the overwhelming part played by the optic thalamus, that it can only show itself in the records when a large extent of the cortex is prevented from exercising its sensory functions. This is most easily brought about in practice by destruction of the fibres of the centrum ovale; for in this situation a comparatively small lesion can throw out of play, by undercutting, a large area of the cortex. Thus we find, that subcortical lesions, with or without destruction of the superficial centres, are liable to be associated with a distinct raising of the threshold to prick.

Pure cortical destruction, on the other hand, produces as a rule no true raising of the threshold, unless it is much more extensive than that of the examples cited in this research. It may produce change in the sensation to prick, which the patient recognises on introspection; the two hands "feel different." He says it is "plainer," "sharper," or "more distinct" over normal parts. Sometimes an intelligent patient will add in explanation, "It is more of a point" on the unaffected side; or "In the good hand it seems like a little wire sticking into me, but in the bad hand it is like the point of a blunt pencil." Sometimes the whole character of the stimulus is said to be changed; "It tingles," "It is like electricity."

Thus we can sum up as follows our present experience of the effect produced by a cerebral injury upon sensations of pricking.

(1) A gross subcortical lesion tends to raise the threshold to measured pricks distinctly, but not to an extreme degree.

(2) Injury to the cortex, uncomplicated by destruction of subcortical tissues, does not tend to raise the threshold materially. But it may produce a profound difference in the character of the sensation; this is due, in great part, to disturbance of that aspect of discrimination sometimes called the "sense of a point."

(3) Cortical activity, however, probably exercises a distinct influence even over the appreciation of the relative intensity of successive pricks. But this is so slight that it was not measurable in most of the cases of injury extending over a comparatively small area which formed the basis of this research.

§ 2.—Vibration

Disease or injury, at lower levels of the nervous system, frequently destroys all power of appreciating the vibration of a tuning fork. But so grave a loss never occurs in consequence of a stationary lesion of the cortex, unless it happens to be associated with epileptiform attacks or other causes of shock.

This is not to be wondered at, when we consider that a large tuning fork, beating strongly, is a stimulus to two aspects of sensation. First of all it produces a series of jarring contacts, which appeal to the activity of the optic thalamus; and, as a matter of fact, vibration is appreciated in many cases where the thalamic centre has been freed from cortical control, although the character of the sensation is entirely altered. Secondly, the tuning fork produces rapidly repeated movements of small range; these can be recognised, provided the appreciation of passive movement is shown to be normal by the usual method of measurement. Thus, in its two aspects, as repeated crude contact stimuli and as a series of small passive movements, vibration makes a double appeal and cannot fail to excite sensation of some kind, unless the block lies in or below the termination of the fillet.

Almost all the cases, on which this research is based, showed some definite shortening of the period during which vibration could be appreciated. Occasionally, the patient volunteered the statement that it was "plainer" or "stronger" over normal than over abnormal parts; but usually he made little comment on any introspective difference between the effect of this test applied to the two hands.

A large tuning fork, beating 128 vibrations in the second, is brought into contact with the terminal phalanx of one of the fingers, whilst the hand is fully supported on a pillow. The patient is asked to say when the vibration ceases: as soon as he indicates that it is no longer perceived, the fork is transferred to the corresponding portion of the other hand. Under normal conditions the vibration usually becomes appreciable again for a time. The period between the transference of the fork to the other hand and the moment when its beating can no longer be recognised, is measured with a stop-watch. In healthy individuals this may last from five up to fifteen seconds; but a few persons allow the fork to run down so far on its first application that it has ceased to beat before it is transferred. Both these modes of reaction are normal, provided the measured periods are approximately equal from right to left and from left to right. Thus it may happen that, in the one form of normal response, the records read as follows for four observations :—

Right to left	+ 6 sec.		+ 4 sec.	
Left to right		+ 5 sec.		+ 4 sec.

or according to the other mode of reaction,

Right to left	+ 0 sec.		+ 0 sec.	
Left to right		+ 0 sec.		+ 0 sec.

In neither instance was there any material difference between the two hands.

But, whenever sensibility to this test is diminished in consequence of a cortical or subcortical lesion, the period during which vibration is appreciated will be found to be shortened to a greater or less extent on the affected side. Transference from an abnormal part to a similar one on the other half of the body is associated with a prolonged period of renewed appreciation; but, on the contrary, moving the fork from a normal to an affected part leads to no further vibratory sensation.

The following records were obtained in No. 17 by this method.

Thumb—				
From R. to L.	+ 8 sec.		+ 9 sec.	
From L. to R.		+ 8 sec.		+ 7 sec.
Index finger—				
From R. to L.	+ 12 sec.		+ 11 sec.	
From L. to R.		+ 9 sec.		+ 8 sec.
Middle finger—				
From R. to L.	+ 10 sec.		+ 10 sec.	
From L. to R.		+ 6 sec.		+ 6 sec.
Ring finger—				
From R. to L.	+ 15 sec.		+ 14 sec.	
From L. to R.		+ 3 sec.		+ 5 sec.
Little finger—				
From R. to L.	+ 15 sec.		+ 10 sec.	
From L. to R.		+ 0 sec.		+ 0 sec.

These figures are typical of the answers obtained in the cases of cortical affection dealt with in this paper. The thumb was obviously normal, but the measurements from the index finger showed a slight shortening, when the fork was transferred from the normal to the abnormal hand. Such small differences lie within the limits of experimental variation; they would have been of no significance had not the readings from the middle finger shown the same tendency in a higher degree. On the ring finger this difference was greatly increased. Finally, over the little finger the defective sensibility to vibration appeared in its extreme form, and it was not appreciated at all when transferred from the normal to the affected hand.

Evidently the five digits were not in the same condition. The thumb was unaffected, but the disturbance steadily increased in a post-axial direction and reached its maximum over the little finger. When we compare the extent of this loss with that shown by the other means of sensory exploration, it is found to correspond exactly with that revealed by measured movement. To this test also the thumb was normal, the index was somewhat affected, and the middle, ring and little fingers showed grave loss of sensibility: no other method of examination revealed such extensive disturbance.

Throughout all these cases of cortical and subcortical injury, there is the same close correlation between the loss revealed by measured movement and by vibration, not only in the number of digits affected, but also in the gravity of the disturbance. In the one instance of my series, where in spite of other disorders of sensibility passive movements were perfectly appreciated, all the digits of the affected hand gave normal answers to vibration.

In the table on p. 713 I have combined the records of a series of cases to the two tests. The number of degrees required for recognising the direction of a passive movement are given in the upper line, whilst the shortened appreciation of vibration on the affected hand is recorded in seconds below. It will be seen how closely the extent of the loss, measured by the number of digits, corresponds with the two tests; at the same time they show a remarkable agreement in the relative degree of the disturbance on any one finger. Individual differences always occur, and it must be remembered that the two sets of records are rarely made on the same day. For a set of observations with the tuning fork must be made when the patient is fresh and free from fatigue.

Both measured movement and vibration, as we have employed it, appeal to the same aspect of cortical sensibility, but for practical purposes the former is the better test; for it is capable of revealing those curious irregularities of response, so characteristic of cortical affections, which appear in the form of hallucinations of movement and positive errors in direction. Moreover, some individuals do not give constant answers to the tuning fork, as we have applied it, and this tendency may be aggravated in cases of injury to the brain. But, on the other hand, many of the patients with whom I have had to deal in this research responded surprisingly well. They were all young and not infrequently looked upon this test as a game to be played to the full extent of their capacity; in such instances the records showed not only the graduated loss from finger to finger, but remarkable relative constancy on different occasions. But it is all important that the observations should be made alone, in a quiet room, and at the beginning, rather than at the end, of a series of sensory observations.

From the periphery upwards, a normal response to the tuning fork test has been shown to be associated with impulses arising in the deep afferent system. So long as deep sensibility is intact, vibration can be appreciated; but, during their passage through the spinal cord, all impulses arising in subcutaneous end-organs pass away into secondary tracts, with the exception of those underlying recognition of posture and movement and the vibration of a tuning fork. A suitable lesion of the posterior columns can abolish all power of responding to these tests.

But, above the point where the fillet ends in the optic thalamus, no lesion produces complete insensibility to vibration, except under conditions of neural shock. We have no right, therefore, to speak of the projection of "deep" sensibility "on the cortex of the brain." Vibration of a tuning fork is affected by a cortical or subcortical lesion, because it is one method of testing the same faculty which underlies appreciation of passive movements. The power of

Case.		Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.
No. 10	Movement	1° to 2°	5° to 7°	5° to 10°	Gross	Gross with hallucinations.
	Vibration	Shortened	12 sec.	16 sec.	16 sec.	17 sec.
No. 22	Movement	10° to 20°	25° to 40°	35° to 50°	20° to 30°	2° to 3°
	Vibration	14 sec.	16 sec.	18 sec.	12 sec.	No shortening.
No. 4	Movement	1° to 3°	3° to 5°. Errors and hallucinations	3° to 5°. Errors and hallucinations	20° to 30°	Absolute loss.
	Vibration	6 sec.	About 7 sec.	About 6 sec.	About 7 sec.	Much diminished.
No. 20	Movement	3° to 4°	15° to 25°	15° to 25°. Errors	Gross loss	Gross loss.
	Vibration	No shortening	5 sec.	9 sec. Irregular	10 sec.	12 sec.
No. 19	Movement	1° to 2°	2° to 3°	4° to 8	10 to 15°	15° to 20°
	Vibration	2 sec.	5 sec.	8 sec.	8 sec.	8 sec.
No. 3	Movement	1°. Direction bad	2° to 3°	2° to 3°. Slow	Gross loss	Gross loss.
	Vibration	7 sec.	8 sec.	10 sec.	10 sec.	10 sec.
No. 7	Movement	1°	2° to 5°	2° to 4°	2° to 4°	10° to 20°. Errors.
	Vibration	No shortening	10 sec.	10 sec.	9 sec.	15 sec.
No. 17	Movement	1°	5° to 8°	10° to 20°. Errors	10° to 20°. Errors	7° to 20°. Errors.
	Vibration	No shortening	3 sec.	4 sec.	12 sec.	15 sec.
No. 2	Movement	1°	3° to 6°	6° to 10°	5° to 8°	15° to 25°
	Vibration	No shortening	2 sec.	10 sec.	7 sec.	15 sec.
No. 12	Movement	1°	1	2° to 4°	5° to 10°	15° to 35°. Errors and hallucinations.
	Vibration	Doubtful	Injured finger	3 sec.	12 sec.	25 sec.
No. 14	Movement	7° to 10°	4° to 8°	1°	1°	1°.
	Vibration	15 sec.	15 sec.	No shortening	No shortening	No shortening.

recognising a series of minute and rapidly repeated vibratory changes is a function of the discriminative mechanism of the brain.

From the periphery to the cortex, vibration and passive movements evoke sensation or are abolished together. So far I have explained this coincident response to the two tests as a consequence of the basic similarity of the physiological changes on which they depend. For in both of them sensation is evoked by afferent impulses, caused by a series of minute passive movements. But closer consideration shows that there is a deeper cause for their fundamental identity.

Both tests depend on the integrity of the deep afferent system; but any sensory loss due to a peripheral lesion is mixed up with disturbance of other aspects of sensation, which also depend on subcutaneous end-organs. Injury to the posterior columns of the spinal cord may, however, abolish all power of recognising passive movement and vibration. Tactile sensibility is perfect; the patient can appreciate the lightest touch and frequently is able to recognise that something is happening to that part of the body which is being moved: but the tuning fork seems to him nothing more than a round flat object pressed upon the skin, and all perception of movement is absent.

Now at first sight it is difficult to see why the repeated jarring contacts of the vibrating fork are not appreciated as a succession of touches, for tactile sensibility is perfect. The manipulations used in testing appreciation of passive movement evoke a series of stresses and varying tactile impressions from joints, tendons and surrounding structures; but in order that these may yield a sensation of movement they must be recognised as an orderly sequence, tending in a certain direction. In the same way, vibration must produce the impression of a series of minute contacts consecutive in time.

Passive movements of any part of the body not only lead to changes in place, but also give the impression of duration in time; we can recognise by introspection that they are taking place in a certain direction and that they occupy a definite period; but the immediate result of such manipulations is the conviction that the limb is being moved in space. On the other hand, vibration is directly translated into its temporal aspect; it produces a series of movements of small range, which give rise primarily to the perception of a sequence in time. It is possible introspectively to recognise that the beating fork produces rapidly repeated contacts; but its dominant psychical effect is recognition of succession in time.

I should like to suggest that both these tests appeal to the same physiological functions. Such a hypothesis is rendered probable by considering the significance of vibration in the life of such a vertebrate as the fish. The organs of the lateral line, so important in the maintenance of posture, respond to vibrations of the water around, and the creature is enabled thereby to maintain its balance in a shifting medium. Here we see the close association between vibration and spacial recognition. But the highest and most perfect of these lateral line organs is the so-called "ear" of a fish. This is the exact homologue of the internal ear of man, but obviously has nothing to do with hearing in the human sense; for it is adapted to pick up and respond to vibrations in the water around. But, like one part of the internal ear in man, it is peculiarly associated with posture. Thus, from a developmental point of view, vibration and changes in posture are closely associated together, and I believe that even in man they evoke the same afferent physiological consequence.

The two forms of movement produce a sensation of orderly sequence both in space and time. But, when the part is moved in one direction passively, the dominant sensation is one of succession in space; when, however, the stimulus is a series of vibrations, we obtain the impression of succession in time. For other sensations tell us that the base of the tuning fork has remained throughout on the same spot, covering exactly the same area; attention is therefore concentrated on the time aspect of the stimulus rather than on the nature of the minute changes in posture it produces.

The corresponding physiological processes, due to vibration and to passive movement, are translated into a predominant recognition of an orderly series of changes in space or in time, according to the concomitant impulses by which they are attended. From the point of view of somatic sensation, recognition of successive movements in time and in space are the psychical correlatives of the same physiological functions.

CHAPTER VII

HYPOTONIA

It is not my intention to attempt a systematic account of the changes in tone produced by lesions of the cortex; but I cannot close this paper without describing that curious hypotonia which so frequently accompanies sensory disturbances of cortical origin. This is the condition to which Guthrie [42] has drawn attention in his paper "On Muscular Atrophy and other Changes in Nutrition associated with Lesions of the Sensory Cortex."

No. 23 was an excellent example, not only of this hypotonia, but of its concomitant phenomena. No photograph can give any but a shadowy indication of the profound difference between his two hands (see p. 787). The affected hand (left) resembled that of a woman, and was soft and rounded with delicate fingers: the right hand was that of a man capable of hard manual work. Its surfaces were squarely modelled, the palm broad and flat, and the fingers had an appearance of shortness in relation to the hand as a whole. The left hand, on the contrary, was rounded and soft; its lines were less deep. The fingers seemed to be longer and thinner than those on the normal side, although by measurement they were actually a little shorter. This illusory appearance was due to the smaller width of the left palm, which measured 8 cm., compared with 9 cm. on the right hand. The tips of the fingers were spatulate on both hands, but less so on the left than on the right. The interosseous spaces were not wasted; they seemed, however, on the affected side to be occupied by smaller and softer muscles. There was no obvious difference in the skin of the two hands, no change in colour and no cyanosis. The patient had done no manual work for four months, and both hands were white and free from corns. The difference between them was immediately evident on contact. In the act of shaking hands, the right grip was firm and well sustained; I was conscious of the elastic pressure of the contracting muscles of the palm and of the tension of the fingers: I had the feeling that, if the patient chose to increase his grasp, it might become painful. But when I gave my left hand into his, it was like the impression received from the hand of a woman. My fingers seemed to be in contact with something soft and without resistance; the pressure was orderly, but gentle and harmless.

All the digits of the left hand could be bent back passively one by one to an abnormal extent; even the thumb seemed to be hypotonic. But the fingers were not paralysed. Individual movements of each digit could be carried out, so long as the eyes were fixed upon them, and the tip of the thumb was approximated without difficulty to that of each finger in turn. But the movements were leisurely and without virility. So long as his eyes were open, the constituent parts of the affected hand remained in alignment with one another, and the thumb did not droop when the limb was extended in front of him.

But, as soon as the eyes were closed, the little finger dropped away from its position, and all the digits tended to fall out of line when abducted. There is nothing specifically diagnostic about this ataxy and defective attitude of the hand; it occurs on closing the eyes whenever the power of recognising posture is disturbed by a lesion of any suitable part of the central nervous system.

Before passing to consider in closer detail this hypotonia, which so commonly accompanies lesions of the sensory cortex, it is necessary to define the condition with which I intend more particularly to deal. Sensory changes of cortical or subcortical origin are not of necessity associated with hypotonia. In one case, the fingers may be atonic, and in another tone is not diminished, and yet spacial recognition is equally disturbed in both. The key to the difference between the two groups lies in the presence or absence of coincident affection of the motor mechanism. If the disordered sensation is associated with inability to carry out individual movements of the fingers, tone may be normal, or is, at any rate, not diminished apart from gross paralysis. The deep reflexes of the affected limb are usually somewhat increased. Both these defects point to some primary disorder of the motor mechanism additional to, and not consequent on, the disturbance of sensibility.

Now my principal interest in this paper is with those cases where none of these accessory motor or reflex signs were present, and yet hypotonia existed in a distinctive form. For under such conditions the loss of tone is distributed according to the gravity of the sensory loss.

But the hypotonia does not depend indifferently on all aspects of want of sensibility, nor on the incidence of the maximum general disturbance; it is associated peculiarly with defective appreciation of posture and passive movement.

This cannot be proved by such cases as No. 23, for the sensory defects were too widely distributed over the affected hand. But in the case of Lieut. J. [No. 15] the various aspects of sensation were disturbed independently in the two feet, owing to a wound of the vertex. On the right side all spacial tests were well recognised, but tactile appreciation was grossly affected. Here tone was not disturbed. In the left foot, however, the spacial aspects of sensibility were measurably affected, and the great toe was profoundly hypotonic. It could be pushed backwards to such an extent that it came to form less than a right angle with the line of the dorsum of the foot, whilst the right great toe could not be brought up to subtend an angle of less than 120°. In this case, sensation was disturbed on both feet in consequence of a cortical lesion, but the hypotonia was on the side of the loss of spacial appreciation.

Not only is the tonic condition of the hand as a whole dependent on the state of spacial appreciation, but this is true for each individual digit. I have shown that the different parts of the hand may be in a very different sensory condition; some fingers may be grossly affected, whilst others exhibit no change of any kind.

The following table has been constructed to show the close association between the condition of spacial sensibility and the tonic state of the various parts of the hand. The most delicate indication of disturbed appreciation in space is the power of recognising passive movement. This has been recorded in degrees for each digit in turn and the condition of tone indicated below. It is at once obvious how closely the two physiological states are associated with one another: the fingers, where the loss of spacial sensibility is profound, are at the same time those which are hypotonic.

TABLE A

HYPOTONIA PRESENT

Case.		Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.
No. 23	Measured movement	10° to 20°	10° to 15°	20° to 30°	15° to 25°	20° to 30°
	Hypotonia	+	+	+	+	+
No. 10	Measured movement	1° to 2°	5° to 7°	5° to 10°	Gross loss	Extremely gross loss.
	Hypotonia	Doubtful	+	+	+	++
No. 22	Measured movement	10° to 20°	25° to 40°	35° to 50°	20° to 30°	2° to 3°
	Hypotonia	+	+	+	+	0
No. 4	Measured movement	1° to 3°	3° to 5°	3° to 5°	20° to 30°	Absolute loss.
	Hypotonia	0	+	+	++	+++
No. 19	Measured movement	1° to 2°	2° to 3°	4° to 8°	10° to 15°	15° to 20°
	Hypotonia	0	0	+	+	+
No. 5	Measured movement	20° to 40°	20° to 40°	10° to 15°	8° to 15°	1°
	Hypotonia	+	+	Doubtful	Doubtful	0
No. 12	Measured movement	1°	1°	2° to 4°	5° to 10°	15° to 35° With many errors.
	Hypotonia	0	0	0	+	++
No. 14	Measured movement	7° to 10°	4° to 8°	1°	1°	1°
	Hypotonia	?	+	0	0	0
No. 3 (2nd stage)	Measured movement	1°	1° to 2°	1° to 3°	Gross loss	Gross loss.
	Hypotonia	0	0	0	+	++

How closely the amount of hypotonia is associated with the degree of defective spacial appreciation was evident in such a case as No. 12, fifteen months after a bullet wound of the left parietal region. He complained that when he played the piano, there was "a want of purpose" in the ring and little fingers of the right hand; "I cannot rely on them, and they will probably blur the note, unless I watch them very carefully." "These fingers and the corresponding part of the hand," he said, "hardly seem to count, compared with the others, in anything I do."

But he had no difficulty in carrying out isolated movements and approximating the tip of each digit in turn to that of the thumb, provided he was allowed to fix his gaze upon them. When he held out both hands in front of him, even the little and ring fingers were in alignment with the others, so long as his eyes were open; but as soon as they were closed, the two ulnar digits fell away, whilst the thumb and index fingers remained as strictly in position as those of the normal hand.

Now it will be seen from Table A that there was no loss of spacial appreciation in the thumb and index, and a slight defect only in the middle finger; these digits were not hypotonic. But the sensory disturbance was considerable in the ring finger and in the little it assumed gross proportions; both were hypotonic, but the loss of tone was undoubtedly greater in the latter than in the former, coinciding with the relative degree of loss of sensibility.

This straightforward relation between the loss of postural recognition and diminished static tone can only exist if there is no primary motor defect or disturbance of reflex excitability. Everyone is familiar with the conditions present in a spastic hemiplegia of cortical or subcortical origin. Not only are all the reflexes profoundly exaggerated, but the hand may be incapable even of the coarsest movements. Here the tonic influence of lower centres has been set free to pour uncontrolled into the affected limbs, and at the same time all high-grade voluntary power has been destroyed. Such cases show the combination of paralysis, due to destruction of the motor mechanism of the cortex, combined with tonic overaction of lower centres. It is sometimes possible to overcome this spasticity in the hand by continuous gentle pressure; the rigidity of the fingers yields, and they can then be bent backwards to a degree impossible on the normal hand. Moreover, all the phalanges may become over-extended at the interphalangeal joints, a condition spoken of as "saddle-backed fingers."

But this want of tone, which so often underlies spastic rigidity of high cerebral origin, is part of the paralysis. The whole cortical motor apparatus is disordered; not only is voluntary power destroyed, but the tonic innervation upon which it is based is also diminished. This motor paralysis affects the hand more severely than any other part, because its movements occur habitually under control of the will. Every aspect of voluntary motion is affected; individual movements of the digits are no longer possible, and the static tone which underlies the maintenance of posture is also destroyed. But the clinical picture is complicated by the massive tonic influence of lower centres. Spastic rigidity invades the limb, attacking the larger joints to a greater degree than those more habitually under control of the will.

Such conditions do not come directly within the purview of this research; but they form a necessary link in the comprehension of an apparently anomalous group of cases. It sometimes happens that a gunshot injury of the surface of the brain produces loss of recognition of posture and passive movement, without obvious increase or decrease of tone in the fingers. The lesion has not been deep enough, or sufficiently extensive, to produce spastic rigidity. Why then is the loss of spacial recognition not associated with hypotonia?

In all such cases individual movements of the various parts of the hand are clumsy and are performed with difficulty, even when the patient fixes his gaze on the fingers. If he is asked to throw out both hands in front of him the digits are not in perfect alignment, and the thumb may droop abnormally. This is usually more evident if he is made to abduct his fingers and then to bring them together again. Not only is this movement badly performed, but the posture finally assumed is obviously defective. Throughout, the patient has kept his eyes open and directed his gaze on to the affected hand.

Usually, in such cases the deep reflexes do not give an identical response in the two upper extremities; the wrist-jerk is somewhat brisker on the affected side and the elbow-jerk may be increased. But we are far from the condition seen in spastic paralysis.

On Table B. I have brought together a set of cases where, at first sight, we might have expected more or less hypotonia of the digits corresponding to the graduated loss of spacial recognition. But, in every instance, individual movements were clumsy and the fingers out of alignment, even though the eyes remained open. The cerebral injury had disordered the motor mechanism of the cortex in addition to its afferent centres.

Defective motor control from the side of the cortex is also shown by the tendency of the wrist-jerk to be brisker on the affected side; but it must be remembered that no deep reflex reveals the state of the various digits. The wrist-jerk indicates the condition of the forearm rather than of the hand, and not uncommonly the difference between these reflexes is very slight in this class of case.

According to the view I have put forward, a lesion of the sensory cortex can produce hypotonia provided the motor activity of the pyramidal system is intact. If, however, the highest grade of voluntary motion is disturbed, the fingers either show no obvious change in tonic innervation, or, if the lesion is more severe, fall into a condition of spastic rigidity or flaccid paralysis.

Should this hypothesis be correct, recovery of motor power without coincident restoration of postural sensibility should lead to the gradual appearance of hypotonia in the affected fingers. This was actually the case in No. 3. He figures on Table B in the first stage in which I saw him; individual movement of the various parts of the left hand could not be carried out, the fingers were out of alignment and the deep reflexes of the upper extremity were exaggerated. At this time his fingers were not hypotonic. But as time went on the movements of the digits improved, and eleven months after the injury he could approximate the tip of the thumb to that of each finger in turn with the eyes open, though more slowly than in the normal hand. Coincidently with this return of movement the little and ring fingers became definitely hypotonic; on the restoration of voluntary power static tone became defective. (See Table A.)

Gross loss of appreciation of posture and passive movement, due to a cerebral lesion, may thus be associated with various states of tonic innervation.

TABLE B

HYPOTONIA ABSENT

Case.		Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.	Movements and posture.	Reflexes.
No. 20	Measured movements	3° to 4°	15° to 25°	15° to 25°	Gross loss	Gross loss	Great loss of R. grasp. Individual movements clumsy. Want of alignment	Brisk wrist-jerk R. and L. Other reflexes normal.
	Hypotonia	0	0	0	0	0		
No. 11	Measured movements	5° to 7°	6° to 10°	8° to 10°	7° to 10°	7° to 10°	Considerable loss of L. grasp. Individual movements clumsy. Want of alignment	L. wrist- and elbow-jerk greater than R. L. abdominal defective.
	Hypotonia	0	0	0	0	0		
No. 3 (1st stage)	Measured movements	1°	2° to 3°	2° to 3°	Gross loss	Gross loss	L. grasp feeble. Individual movements impossible. Want of alignment of little and ring fingers	L. wrist- and elbow-jerk greater than R. L. lower abdominal sluggish.
	Hypotonia	0	0	0	0	0		
No. 2	Measured movements	1°	3° to 6°	6° to 10°	5° to 10°	15° to 20° With errors	R. grasp poor. Individual moments defective. Want of alignment of little finger	R. wrist-jerk greater than L. Otherwise reflexes normal.
	Hypotonia	0	0	0	0	0		
No. 17	Measured movements	1°	5° to 8°	10° to 20° With errors	10° to 20° With errors	7° to 20° With errors	R. grasp weaker. Individual movements bad. Want of alignment	R. wrisk-jerk greater than L. R. lower abdominal defective.
	Hypotonia	0	0	0	0	0		

(1) Provided there is no direct interference with the highest motor functions of the cortex, hypotonia may be directly associated with want of spacial appreciation.

(2) But if, when the eyes remain open, individual movements are clumsy and the fingers are out of alignment, and especially if the deep reflexes point to some interference with the activity of the pyramidal system, no hypotonia may be present.

(3) Should the lesion be sufficiently gross to set free the lower centres from cortical control the limb may be spastic and the fingers rigidly contracted.

(4) Severe lesions of the cortex and subcortical tissues may cause a complete flaccid paralysis, especially in the early stages. Here the fingers are atonic because both voluntary movement and static tone are destroyed by the injury. The phasic and tonic aspects of motion are paralysed.

This paralytic loss of tone may in certain cases exist under cover of general spasticity of the limbs. Once the coarse influx of tone in the hand is overcome by gentle and steady pressure, the fingers can be bent back to an abnormal degree, and the terminal phalanges can be brought into a "saddle-backed" posture.

My business is with the first of these states of tonic innervation; for it alone stands in direct relation to cortical disturbances of sensation. Paralytic atonia and hypertonia deserve a treatise to themselves, and cannot be dealt with within the limits of a paper devoted to the afferent mechanism of the cortex.

All spacial aspects of sensation rise into consciousness influenced by the consequences of some previous experience. For it would be impossible to discover the position of any part of the body, unless the immediate postural sensation was related to something that had preceded it. A direct perception of posture, analogous to that of roughness or of pain, is impossible; every new position of the limb is relative to those which have preceded it.

The sensory cortex is the organ to which we owe the faculty of relating one sensation to another either simultaneously or consecutively. Consequently all spacial aspects of sensation suffer severely from a lesion of the cortex. Not uncommonly a patient with a cortical lesion can recognise that some movement has taken place, but is unable to discover its direction or amplitude; complete appreciation of spacial relationships is the recognition of serial changes in a certain direction.

The cortex has been said to be the repository of "images of movement." This is, however, an unsatisfactory term when we consider the actual effects produced by a cortical lesion; for when we speak of an image we mean something that can be recalled into consciousness under suitable conditions.

When we sit immobile and imagine our fingers touching some object on the table, many of us see at once the mental picture of an outstretched arm; the only image in consciousness is a visual one. Now if we examine an intelligent patient in whom the power of recognising posture or passive movement is gravely affected, this visual image may remain as vivid as ever. In such cases it is possible to make the following instructive experiment. Place his arm in front of him on the bed, allowing him to see the position in which it lies; touch several spots in succession on the affected hand and ask him to point to them with his finger, his eyes remaining open throughout. Then close his eyes and carefully remove the arm into some distant position, say at right angles to the bed. If he is a strong visualiser he will tell you that he can still see the picture of his arm and hand as vividly as before on the bed in front of him. Now touch some point on the hand; if tactile localisation is not too grossly disturbed, the patient will indicate a spot in the position where that part of his hand originally lay on the bed. This phenomenon may be called "exploration of the phantom hand." Here the visual image of the limb remains intact, although the power of appreciating changes in position is abolished.

It is evident therefore that the standard to which immediate reference is made, when a fresh position is recognised, cannot be a visual image. The existence of normal human beings, whose conscious life by day is devoid of all visual images, would be sufficient evidence of this fact, apart even from the direct results of experiment in cases of cortical lesions. Some such persons undoubtedly possess true movement images. That is to say, the assumption of an imagined posture may be accompanied by re-presentation of movement, equivalent to the pictures of those who visualise strongly.

But in both cases the image, whether it be visual or motor, is not the fundamental standard against which all postural changes are measured. Every recognisable change enters into consciousness already charged with its relation to something that has preceded it. Before the afferent processes caused by movement of a joint can evoke a change in consciousness, they have already been integrated and brought into relation with the previous physiological dispositions, due to antecedent postural changes. Just as on a taximeter the measured distance is presented to us already translated into shillings and pence, so the final product of spacial changes rises into consciousness as a measured postural appreciation.

For this standard, against which all subsequent changes of postures are measured before they enter consciousness, we have proposed the word "schema." By means of perpetual alterations in position we are always building up a model of ourselves, which constantly changes. Every new posture or movement is registered on this plastic schema and the activity of the cortex brings each fresh group of sensations evoked by altered posture into relation with it. Immediate postural recognition occurs as soon as this relation is complete.

Recognition of posture and movement is obviously a conscious process. But the activities on which depend the existence and normal character of the schemata lie for ever outside consciousness; they are physiological processes with no direct psychical equivalent. The conduct and habilaments of the actor who appears before us on the stage are the result of activities behind the scenes of which we must remain ignorant, so long as we are only spectators of the play.

The only constant and continuous record of the movements of our bodies in space exists in the condition of our schemata. These physiological dispositions of the cortex ensure that the inception of a voluntary movement will find the part to be moved in a suitable attitude. For, unless postural impulses perpetually modified these unconscious physiological activities consonantly with every change in position, we might will a certain movement although the limb was not in a suitable attitude to bring it into being. This is evident in every case of ataxy.

But in order that the part of the body to be moved may be ready to spring off, like a runner, at the word of command, its static tone must be normal. Should it be posed atonically, the voluntary motor act has first to gather in slack before the limb begins to move. Normal posture and normal tone are coincident terms.

It is obvious therefore that any lesion which disturbs postural schemata will interfere with static tone. For, in order that a part of the body at rest may retain a normal posture, afferent postural impulses must exert a constant influence on the activity of the appropriate receptive centres of the cortex. These are the repository of spacial schemata. The physiological changes brought about by this stream of afferent impressions not only checks and controls voluntary movement, but ensures that the static tone of the part shall be adapted to maintain its position. Consciousness is in no way necessary for such co-ordination; in fact the regulation of tonic innervation occurs entirely on the physiological level. Any lesion, which tends to destroy postural schemata, not only disorders voluntary movement, but under suitable conditions may diminish static tone.

In order that this disturbing effect may show itself in a permanent diminution of tone when the part is at rest, the pyramidal system must be intact. For, if the motor mechanism of the cortex is directly affected, fine regulation of postural tone is no longer possible; the general tonic condition of the part tends to be increased, as shown by exaggeration of its deep reflexes. The more profound the lesion the grosser becomes this spastic rigidity due to the uncontrolled massive innervation from lower centres.

But the hypotonia, so closely associated with defective recognition of posture and passive movement in the absence of any defect in the highest motor apparatus, is in reality a false co-ordination. The receptive centres of the cortex are badly informed of the position of the affected parts: at the same time those physiological dispositions past and present, on which depend the existence of spacial schemata, are disordered. Voluntary movement is badly co-ordinated except when guided by vision. But tonic innervation is a purely automatic process, not under the control of the will except in so far as it is the aftermath of a voluntary movement. Static tone consequently suffers and the affected fingers are more or less permanently hypotonic.

I have laid stress throughout on this twofold influence of a cortical lesion on spacial recognition. A subcortical injury may also disturb recognition of posture by cutting off, to a considerable extent, afferent impulses from the receptive centres in the cortex. In such a case the threshold is raised, but it may be possible to obtain orderly and coherent responses if the intensity of the stimulus is sufficiently increased. Thus it may be necessary to move the finger passively through an angle of 20° before appreciation occurs, but all the answers will tend to lie round about this degree. If, however, the cortex itself is destroyed it may be impossible to obtain a true movement threshold. Not only is the range at which appreciation occurs widely different, but false answers and hallucinations mar the records. We are now dealing not only with the disturbance of afferent impulses, but with the destruction of the centre for those physiological processes which underlie the recognition of posture and movement.

This difference between the consequences of a pure subcortical lesion and one which involves the cortex is, I believe, also manifest in the condition of static tone. The former leaves the permanent dispositions of the afferent centres intact; the patient still possesses complete spacial schemata, but incoming influences are defective. The internal organisation is intact, but it is badly served with information from without. Now, static tone is automatic; it is the product of a constant stream of influence exerted by the simple existence of the physiological dispositions we have called schemata. So long as they remain intact, tone will not be grossly diminished, apart from the effects of a primary paralysis. Once, however, the inherent activities of the afferent centres are destroyed by a cortical lesion, tone tends to be diminished because of the loss of the constant automatic influence they exert on the highest efferent mechanism.

This is one of the reasons why a pure subcortical lesion, such as that in No. 6 (p. 705), was not associated with hypotonia of the fingers. We might at first sight have anticipated a graduated diminution of tone increasing towards the post-axial aspect of the hand corresponding to the want of recognition of passive movement. But all the signs pointed to an uncomplicated lesion of the centrum ovale as far as the post-central cortex was concerned. A threshold could be obtained to all the sensory tests, although to most of them it was raised considerably above the normal. The answers were free from the gross irregularities and inconstancy so common when the sensory cortex is itself affected. Here the normal condition of static tone was due to the continued exercise of that co-ordinating influence, which constantly flows from the highest afferent to the efferent centres.

Thus, it is evident that the so-called sensory cortex exercises by its very existence a double effect upon motor activity. First of all it controls voluntary movement; conscious appreciation of relations of the body in space go hand in hand with the effector activities of the will. But these phenomena of mind are based on physiological processes which may be directly disturbed by a cortical lesion. It is these underlying non-mental dispositions which influence postural tone. Thus, at this anatomical situation in the nervous system, the vital activity of the centre is expressed as presentations to consciousness, concerned with the position of the body in space, and also as the purely physiological condition of postural tone.

CHAPTER VIII

THE PRINCIPLES WHICH DETERMINE ANATOMICAL LOCALISATION OF SENSORY FUNCTIONS IN THE CORTEX

No one now denies that sensation can be affected by a lesion of the cerebral cortex, and the disputes, which raged over this question, can be relegated to the past history of medicine. Moreover, it is certain that the "excito-motor" area, that portion which gives origin to the pyramidal tract, is situated almost entirely within the precentral convolution; it is not coterminous with the so-called "sensory cortex." For, although the anterior and posterior limits of the sensory centres are still undetermined, every one is now agreed that the post-central convolutions form the most effective focus, from which sensory changes can be evoked by a suitable injury to the brain.

But preoccupation with the practical problems of topographical localisation blinded neurologists to the true nature of the functions, which are disturbed by a cortical lesion. They assumed that all disorders of sensation would fall into the categories of touch, pain, heat and cold, together with some "spacial" or "muscle-sense" constituent, and were surprised to find that researches on these lines ended in confusion.

Russel and Horsley ([101] p. 139) frankly stated in 1906 that "all observers are agreed that isolated lesions of the Rolandic zone do not produce complete tactile anæsthesia or analgesia (to these must be added temperature anæsthesia)"; but they offered no solution of this apparently anomalous conclusion, and did not state definitely in what way sensibility was disturbed by a lesion of the cortex.

Recently, however, some authorities on cortical topography have attempted to avoid this difficulty by adopting a most disastrous nomenclature. Thus v. Monakow speaks of disturbances of "deep, proprioceptive, protopathic and epicritic sensibility" in connection with cortical lesions ([84] pp. 270–271). Even so recently as 1916 van Valkenburg [127] published a paper entitled, "Sensibilitätsspaltung nach dem Hinterstrangtypus in Folge von Herden der Regio rolandica."

Dejerine [23] in 1914 wrote as follows: "Une autre question se pose depuis quelque temps; on a constaté dans plusieurs cas d'hémanesthésie cérébrale une topographie spéciale de l'anesthésie, qui se traduit sous forme de bandes reproduisant plus ou moins exactement la distribution radiculaire spinale. En présence de ces faits, on est amené à se demander s'il n'existe pas dans les centres corticaux sensitifs une systématisation radiculaire comparable à celle qui existe pour les centres moteurs corticaux." Here, it is true, he did not state that the nature of the loss of sensibility corresponded to that caused by injury of the posterior roots; he only asserted that the distribution of the disturbance might follow a radicular type. But, as a matter of fact, the anatomical form and the essential character of any loss of sensibility are closely bound together; when it follows a peripheral, radicular, or spinal distribution, the nature of the sensory change corresponds to the situation at which it is produced. To suppose that a cortical lesion could be associated with a sensory loss of radicular form is as absurd as to postulate a spinal lesion with changes in sensation resembling those of an ulnar nerve paralysis.

I have attempted to show that sensory changes, produced by a lesion of the cortex, must be considered in terms of the psychical act and not of the physical stimulus. The function of the cortex in sensation is to endow it with spacial relationships, with the power of responding in a graduated manner to stimuli of different intensities, and with those qualities by which we recognise the similarity or difference of objects brought into contact with the body. It is these aspects of sensibility which are disturbed by cortical injuries. The anatomical lesion upsets the orderly sequence of physiological processes and this defect of function is manifested in disorder of the psychical act of sensation. The terms in which this disturbance is manifested are categories of the function itself; a sensory loss of cortical origin is not expressed in anatomical or physiological terms, but in those of the most elementary processes of mind.

If the view I have put forward in this paper is correct all previous theories of cortical localisation, as far as sensation is concerned, must be put aside. The two conceptions are mutually antagonistic and cannot be combined; there is no *via media*. Unless this fundamental diversity of outlook is recognised from the start, it will be impossible for the reader to grasp the attitude I have assumed with regard to the topographical significance of sensory disorders of cortical origin.

We may accept as a sufficiently well observed fact, that a lesion of the post-central cortex can produce a profound effect on sensibility. But we have no right to assume that those forms of sensation, which are disturbed, are of necessity functions of the injured cortex. For any sudden injury of the surface of the brain produces widely radiating shock effects within the structures of the nervous system. Sometimes a blow on the head, or a cerebral operation, may be followed by loss of sensation so severe that it is difficult to believe the mid-brain has not been affected. The whole of one half of the body may become insensitive to touch, pain, heat and cold; and yet the rapidity with which this loss of sensation disappears shows that it was not due to gross structural changes in the lower afferent centres.

An epileptiform attack is a potent cause of neural shock, and in the attempt to determine the sensory function of the cortex, it is better, if possible, to reject those patients who suffer from any form of seizure or periodic disturbance of consciousness. No demonstrative value can be laid on sensory changes which follow directly on a Jacksonian convulsion.

This widespread consequence of a cerebral injury or convulsive attack has been called "diaschisis" by von Monakow ([83] p. 237). He believes that the shock is so great that it passes backwards, over one or more synaptic junctions, to affect the functions of anatomical systems remote from the site of the injury. He adds: "Es handelt sich auch bei der Diaschisis im wesentlichen um Herabsetzung oder Aufhebung der Anspruchsfähigkeit . . . der zentralen Elemente für Reize innerhalb eines bestimmten physiologisch wohl definierten Erregungskreises; dieser Kreis fällt indessen mit dem gewöhnlichen. von der Peripherie und vom Zentrum aus sich ausdehnenden *physiologischen* Innervationswege *nicht* zusammen."

Now, whatever we may think of this exclusively anatomical standpoint, the widespread effect of a strictly local injury of the cortex is undoubted. It is impossible to say, in the early days of a wound of the head, how much of the loss of sensation is due to destruction at the site of the lesion and how much to irradiation. The profoundness of the effect is even more disconcerting than its wide extent. Not only is sensation disturbed over a larger area of the body than might have been expected from the situation of the injury, but the character of the loss differs fundamentally from that found with a stationary lesion of the cortex. Slowly, day by day, sensation returns to those parts of the body which do not correspond to the focus of disturbance. At the same time, the nature of the sensory loss changes; it no longer consists of a gross defect of tactile, painful and thermal sensibility, but, in favourable cases, begins to assume the characters I have described in this paper.

All aspects of cerebral activity are liable to undergo similar profound and extensive changes in consequence of trauma; these are particularly evident in the phenomena which follow cerebral concussion. At first the patient lies in flaccid unconsciousness, with shallow breathing, scarcely able to swallow fluid placed in his mouth. Then the lower centres recover from the shock and he becomes restless and even violent. As normal consciousness returns he grows amenable to control and his conduct is no longer dominated by the activities of the lower functional levels.

In the same way, on the sensory side, the gross effects produced by the initial lesion, or by a subsequent operation, gradually pass away. If the wound heals well and there are no epileptiform attacks, all the initial loss of sensation may disappear. But, if the lesion lies over the post-central convolution, some defect of sensibility may remain for months or years in that part of the body which corresponds to the focus of the lesion. This loss is never completely hemiplegic, provided the cortex alone is injured; it occupies a part only of the opposite half of the body and may even be confined to a few digits on the hand.

It is most instructive to watch the order in which the sensory loss gradually diminishes. The outlying parts become normal and sensibility is defective in those parts only, which formed the focus of the previous disturbance. Thus in No. 23 the whole hand was affected; in addition the records at the wrist, elbow and great toe originally showed some loss of recognition of passive movement. These three joints became normal within six months of the injury. During this recovery the sole of the foot regained its sensibility to the tactile hairs, which had been profoundly disturbed. Coincidently with the gradual restriction of the affected area came a diminution in the severity of the sensory loss on the various parts of the hand; the amount of the loss to measured movement and to the tactile hairs became less, even over those fingers which were most affected.

But when once the wound has firmly healed, particularly if the opening in the skull is small and does not pulsate, it is remarkable how constant may be the extent and character of the sensory changes. Such are the cases which form ideal material for determining the part played by the cortex in sensation. Much can, however, be learnt from less perfect examples, provided care is taken to eliminate the effect of shock and other transitory consequences of cerebral injury.

§ 1.—Representation of Parts of the Body

Many of the tests I have used are not applicable to any part but the hand; for instance, the power of discriminating different weights and textile fabrics can be explored over the feet in the rarest instances only. Even such a universal test as the compass points does not yield equivalent results on the hand and on the foot. For, on the palmar aspect of the tips of the fingers, the two points applied at the same moment can be recognised in many cases, when they are separated by 0·5 cm.; whilst on the sole of the foot it is not possible to depend on correct answers at a smaller distance than about 2·5 to 3 cm. Thus, if the power of discrimination were reduced to one half, good readings might be obtained on the hand at 1 cm., but on the foot we should be compelled to separate the two points to a distance of at least 5 to 6 cm. In the same way the range of this test is greatly limited on the forearm, where it is impossible in a normal person to be certain of obtaining a complete series of correct answers under about 4 cm. Over such parts the two points must be separated so widely, before we can obtain even a normal threshold, that the limits within which the test can be applied are rapidly exceeded, whenever sensibility is affected to any considerable degree. Again, it must not be forgotten that the sole of the foot is the equivalent of the palm of the hand and not of the fingers. As we cannot use the compass test with any satisfactory results on the toes, we are unable to explore the condition of the distal segments of the lower extremity; the first evidence of changed sensibility must be drawn from the penultimate parts of the limb.

Similar difficulties apply to all the other tests, and the results obtained from the feet are always less distinctive and coarser than those from the hand. As far as the face is concerned, most of them are quite inapplicable. It is impossible to test the power of appreciating passive movement, or recognition of weight, form and the situation of the stimulated spot. Fortunately, however, in the voluntary movements of the face and tongue, we possess a delicate measure of any loss of motor power that may be caused by the lesion. By this means it is often possible to decide whether the main impact of the injury has fallen on the centre for the face; if so, the sensory changes in the hand may be due to its radiating effect and should ultimately disappear slowly. If they are still present at the end of six months, they are probably caused by some permanent destruction of cortical tissue affecting the arm-centre, although the main incidence of the lesion has fallen on that for the face.

In the same way, the sensory changes in the hand may be accessory to a more severe disturbance of function in the foot. Passive movements may be badly recognised in the great toe, at the ankle and even at the knee; the compass points may not be appreciated at 10 cm. on the sole, and no threshold obtained with the tactile hairs. Obviously, in such a case the sensory changes are extremely gross and the cortical centre for the foot has been badly injured. But the loss of sensation in the hand may occupy one or two digits only and be of a more delicate character; the various forms of sensory activity may be dissociated, one may be lost over the affected parts, whilst another is entirely unaffected. In such a case it is evident that the hand does not lie in the central focus of the disturbance.

Thus, for all delicate exploration of the sensory faculties of the body, we are thrown back on to the hand. Sometimes, in the cases I have used for this research, the disturbance of sensation is the result of direct injury to that part of the sensory cortex in which the hand is topographically represented; in other instances it is due to the outlying effect of a lesion, that has fallen either on to the centre for the leg or on to that for the face. This makes any precise determination of the limits of these centres extremely difficult, from such material as I have brought forward in this paper.

But there can be little doubt that the higher the lesion on the central convolutions the more certainly will the lower extremity be affected, whilst the closer it lies to the Sylvian fissure the more definite will be the affection of the face. Thus when an injury affects both the face and hand we should expect it to lie lower on the surface of the hemisphere than when it disturbed the functions of the hand and foot. This is actually the case.

It is now generally recognised that a lesion of the post-central convolution is more likely to lead to definite and severe disturbances of sensation than of any other part of the cortex. Here those physiological activities, which underlie sensation, are concentrated more thickly than at any other part of surface of the brain. The sensory condition of the hand or the foot is more or less gravely disturbed, whenever the incidence of the injury falls upon this area. If the middle portion of the convolution is struck, and the destruction of tissue is not severe, the hand alone may be affected; but the nearer the lesion lies to the vertex, the more certainly will the foot participate in the disturbance. If it happens to lie on the vertical aspect of the hemisphere, any affection of the hand that may be present will almost certainly be less severe than the loss of function in the lower extremity. Conversely, when the injury falls upon the lower half of the post-central convolution, some affection of the face and tongue is likely to accompany the loss of sensation in the hand. Evidently the sensory activities of the hand are more closely represented in the middle of the convolution.

But it is possible to determine more in detail the topographical representation of the hand upon the cortex. This research has been based upon cases where the various fingers were not all in the same sensory condition; sometimes the pre-axial, sometimes the post-axial digits were most severely affected. Now whenever the loss of sensation reaches its maximum over the thumb and index finger, the face and tongue tend to be affected; if the lesion lies in the left hemisphere, speech will also have been disturbed, to a greater or less extent, at some time in the history of the patient. This is shown by the five cases in Table C where the impact of the wound lay mainly over the central convolutions. If, however, the loss of sensation was greatest over the little finger and its neighbouring digits, it is the foot which tends to show some motor or sensory change. Out of seven such cases, four showed some disturbance of the lower extremity, although in most instances it was slight and transient; but movements of the face and tongue were normal in all and speech had not been affected (Table D). I do not intend for a moment to assert that, because the little finger shows the profoundest changes in sensibility, the face and tongue cannot suffer; one of the commonest results of a wound of the skull in the region of the central convolutions is to produce a more or less transitory hemiplegia. But it is not with these cases that I am dealing at present; my interest is centred in those where the various digits were in a widely different sensory condition. These are the less severe cases. It is among them that we tend to find this association between the pre-axial parts of the hand and some affection of the face and tongue; or, conversely, a tendency for the functions of the foot to be disturbed, when the main loss of sensation lay over the little finger.

Moreover, even the rough verbal description of the locality of the injury, given in the last column of the table, brings out the same point. For in those cases where the maximum incidence of the loss of sensation lay over the little finger, the lesion was usually situated higher on the post-central convolution than when the thumb and index were most affected. Thus it is evident that the pre-axial digits are more definitely represented in the lower part of the centre for the hand, whilst the post-axial portions lie topographically higher on the surface of the hemisphere.

But it must not be supposed that the maximum loss of sensation fell either over the thumb or over the little finger in every instance. Four of my cases showed preponderating affection of the little finger; in six the disturbance reached its greatest intensity over the little and ring fingers; in one it was more severe over the thumb and in three others over the thumb and index finger; in one case the most intense sensory loss was found in the index and in another it was greatest in the index and middle fingers. Finally, in one instance, it reached its maximum over the middle finger.

TABLE C

Case.	Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.	Affection of face.	Affection of foot.	Locality of the lesion.
No. 9	+	++	++	0	0	Speech and face at first	0	Middle pre-central.
No. 13	+	++	Intro-spective	Intro-spective Very slight	Intro-spective	Speech at first; face weak; tongue to R.	0	Inferior pre-central and post-central.
No. 14	++	+	0	0	0	Speech and face	0	Middle pre- and post-central.
No. 18	++	++	Slight	0	0	Face affected; tongue to L.	0	Inferior pre- and post-central.
No. 11	++	+++	+	Intro-spective	Intro-spective	Speech at first; face and tongue slightly	0	Middle post-central.

TABLE D

Case.	Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.	Affection of face.	Affection of foot.	Locality of the lesion.
No. 2	0	Slight	+	+	+++	0	0	Middle post-central.
No. 3	0	? very slight	Slight	++	++	0	Leg affected at first	,, ,,
No. 4	Intro-spective	+	++	+++	+++	0	Leg slightly affected	,, ,,
No. 7	+	+	+	+	+++	0	Definitely affected	Upper pre-central and post-central.
No. 12	0	0	+	+	+++	0	0	Upper post-central and upper parietal lobule.
No. 19	0	Slight	+	++	++	0	0	Middle pre-central and post-central.
No. 20	Slight	++	++	+++	++	0	Slight weakness and sensory change	Middle post-central

Thus, it is evident that the various fingers are represented topographically in the cortical centres; sometimes one and sometimes another lies in the focus of the disturbance. It is convenient to speak of the thumb in this connection as pre-axial and of the little finger as post-axial; but it must be clearly understood that the axis of the limb is not represented topographically on the cortex. Certain motor and sensory functions of the body are more concentrated at some parts of the hemisphere than at others. In the same way, the physiological activities corresponding to each separate digit are relatively more highly represented in a certain portion of the cortical centre for the hand. But axial lines are a conception drawn from developmental anatomy; they have no place in the functions of a limb free to move in space. From the point of view of sensation, anatomical representation ceases as soon as the first synaptic junction is passed. The body is not represented on the cortex as an anatomical unity, but only in so far as it is capable of undergoing conscious changes in function. Thus, all attempts to establish a local representation of such purely anatomical factors as axial lines are based upon a false conception of the nature of cortical activity, and of the significance of central representation.

Russel and Horsley [101] were not content with speaking of topographical localisation of the pre- and post-axial halves of the limb, but even postulated the "representation in the cerebral pallium of the mid-axis of the upper limb" (p. 149): This conception they based on no more valid evidence than sensory changes "in the two middle fingers of the hand." This, they say, seemed to them "such an obvious corollary to the pre-axial and post-axial representation we have just discussed, that we bring forward the following case as a good example of the clinical fact." This case showed nothing more, however, than an "aura beginning in the third and fourth fingers of the left hand, spreading to arm, face, trunk and leg of the same side," and seventy-three days after removal of a large subcortical tumour, anæsthesia to cotton wool on the dorsum of the hand with tactile localisation "towards the mid-axis."

No better example could be given of the difference between the older methods of thought and the conceptions I have attempted to put forward in this paper. Sensation is a psychical act, and even the regional representation of the processes on which it depends is based on functional habits, rather than on phylogenetic development. Each digit is a unit and can be used in an isolated act, either of motion or sensation; as such it is represented topographically on the cortex.

The same rule applies to loss of sensation on the palm of the hand; the distribution of the changes in sensibility bears no relation to axial lines, but corresponds to the proximal extension of the affected digits. Many of the tests I have applied to the fingers cannot be employed on the palm; but the compasses, tactile hairs and weights can all be used over limited areas. If, then, the palm is marked out by lines running from the four fingers in the direction of the fold of the wrist, whilst the greater part of the thenar eminence is reserved for the thumb, it is found that the sensory condition of the intervening portions closely resembles that of the digits to which they correspond.

This is particularly evident in such cases as No. 3, where the compass test was disturbed over the post-axial digits, but tactile sensibility was entirely unaffected. This dissociation both in the extent and quality of the sensory loss was equally manifest on the palm. Over the thenar eminence, and in a line with the index finger, his answers to the compasses applied simultaneously were perfect; but over the post-axial portion of the palm they were grossly disturbed, even when the two points were separated by a distance of 5 cm. At the same time, tactile sensibility was everywhere normal.

In No. 9 the index and middle fingers showed the most severe loss of sensation, but the ring and little fingers were unaffected. On the pre-axial side of a line, drawn vertically down the palm from the cleft between the third and fourth digits, he was unable to appreciate weights correctly, just as on the corresponding fingers. But, on the ulnar half of the palm, sensation was entirely unaffected to this test. In other cases the tactile hairs revealed exactly analogous changes.

Thus, it would appear as if the loss of sensibility on the palm, produced by a cortical lesion, corresponds roughly both in situation and quality with that of the affected digits. There are no "axial" lines or borders; as the sensory condition changes from finger to finger, so it alters both in quality and intensity on passing from one part of the palm to another.

When sensation is disturbed over the whole of the hand, it may be defective at the wrist, elbow, or even at the shoulder. Under these circumstances the foot usually participates in the sensory loss. This is particularly liable to occur when we have reason to believe, from other signs and symptoms, that subcortical tissues have been affected; in fact, the deeper the lesion the more certainly will the sensory loss assume a hemiplegic distribution.

Occasionally, however, both hand and foot may be normal to measured tests, and yet some more proximal part of the upper or lower extremity may show definite loss of sensibility. But these cases are rare. No. 8 is a particularly good example, because not only have we definite evidence that both hand and foot were little, if at all, affected at an early stage in the progress of the case, but I saw him for the first time six weeks after he was wounded and could discover no gross changes, except at the elbow and to a less degree at the wrist. Recognition of passive movement was profoundly disturbed and the tactile hairs also revealed considerable sensory loss over the forearm. No measurable defect could be discovered in the palm and digits; introspectively, however, he found it more difficult to make up his mind with certainty over the hand of the affected than of the sound limb. The lower extremity was in every way normal. In this case the elbow evidently lay in the focus of the cortical disturbance, and the wrist suffered to a less degree.

All experimental evidence points to the topographical representation of the various movements of any one limb in different parts of the cortex (Sherrington and Grünbaum [113]). Of all the centres associated with the upper extremity, that for the fingers and thumb lies lowest on the precentral convolution; then follow in order those for the wrist, elbow and shoulder. Between the shoulder and the hip, lies the area devoted to movements of the trunk.

Now, I have already shown that, from a sensory point of view, a lesion which affects the thumb and little finger is liable to be accompanied by some defect in speech or disordered movement of the face and tongue. Thus of all the centres devoted to the physiological activities underlying sensation in the hand, that for the thumb must lie lowest on the surface of the brain. Conversely, the foot occasionally shows some loss of sensibility, when the maximum disturbance lies over the little finger; this digit must therefore be represented in the highest part of the cortical centre for the hand.

It follows, as a corollary to this conclusion, that, whenever the little finger shows gross changes in sensibility, the wrist also tends to be affected. Should the whole hand be involved, but the maximum loss lie over its post-axial parts, not only the wrist, but the elbow and shoulder, may show some defective recognition of posture and passive movements.

So far I have shown that the disturbance of sensation produced by a cortical or subcortical lesion tends to follow a regional distribution corresponding to the contiguity of the centres on the cortex. But it is the functions, rather than the anatomical relationships, of any one part of the body that are represented. Consequently those portions, such as the hand, which are endowed with the greatest powers of discriminative sensibility, are represented, and to the highest degree, in the sensory cortex; for the fingers and thumb of man are little more than stalked sense-organs. Next in order comes the sole of the foot, which constantly exerts discriminative activity in walking. One of my patients (No. 6), in whom the right foot was affected, said: "When I am in the dark, I always take my feeling from my left foot, whereas before I always used to test the ground with my right. I have changed over since I was wounded."

In consequence of this more exclusive representation, the hand and the foot may suffer, although the sensory functions of the intervening joints are not measurably disturbed. In No. 20, for example, all the digits were affected, but the grossest loss of sensibility was found in the little and ring fingers; the wrist showed slight want of recognition of passive movements, but the elbow and shoulder were normal. In spite of the escape of these two joints, the great toe was affected and the sole of the foot showed an introspective difference to the tactile hairs. In a similar way it is possible for the great toe and the sole to show sensory changes, and for the little finger to be affected, although passive movements are perfectly appreciated at the ankle.

Thus, although the cortical centres are arranged according to the relative position of the different parts of the body, a lesion of a definite area does not, of necessity, disturb sensation in this anatomical order; hand and foot may suffer without obvious loss at the elbow and shoulder. The extent of cortical representation depends on the degree to which function is developed. The hand, with its five mobile digits, stands at the head of this functional hierarchy. It is therefore most highly and most widely represented in the sensory cortex. It is important to remember that even the regional representation of parts of the body, as revealed by a cortical lesion, is governed by the degree of functional development rather than by purely anatomical considerations.

§ 2.—Representation of Sensory Functions

The part played by the cortex in sensation is concerned with those physiological processes which underlie projection and discrimination. I have attempted to show that these activities fall into three groups; they are represented on the sensory side by appreciation of relationships in space, by appropriate reactions to stimuli of different intensities, and by recognition of the similarity and difference in test-objects of various weights and shapes.

We saw reason to believe that these three aspects of cortical activity were not always affected uniformly, or in any constant relation to one another. In one case the spacial tests yielded normal results, in spite of considerable defects in the remaining aspects of sensation; whilst in some instances the tactile hairs, or in others the graduated weights, failed to show any abnormality.

These are, however, extreme examples, but they demonstrate that the three aspects of sensibility cannot be equally represented in all parts of the sensory cortex. Even cases where the dissociation is less complete point in the same direction; for it is not uncommon to find that one group of tests shows a disturbance of sensibility in five digits, whilst another group reveals defects in one finger only.

These three faculties might have stood to one another in some such relation of graduated complexity as that which we discovered for appreciation of tests in three-, two-, and one-dimensional space. The cortex is the organ for controlling and guiding voluntary movement, and recognition of the relations of the body in space is one of its most important functions. It would not, therefore, have been unreasonable to suppose that whatever the changes on the afferent side produced by a lesion of the cortex, this aspect of sensibility would suffer. To a certain extent this is true. But at the same time the existence of one such case as No. 7, where the spacial tests gave normal results, shows that the physiological processes underlying the three forms of sensibility can be completely dissociated by injury to different parts of the cortex. They must then be based on processes which can be disturbed independently.

Moreover, if the three functions stood in a graduated relation to one another, one aspect of sensation would always show a more severe and more extensive disturbance than either of the others. But this is not the case; sometimes one group of tests, sometimes another, reveals a disturbance of greatest severity and widest extent. If we take passive movement, the tactile hairs and graduated weights as representative means for exploring the three sides of cortical sensibility, Table E shows to what extent they may be affected independently of one another.

Such extreme dissociation shows that the maximum activity of all three physiological processes cannot be situated within the same region of the sensory cortex. Each one must be represented more highly at some part than at another; in this way it may sometimes be more severely affected than its fellows, and at others may escape entirely. But any attempt to demonstrate the locality of the centres for the various aspects of sensibility is hampered by the extreme difficulty of determining the incidence of the lesion. One wound extends deeply and produces widely radiating changes, both anatomical and physiological; another, less severe, in an identical situation, may be followed, after the first shock has passed away, by changes in sensation which reveal the functions at the site of the lesion. Not only is it difficult to gauge the extent and severity of the original injury, but we can rarely tell how far the activity of the surgeon extended amongst the structures of the brain itself. All cases are not of equal value, from the point of view of topographical localisation. Some showed evidence of severe destruction of tissue; they had been trephined, the dura was found to have been ruptured and disintegrated brain was removed at the operation. In others the skull had not been opened and may not even have been fractured; and yet there were obvious signs that the cortex had been structurally affected.

TABLE E.

Case.	Measured movement.	Tactile hairs.	Weights.	Situation of lesions.
No. 18	0	3 digits	2 digits	Inferior post- and pre-central touching Sylvian fissure. (Trephined, cerebral substance removed).
No. 3	5 digits	0	2 digits	Middle post-central. (Trephined, extradural blood-clot removed).
No. 21	Whole hand and up to elbow	0	Defective	Middle pre-central. (Trephined; no notes, but on arrival dura open and brain substance protruding).
No. 16	Whole hand and upper extremity	0	Gross loss over whole hand	Middle post-central. (Very small removal of bone. Dura lacerated; hæmorrhage from vessel of dura).
No. 2	4 digits	0 (1 digit introspective)	1 digit (slow and introspective)	Middle post-central. (Not trephined).
No. 19	5 digits	2 digits slightly (1 digit introspective)	0	Middle pre-central, post-central and superior parietal lobule. (Trephined; brain pulp removed).
No. 13	4 digits (3 slight only)	5	0	Inferior pre- and post-central, very low. (Trephined; blood-clot and ruptured brain matter removed).
No. 22	5 digits	3 introspective only	0	Pre-central extending into middle post-central. (Small trephined area. No notes).
No. 14	2 digits	2 digits	0	Middle pre- and post-central. (Not trephined).

All attempts to localise the site of the various forms of sensory activity, with the help of such material, must be purely tentative. But by comparing the cases where one function was gravely affected with those where it had escaped entirely, we arrive at certain general conclusions.

First of all, we are justified in asserting that a lesion situated anywhere within a certain area on the hemisphere will disturb somatic sensibility to a greater or less extent; this is the so-called "sensory cortex." It consists of the pre- and post-central convolutions, the anterior part of the superior parietal lobule and the angular gyri. Loss of sensation may show itself in the hand even though the lesion lies low on the pre- or post-central convolutions in a position associated with the centre of the face. Conversely, when it is situated so high as to come within the area usually assigned to the lower extremity, the hand may show characteristic sensory abnormalities. But, whenever the main incidence of the lesion falls on those parts which contain the centres for either the leg or the face, the character of the sensory loss in the hand tends to be peculiar; one form or another of sensation may be entirely unaffected or show comparatively slight alteration.

Injury anywhere within this "sensory area" on the hemisphere is liable to cause some loss of appreciation of spacial relationship in the hand or in the foot. But the further forward it lies within this region, the grosser and more extensive is the disturbance shown by the spacial tests. Thus in No. 21, where the whole hand and elbow showed want of recognition of passive movements, the lesion lay over the middle of the precentral convolution; but tactile sensibility was completely unaffected. If the middle of the post-central convolution is struck by the injury the spacial aspects of sensibility are usually profoundly diminished in the hand; but some other faculty is also disturbed at the same time.

The power of recognising differences in weight and form is most severely and most extensively affected by a lesion, which falls mainly over the post-central convolution. But these tests can rarely be applied to the foot with any satisfactory result; for this reason we are only justified in saying that, if the lesion lies over the middle of the post-central convolution, the faculty of appreciating similarity and difference in objects of various weights and shapes, placed in the hand, will be more or less profoundly affected (No. 3. No. 16. No. 20). Among the patients in whom this form of discrimination was not disturbed the lesion was mainly pre-central in two (No. 13. No. 22); in two other cases it lay in the supra-marginal region and the loss was extremely slight (No. 10, No. 23). In all four instances the injury fell either mainly in front of or behind the post-central convolution.

The most surprising conclusion is reached in those cases where the power was impaired of responding appropriately to stimuli of graduated intensity. The most frequent consequences of a lesion within the "sensory area" of the cortex is some loss of recognition of spacial relationships and of similarity and difference; this is the well-known group of symptoms sometimes called "astereognosis and atopognosis." It is notorious that in many cortical cases tactile sensibility is not disturbed, even when we employ such fine tests as the graduated hairs. But in other instances this faculty is profoundly affected; in No. 10 the loss exceeded that of any other form of sensibility, and here the lesion lay over the supra-marginal convolution. The power of responding adequately to stimuli of graduated intensity was diminished, throughout my series of cases, whenever the focus of the injury lay over the superior parietal lobule (No. 5), over the supra-marginal region (No. 10), or over the foot of the post- and pre-central convolutions (No. 13 and No. 18). It is noticeable in other instances that, when the lesion was situated over the lower part of the central convolutions, tactile sensibility tended to show characteristic changes, even though other forms might also be profoundly disturbed. But the higher it lies on the hemisphere and the further forward its situation, the less will be the affection of tactile sensibility. Thus it is possible to construct a zone, running backwards along the foot of the pre- and post-central convolutions, over the angular and supra-marginal gyri to the superior parietal lobule. Any lesion which falls mainly within this area will probably be associated with disturbance of tactile sensibility; if this is severe and extensive, the patient may also be unable to distinguish various degrees of warmth about which he has no doubt on the normal hand.

Thus, the three aspects of sensibility, which are due to cortical activity, are not all equally represented in different parts of the sensory cortex. The spacial tests are most profoundly affected, when the lesion affects the pre-central convolution. The faculty of appreciating similarity and difference, in objects of different shapes and weights, suffers most with an injury of the post-central convolution; whilst the power of responding to the various degrees of intensity of such stimuli as the graduated hairs or warm test-tubes is most certainly diminished by a lesion of the parts behind the post-central convolution and also its extreme foot. That is to say, the centre for the spacial elements lies mainly in front, that for response to varying intensities behind, and that for recognition of similarity and difference between them. At the same time these roughly vertical areas fall somewhat obliquely, so that the representation of the thumb is much farther forwards than that of the foot.

CHAPTER IX

GENERAL CONCLUSIONS [1]

§ 1.—The Significance of Dissociated Sensibility

We have been able to show, that between the impact of a physical stimulus and the sensation it evokes, a multitude of changes occur, which do not normally enter consciousness. These are essentially physiological and can only be discovered by some form of dissociation.

The day of the *a priori* psychologist is over as far as sensation is concerned. A man can no longer sit in his study and spin out of himself the laws of psychology by a process of self-examination. For we have been able to show that, at a level deeper than any he can reach by introspection, are prepared those states, which condition the nature and characteristics of the ultimate sensation. Appreciation of position in space, graduated response to stimuli of varying intensity, and recognition of the similarity and difference of objects in contact with the body, were all thought to be matters of " judgment." We have shown that the forms assumed by these aspects of sensation are ordered and predestined on the physiological level, as the result of innumerable integrations, which take place outside consciousness. These processes are not open to conscious analysis ; it is only the interplay of sensations that can be discovered by introspection.

The psychologist, who attempts to discover a strict psychophysical parallelism, ignores the central link of the problem. He assumes that the nature and conditions of the physical stimulus can be brought into direct relation with the psychical act of sensation. Light can be analysed by the spectroscope into certain constituents, and he attempts to establish a strict correlation between these " primary colours " and elementary visual sensations. This fundamental error vitiates much of the work on the psychology of the senses. It is only under artificial conditions, that the physiologist can foretell exactly what reaction will follow a given physical stimulus ; previous occurrences in the tissue may entirely change the nature of the response. Adaptation, biphasic activity, and facilitation form a normal part of the vital activity of the nervous system ; they may intervene between a measured physical stimulus

[1] It will be evident that most of the ideas expressed in this chapter are based upon the theories of Hughlings Jackson (especially [57]) and the brilliant experiments of Sherrington [112], but I have thought it better not to interrupt my exposition in order to attribute to their originators conceptions, that form the basis of our present neurological knowledge.

and the physiological effect, and make it impossible to establish a direct and immediate correlation.

Therefore, between the impact of some physical force on the tissues of the body and the psychical act of sensation, are interposed reactions, which, in many cases, cannot be predicted. What wonder that those, who examined the phenomena of the senses at first hand, were dissatisfied with current psychological teaching. The neurologists were driven back more and more on to an examination of changes in structure. They found that, when certain conducting paths were destroyed, sensation was disordered in a definite manner. From this they justly concluded, that the affected paths carried certain specific impulses; and in this they were strictly within their rights. Out of this examination of the loss of sensibility, caused by lesions of the spinal cord and brain-stem, grew the dissociation method, which is the basis of this research.

But many workers on these lines failed to recognise the significance of the method they employed. They discovered that dissociation occurred as a consequence of injury to various tracts in the spinal cord; for instance, sensibility to pain, to heat or to cold may be disturbed as an isolated manifestation of a lesion of the lateral columns. This is due to interference with the conduction of impulses, which have already undergone a certain amount of qualitative integration. It is the most easily determined form of afferent dissociation, and the results seemed to coincide closely with the conceptions usually held of the natural divisions of sensation.

Lesions of the spinal cord can abolish sensibility to pain, heat, and cold, and any one of these qualities of sensation may be lost, although the others remain more or less undisturbed. But this is not the case with lesions, either of the peripheral nervous system, or of the cortex; they produce changes which cannot be classified strictly in this manner. There is a tendency, therefore, to confine the term " dissociation " to those cases, where sensibility is lost to touch, to pain, to heat or to cold, either in an isolated form or in some specific combination. Other sensory changes are spoken of as a " hypoæsthesia "; and the French include all modifications of sensibility, except anæsthesia and hyper-æsthesia, in the term " paræsthesia " ([23] p. 785).

But under both these expressions lies the false assumption, that afferent impulses are isolated specific reactions to four categories of sensory experience. Let us then avoid the use of these question-begging terms, and in each case determine the exact form assumed by the abnormal response. The researches summarised in this paper show, that the sensory elements revealed by dissociation differ according to the site of the lesion. Division of the peripheral nerves, at any rate in the limbs, reveals the specific characters of deep and superficial sensibility. Whatever may be the phylogenetic significance of this dissociation, it corresponds in man mainly to a difference in the situation of end-organs and in the course of afferent fibres. In the spinal cord this peripheral grouping has been broken up; dissociation reveals, on the one hand, qualitatively distinct groups of impulses travelling in secondary paths, on the other it may expose the primary spacial and discriminative elements of sensibility, which travel up uncrossed in the posterior columns of the spinal cord.

At each anatomical situation in the central nervous system, dissociation assumes forms appropriate to the functional combinations of afferent impulses at that point. Finally a lesion of the cortex causes changes which can be expressed in psychical terms only. The physiological substrata of sensation are disturbed, and the defects appear as want of discrimination. This is not a "hypo-æsthesia" or "paræsthesia," but a definite loss of power to recognise spacial relationships, graduated intensity, and similarity or difference in objects in contact with the body.

Analysis of afferent impulses, on their passage through the central nervous system, tells us nothing of their origin or final fate. If we wish to learn how they arose, we must produce an analogous dissociation in the peripheral nervous system; and their ultimate grouping can only be shown by breaking up those complex physiological activities, which directly underlie sensation. At either end of the physiological chain, we are brought face to face with elementary processes. At the periphery, we see how a measurable physical stimulus is transformed into various physiological reactions. At the other end we can observe the ultimate condition of these impulses, in the act of subserving sensation, after they have undergone integration and selection.

Now the grouping of afferent impulses, on their way from the periphery to the highest physiological centres, is of considerable theoretical interest and profound diagnostic importance. But it reveals little or nothing of the reactions of the sensitive tissues to the impact of physical forces, or of the physiological basis of sensation. Consequently, whilst the practical neurologist tends to concentrate his attention on the mode of conduction, the physiologist and psychologist are interested primarily in the conditions at the two ends of the physiological chain.

It is therefore important that we should appreciate clearly the significance of the facts of dissociated sensibility. We have laid down that the superficial structures of the body are innervated by two mechanisms, one of which we say exhibits more primitive characters than the other. Removal of epicritic sensibility exposes the activity of the protopathic system in its full nakedness. In the same way, when removal of the influence of the cortex cerebri sets free the optic thalamus from control, sensation assumes an overwhelmingly "thalamic" character.

In each case a lower, more primitive organisation, is permanently kept under control by the activity of a higher afferent system. But removal of this dominant mechanism does not reveal the functions of the phylogenetically older organs in all their primary simplicity. The original thalamencephalon contained elements, not only of the human optic thalamus, but also, in a crude form, of certain physiological processes, now entirely relegated to the cerebral cortex. Even the specific activity of this original thalamus was incomparably less highly developed than the dissociated thalamic functions of man. A lesion, which sets free the human optic thalamus, produces a highly specialised series of phenomena, which have never existed in this form in phylogenetic history. For a sensory reaction is the product of the activity of two great receptive centres; as we ascend the biological scale, each of these two physiological organs takes over more exclusively the initiation of certain aspects of sensation.

The setting free of a primitive activity from higher control reveals a condition, which is a part of the complete act and does not reproduce an ancient mechanism in its original form. This is evident in such a reaction as the "mass-reflex," which may make its appearance, under favourable conditions, when the human spinal cord has been completely divided. On pricking almost any part below the lesion, the movements evoked consist of flexion of the lower extremity at all joints, accompanied by an upward movement of the great toe. No primary extension occurs under such conditions, but the reaction is always a defensive withdrawal of the part from stimulation. But this is not the only effect: the bladder and rectum are excited to evacuate their contents prematurely, and a profuse outburst of sweating may be evoked by pricking the sole of the foot. Local signature has been abolished, and the response has assumed a massive and primitive character. Normally, this old protective reaction is dominated by centres in the mid-brain; its flexor movements are employed as an element in the assumption of posture, and the overflow of energy into the visceral system is inhibited from above. When this control is cut off, by division of the spinal cord, flexion occurs alone: but it now appears in its primitive form, as a massive reflex response, accompanied by visceral activity. This reaction is more perfectly and specifically flexor, than that which occurs in the dog under similar circumstances. For, in the lower animals, the specialisation of function is less complete, and, when dissociation occurs, the separated spinal cord still retains certain functions, which in man have mostly been assumed by higher centres. No flexor response is so free from postural characters, as that obtained from the human spinal centres, after complete division of the cord. In the same way, the reactions of the optic thalamus in man, freed from cortical control, are an almost perfect expression of the non-discriminative aspects of sensation.

In this way many lower activities are retained in a controlled form and are not abolished in the course of evolution, because they may be required, at some time or another, for their primitive purpose. Under abnormal conditions painful impulses of visceral origin can break through the normal resistance against them and appear in consciousness as a sensation. If so, the distribution of the areas of tenderness represents an old segmental arrangement of the central nervous system, and the reflexes, especially of the abdomen, take on a protective character. This is also the case with the curious diffuse sensation, which alone represents superficial tactile sensibility over protopathic parts. It is normally dominated by more discriminative aspects of touch, but is not abolished; for, under suitable conditions, even in normal life, it may appear as a diffuse and intolerable itching.

Pain is the oldest defensive reaction, and potentially painful stimuli are the basis of all primitive reflexes. It is, therefore, of importance for higher development, that these impulses should be rendered less effective in favour of those impressions which can lead to a more discriminative response. But, although they are controlled and even abolished, the mechanism underlying the production of pain must remain in full physiological activity, ready to play its part, should occasion arise, in the defence of the body against noxious influences.

The functions of the central nervous system are not a palimpsest where a new text is written over an earlier manuscript partly erased. The more primitive activities have been profoundly modified by the advent of the new centres, which utilise some of the faculties originally possessed by the older mechanism. In many cases the higher function could not be exercised without the existence of those lower powers which it dominates and controls. Postural reflexes, strictly adapted to conditions of space and time, could not occur without the outburst of energy which occurs in lower spinal centres on peripheral stimulation. The afferent impulses, which pour into the cerebellar system from the limbs, can only manifest their existence through the lower motor activities they co-ordinate. In the same way, the part played by the sensory cortex is based upon the activities of the optic thalamus; without crude sensations of heat and cold, discrimination would be impossible, and the finer thermal relations could not be appreciated.

When dissociation occurs, either on the reflex or psychical level, the manifestations represent that portion of the complete function which still remains active. If the factor, which has been eliminated, exercised some control over that which remains, primitive characters may appear which are not manifest under normal conditions. Should the function lost belong to the same level as that which remains, the loss of the one does not materially affect the other. But, when one of them is higher in the functional hierarchy than the other, the removal of the dominant influence sets free the lower activities to manifest themselves unchecked.

§ 2.—Integration

Between the impact of a physical stimulus on the peripheral end-organs of the nervous system, and the simplest changes it evokes in consciousness, lie the various phases of physiological activity. The diverse effects produced on the living organism by a stimulus are sorted, combined and inhibited in their passage through the central nervous system, and the ultimate results finally act upon their appropriate centres. This process of integration takes place apart from any direct participation of consciousness; and, by the time afferent impulses reach one of those centres, where they can form the underlying basis of sensation, they have been profoundly modified. Such integration is the essential task of the central nervous system; it is carried out by the exercise of certain functional activities, which I shall now consider from their theoretical aspect.

We are accustomed to think of the external stimuli we employ in scientific investigation, as if they were simple physical conditions; thus we speak of the effects produced by "a temperature of 45° C." But in reality the stimulus is always an external object, which evokes a multitude of physiological reactions; it is not only warm, but has certain tactile values, and a definite size, shape and texture. From the physiological point of view, a simple stimulus is an abstraction and an external object is a group of functional events.

Each aspect of the complex stimuli of daily life acts on one or more peripheral end-organs; in this way, the physiological response is rendered more or less specific at its inception. From the first impact of a hot or cold object on the skin, the presence of the heat- and cold-spots ensures that, under normal conditions, the reaction will be specific. Any temperature, which excites the cold-spots, generates a set of afferent impulses capable of evoking a sensation of cold. Whatever their ultimate fate, they are stamped from the beginning with a certain character, for they are capable of exciting the activity of those terminal physiological centres which subserve thermal sensibility.

So far, the conception we have put forward corresponds to the original doctrine of specific nerve energy. The older investigators believed that an impulse, once started in specific end-organs, travelled unchanged to the highest receptive centres, to evoke a response corresponding in quality and degree to the sensory attributes of the physical stimulus. Such a theory ignores the fact that a temperature of 45° C. is an effective stimulus to the heat-, the cold-, and the pain-spots, and yet, under normal conditions, produces a sensation of pleasant warmth only. In such a case, a definite physical condition excites three separate groups of end-organs. The impulses evoked are specific in quality; excitation of the cold-spots produces a sensation of cold, although the stimulus is a temperature of 45° C., and even 40° C. can evoke pain in the absence of the dominant thermal mechanism.

The simplest physical condition acting on the peripheral nervous system may produce afferent impulses which are incompatible from the point of view of sensation. But the stimuli of daily life are not simple; they are extremely complex, and give rise to a multitude of diverse impressions. These must be sorted and regrouped; some are facilitated, others are repressed before the final sum is presented to consciousness. Many afferent impulses remain on the physiological level and never form the basis of a sensation; they are destined to control reflex activity, or to co-ordinate movements of the body and limbs.

Such integration is the task of the central nervous system, and it is carried out by means of a series of receptors, which guard certain synaptic junctions on the centripetal paths. These are in reality end-organs, exposed to the influence of the complex mass of afferent impulses generated in the peripheral nervous system by the impact of an external stimulus. They are not influenced directly by the forces of the world around; they react to the diverse physiological conditions produced by the action of physical stimuli on the receptive mechanism at the periphery. Like resonators placed in a concert hall, each group picks up those qualities to which it is attuned, and refuses those with which it is not in harmony. This process is repeated throughout the central nervous system, until the final products of integration come to act on two terminal physiological centres, the cortex and the optic thalamus. Here they excite those conditions which underlie the more discriminative or more affective aspects of sensations.

But we must not forget that the larger number of afferent impulses, arising in peripheral end-organs, do not traverse the whole length of the central nervous system. Their essential task is to excite and co-ordinate reflex action without of necessity giving rise to sensation, and the earlier phases of integration are undoubtedly adapted to this end. Sensation, in the strict sense of the term, demands the existence of consciousness and is, therefore, a late development in phylogenetic history. On the other hand, reflex adaptation is one of the earliest manifestations of multicellular existence, and the central nervous system is pre-eminently an organisation for controlling reflex activities.

Such co-ordination could not occur, if there was no qualitative selection of afferent impulses at the receptive junctions of the various reflex arcs. The main function of intramedullary receptors is to lower the excitability of the reflex arc for one kind of stimulation, and to heighten it for all others. This ensures a selective response to the complex results of peripheral excitation, and at the same time precludes many afferent impulses from influencing consciousness. Thus, for example, visceral insensibility is a function of the specific reaction of receptors, and not the consequence of an absence of afferent impulses.

Each specific group of end-organs, within the central nervous system, works on the same principles; it accepts those elements of a massive reaction which can excite it to activity, and rejects those to which it cannot respond. At the same time there is evidence to show, that the synaptic junctions are subject to those refractory states and phases of heightened receptivity characteristic of all neural action.

These three processes, selection of certain impulses, rejection of others, together with biphasic states of the receptive mechanism, are sufficient to produce coherent reactions on reflex levels. The movements evoked by a stimulus bear a strict relation to its quality and intensity; they are also influenced by the conditions to which the reflex arc has been previously exposed. Thus, pricking and pressure, applied to the sole of the foot, produce different responses; and the nature of the antecedent reflexes is of fundamental importance in determining the form of the reaction to stimuli of the same quality and strength.

At this level of neural activity, all functions are simple, but at the same time highly organised. The response is rigidly pre-determined within certain limits; there is little choice, and the answer is physiologically inevitable. In strict accordance with such an arrangement, we find that the first sorting of afferent impulses within the spinal cord is concerned mainly with their redistribution according to quality. Those capable of exciting pain are gathered together, whatever their peripheral origin, and all those which can evoke sensations of heat are combined into a specific group.

After these multitudinous impulses have carried out their reflex and co-ordinating functions, the remainder are destined to act upon those centres which underlie sensation. Here the rigidity of response, so characteristic of reflex activity, would be disastrous. The limited freedom of the lower levels must be expanded, so that the physiological reaction may become less inevitable and more elastic; for we are dealing with impulses which are capable, under favourable conditions, of exciting consciousness. But the sensations to which they would naturally give rise are incompatible, and cannot exist simultaneously. Thus 45° C. is capable of producing sensations of heat, of cold, or of pain. If they could all coexist in consciousness, mental activity would be chaotic and discrimination impossible. The struggle between these various impulses takes place, therefore, on the physiological level, and the victor alone appears in consciousness as a sensation.

The simplest sensory act is the result, not only of prolonged qualitative integration, but of a constant struggle for physiological dominance. In the example I have just cited the answer is under normal conditions inevitable. But there are many cases, especially within the visceral field, where no general rule can be laid down; the response depends on the patient's idiosyncrasy or general resistance. This may be naturally low to certain afferent impressions and high to others. Moreover, his usual reaction may become changed in consequence of some functional alteration in the activity of the central nervous system; impulses may then excite sensation, which would normally have remained outside consciousness in its widest sense.

On the lowest levels of reflex activity, an impulse that is inhibited and rendered non-effective is to a great extent abolished. It may perhaps exert some influence in determining the future behaviour of the receptive synapse; but it is not manifested in any direct and immediate change. But on the higher physiological planes, impulses, which are precluded from exciting sensation, are not wiped out; they may produce a profound and manifest effect, although they cannot excite consciousness. The postural impulses, ascending in the posterior columns, normally affect two terminal centres. They reach the cortex and evoke sensations of the position of various parts of the body in space, and at the same time pass to the cerebellum to aid in the co-ordination of voluntary movement. But if they are prevented from reaching the cortex, the patient may be entirely ignorant of the position of his affected limbs, and yet the motions of these parts are perfectly co-ordinated. The sensory aspect of these impulses has been abolished, but their unconscious activity remains unimpaired.

The closer we come to those centres, which directly underlie sensation, the more evident is it that impulses, which fail to excite consciousness, do not of necessity cease to exert any physiological influence. They may be repressed by their successful rivals, but they are not therefore abolished. At any moment they may manifest their existence if the dominant influence is removed. In the absence of the afferent heat mechanism on the periphery, 45° C. produces a sensation of cold; if in addition the skin is devoid of cold-spots, the same stimulus evokes pain. Under normal conditions, there is nothing to prevent this temperature from seeming cold, except the prepotent activity of the impulses which are capable of exciting a sensation of heat. In the same way this stimulus produces impulses that can cause pain; but these are dominated by that feeling of pleasure usually associated with warmth of this degree. If, however, for some reason, no coincident thermal impulses reach the physiological centres, or if the patient's resistance to painful impressions is low, 45° C. may cause pain with its customary disagreeable feeling-tone. There is no inherent structural block on the passage of these painful impulses. Temperatures as low as 40° C. undoubtedly stimulate the pain-spots; but the impulses so produced fail to excite consciousness, because they are repressed by the other sensory effects evoked by the same external stimulus. This is even more evident on the psychical plane, when we are dealing with the interplay of two or more highly organised sensations, or other fully developed mental processes.

Sherrington has firmly established the influence of previous occurrences in a reflex arc on the nature of its immediate response. This action of the past, in the event of the moment, is even more evident when the afferent impulse excites, not a reflex, but a sensation. The phenomena of adaptation owe their existence to this factor. Thus, under favourable conditions, a temperature of 30° C. not uncommonly seems neutral to the normal hand. If, however, it has been soaked in hot water for some time, a tube at 30° C. may appear to be cold. Conversely, if the hand has been adapted to cold water, the same temperature, that seemed at one time neutral and at another cold, is now thought to be warm. The external stimulus is identical, but the reaction is fundamentally changed, owing to the diverse dispositions created by occurrences in the past.

The effective influence of the past on the reaction of the moment is even more evident in the recognition of spacial relationships. These sensations enter consciousness already measured against a postural standard, built up out of previous movements, and subject to constant change. The dispositions on which this standard depends exist on the physiological level, and a normal sensation of posture is based on activities that are integrated outside consciousness.

From the lowest co-ordinated reflexes to the psychical processes of sensation, discrimination, and feeling, the part played by the activity of the central nervous system is the same. It ensures that impulses of similar quality facilitate one another. Conversely, if two incompatible impulses are excited together, one is allowed to pass, whilst the other is rejected during one of the many integrations, either at a low or high level of functional activity. Thirdly, the vital processes of the nervous system are responsible for the phenomena of adaptation. No stimulus, however mechanically unvaried, can evoke a constant response, because the very existence of the impulses it produces changes the disposition of the reacting centre.

The effect of these three simple processes is evident at every level of neural function, from the lowest to the highest. If we trace a group of afferent impulses from their origin to the final sensations they excite, we find at each stage that the response is given in terms of the function exercised at each particular level. Thus the effect produced by a set of postural afferents is first manifested in the spacial co-ordination of reflexes. Higher in the nervous system their influence is seen in the control of posture and regulation of tone. Finally they evoke recognition of the position and movement of the body in three-dimensional space. But, whether the product of their activity be physiological or psychical, the same three fundamental processes are evident.

If, then, a receptive centre is thrown out of activity by some mechanical injury, the loss of function will be expressed negatively in terms of that level. But the positive manifestations will represent the various influences that can still be exerted by the blocked impulses. Those that can no longer express themselves psychically as a sensation can still exert their action on co-ordination and the reflexes.

The same physiological processes underlie the afferent integration of a reflex and the co-ordination of two sensations or even of two concepts. But, in each instance, the product of these vital functions is given in the terms of the level at which the impulses exert their influence; in the one case it is expressed reflexly, in the other it is manifested in some psychical act, such as sensation.

§ 3.—Projected Sensations

In the less highly developed forms of animal life the body is composed of many segments, each of which retains a considerable degree of autonomy. With the process of evolution the headward parts become increasingly dominant; they contain what Sherrington calls the "distance receptors," organs, such as the eye, associated peculiarly with projected sensations.

As far as somatic sensibility is concerned, it is the body and limbs which contain the "distance receptors"; but the cerebral cortex forms the highest physiological centre for all but the simplest projectional aspects of sensation. When the influence of the cortex is removed, and the optic thalamus exerts its activity uncontrolled, the patient may cease to associate his sensory experiences with any external agency. He complains that he is being hurt, or that something is happening to him, but fails to recognise that he is being pricked with a pin. Removal of the cortical factors in sensation has reduced to elementary proportions the power of projection, as we know it in the intact human being. It is no longer possible to recognise the size, shape, weight, and spacial relations of an external object, nor, indeed, to appreciate the relative intensity of the stimulating action it excites.

All these aspects of sensation are said to be projected; we attribute them to something inherent in the external object. The affective consequences of a stimulus betray its relation to ourselves; it is pleasant or unpleasant, salutary or harmful. But the projected sensations reveal to us the world without. They are responsible for recognition of our relations in space; to them we owe conscious appreciation of degrees of sensory intensity and the power to appraise the similarity or difference of external objects.

These factors in sensation do not depend primarily on "judgment" or "association"; for, on the physiological level, afferent impulses possess projectional characteristics. The same class of impressions which underlie discriminative sensibility can be discovered at work controlling and regulating purely unconscious actions. Analysis of the reflexes, even in man, shows that the character of the response depends not only on the quality, but on the position of the stimulated spot; scratching the sole of the foot is followed by a different movement from that caused by stimulating the skin of the thigh.

Study of the reflexes at higher functional levels shows that they are governed by remarkably complex projectional relations. So purposeful and varied is the response that it is difficult to believe the movement is not controlled by the will; and yet the patient may be ignorant that anything has happened to him. The movement is not only adjusted to the locality of the excitation and the position of the limb, but depends on the intensity and character of the stimulus. The nature of the response is determined, not so much by the absolute intensity and quality of the stimulus as by the relation it bears to those which have preceded it in time, or are in action simultaneously; the capacity of a stimulus to evoke a particular reaction depends on its relations in the past or in the present. Thus, on the reflex level, afferent impulses can be shown to be adapted to spacial conditions and to the intensity and relative character of the stimulus, although the whole procedure remains outside consciousness. If, however, they succeed in reaching the highest receptive centres, they endow sensation with spacial attributes, relative intensity, and individual character.

Evidently, therefore, the impressions produced on a sentient surface by an external stimulus are endowed with certain sensory potentialities from their origin as physiological reactions. The immediate consequence of the impact of some physical force is the production of an incoherent mass of afferent impressions, which must undergo integration before they can exercise any useful function. This is true not only for their qualitative, but also for their projectional characters.

The simplest projected aspect of sensation is shown in the power to localise the site of the stimulated spot on the surface of the body. But observations on my hand showed that the faculty was the product of a struggle between various different impulses with diverse sensory potentialities. During the earlier stages of the experiment, when the surface was entirely insensitive, all sensations were due to excitation of the end-organs of the deep afferent system which had not been affected by the lesion. At this time any tactile stimulus, applied with sufficient force to excite a sensation, was localised with remarkable accuracy. If the back of my hand was pressed with some hard object, such as a pencil, I was able to indicate the spot without difficulty. But with the return of protopathic sensibility to the surface, a struggle arose between the different forms of projection characteristic of the two different systems. Any stimulus capable of evoking a cutaneous response aroused a widespread sensation, referred to some remote part of the affected area. Brushing the back of the hand with cotton wool, in the neighbourhood of the index knuckle, produced a tingling over the whole dorsal aspect of the thumb. Not only was the sensation localised in a part distant from the point of excitation, but it seemed to be spread over an extensive area; this bore little direct relation to the size of the stimulated surface. This erroneous localisation was not fortuitous, but remained the same whatever the stimulus employed, provided it was effective; heat, cold, and pricking, applied in the neighbourhood of my index knuckle, all evoked diffuse sensations on the back of the thumb.

If, however, the stimulating object was capable of arousing a sensory reaction in both the protopathic and deep afferent systems, a struggle occurred between the two forms of projection. Suppose, for example, that a tube containing ice-water was applied to the affected area; excitation of the cold-spots produced a massive, diffuse sensation in some remote part of my hand or arm. But, if the pressure was sufficient to excite the deep system of end-organs, I showed a tendency to localise the stimulus in the neighbourhood of the spot where it was applied. The ultimate results depended to a great extent on the relative strength of the two sensations; the dominant reaction tended to determine my localisation of the site of the stimulated spot.

At first sight it is difficult to understand the significance of this double method of projection; but, in the diffuse response of the protopathic system, we find the remains of an old protective reaction, intended to preserve the part from injury. A reaction of this kind is admirably fitted to defend the animal from noxius influences: it produces movements of withdrawal, which permit of no choice. It is essentially segmental, and is seen in its most perfect form in the distribution of referred pain and tenderness due to visceral disease. The internal organs are supplied from the protopathic system; there is no controlling epicritic mechanism. Any stimulus capable of exciting pain produce a segmental response; the sensation radiates widely and is referred to remote parts, including the surface of the body. Whenever the site of the stimulated spot can be correctly indicated in visceral disease, this is due to the coincident excitation of end-organs of the deep afferent system, present in the coverings and tissues of the viscera.

With the higher development of function in the central nervous system these segmental responses are replaced by massive reactions of withdrawal affecting the body as a whole. Local defensive retraction is replaced by movements of the whole animal. The mass-reflex, which occurs in certain favourable cases after total division of the spinal cord, is an example of such a method of response. The lightest stimulation of the sole of the foot may still evoke some small adapted movement; but a vigorous scratch, or a series of pricks, causes a violent flexion of the lower extremity at all joints and contractions of the abdominal muscles. This may be associated with increased activity of the bladder and rectum and an outburst of sweating in the parts supplied from the cord below the lesion. All local adaptation to the site or nature of the stimulus is swept away in a violent and indiscriminate outburst of energy in centres cut off from higher control.

Both the segmental and the massive response are means of defence and lead to withdrawal of the part from noxious influences. But they hamper voluntary action by the uncontrolled movements they evoke, and tend to prevent escape by fixing the body in a position unfavourable for flight. The animal crawls into a hole to die or to recover, whilst man becomes fixed to his bed. It is necessary, therefore, that these modes of reaction should be brought under control of centres which allow of choice and determine movements of the complete animal. The chief of these centres is the cerebral cortex which, as we have shown, is devoted to the more highly projected aspects of sensation. It is by means of sensory projection that the affective reactions can be controlled. When we attempt to climb through barbed wire, we are forced to respond not only to the pain but to the position of the wire. The pain produced by pricking a protopathic hand is all-compelling; it is impossible not to make a movement of withdrawal. But under normal conditions this ungovernable reaction is controlled by the existence of those forms of sensibility which underlie recognition of relations in space. This enables us to choose whether the hand shall be removed or not.

Thus, in their projectional characteristics, the defensive reactions in man still show evidence of stages in their functional development. The lowest form of response is segmental, seen in the case of referred pain and tenderness of visceral origin. Higher in the scale stands the mass-reflex, which may make its appearance after injury of the spinal cord. The situation of the stimulus does not determine the distribution of the response; local signature is abolished, and the outburst of energy overflows into channels that would be blocked under normal conditions. This inevitable and diffuse reaction is in turn brought under control by those centres which are concerned with postural adaptation. They determine whether a stimulus shall be followed by withdrawal of the affected part or by locomotion of the animal as a whole. Thus, it is essentially the spacial elements in sensory impressions which have led to the transformation of an inevitable segmental reaction into a discriminative response of the complete organism.

It is possible to recognise the qualitative aspects of a sensation without attributing them to an external stimulus; such reactions are related to curselves, and do not of necessity reveal the character of the stimulating object as a constituent of the world around. Affective states associated with these sensory qualities are discontinuous; for pleasure and discomfort can no more form parts of a sensory continuum than pain, heat, and cold. They appear and disappear in consciousness, toning the sensation in a distinctive manner, without forming a connective factor in the activities of the mind.

On the other hand, the projected aspects of sensation are not related to ourselves, but to external objects. In fact, an "object" might be defined as a complex of projected responses; it is said to have characters, such as size, shape, weight, and position in space, which distinguish it from all others. The recognition of such features, however, depends on physiological activities, the product of certain definite centres in the cortex. If these processes are unable to influence consciousness, the "object" disappears, although its affective and qualitative aspects still produce their appropriate sensory reactions.

These physiological responses, which are closely bound up with the activities of the sensory cortex, are characterised by a strict dependence on past events. All projected sensations leave behind them certain physiological dispositions; for instance, the existence of the schemata ensures that a movement, occurring at one moment, is measured against the consequences of those which have preceded it. This is not a psychical act, but occurs on the physiological level; every recognisable change in posture enters consciousness already charged with its relation to something which has gone before, and the final product is directly perceived as a measured postural change. This is the case with all the higher projectional aspects of sensation; they form a continuous series of dispositions, determined by previous events of a like order. The unit of consciousness, as far as these factors in sensation are concerned, is not a moment of time, but a "happening." This consists of a group of occurrences belonging to profoundly different orders in the psycho-physiological hierarchy. For example, a voluntary movement of the hand to the face depends on simultaneous changes in at least three sets of serial activities. We must become conscious of the part of the face which is the goal of the intended movement. But the complete motor act cannot occur without the participation of perfect postural schemata; it also demands the existence of an appropriate state of active muscular tone. All these three factors are products of the immediate past, active at the moment when the movement is willed, and may be affected by injury to the sensory cortex.

The sensory activities of the cortex are not only responsible for projection in space, but also ensure recognition of sequence in time. For this would be impossible if a sensory impression had no necessary beginning or termination. One of the commonest defects produced by a cortical injury is this want of temporal definition; a stimulus, rhythmically repeated, "seems to be there all the time." The patient cannot appreciate the moment at which it is applied or removed. There is no complete recognition of an extended sequence of events.

Thus, it is the projected elements in sensation to which we owe our conceptions both of coherence in space and in time. I have attempted to show that these factors are not essentially due to judgment or conscious association, but depend to a great extent on physiological activities and dispositions. When these are permitted to excite consciousness, they appear as an ordered sensation, related to other events in the external world and extended serially in time.

Summary

The Method.

(1) All the tests we have used in our previous work on disturbances of sensation were chosen because they gave measurable results. But the numerical answers yielded by the one could not be directly correlated even with those of another closely related test.

(2) A lesion of the central convolutions sometimes produces loss of sensation in the hand which is not distributed uniformly over all the digits. Some of them may be grossly affected, others may show little or no sensory disturbance.

(3) The first sign that sensation is affected in consequence of a cortical lesion is the statement of the patient himself, that the tests are less easy on the abnormal digits. This is spoken of throughout this paper as an "introspective" change.

A more advanced disturbance is shown by a raising of the threshold. Perfect answers can be obtained if the task is made easier.

The next stage is shown by the absence of a threshold; increasing the strength of the stimulus does not of necessity produce a perfect series of responses.

(4) In such cases the test which reveals the most severe loss of sensibility will be affected over the largest number of digits.

(5) In any group of tests, which appeal to the same aspect of sensation, the one which offers the hardest task suffers most severely.

Thus, amongst the methods for examining the power of spacial recognition, a test in three dimensions is more affected than one requiring discrimination of two points or simply localisation of the stimulated spot.

(6) Thus we are able to correlate these empirical tests and divide the loss of sensibility they reveal into qualitative groups by noting the number of digits affected and the nature of the sensory disturbance on each finger.

The Results obtained from the Study of such Sensory Dissociation.

(7) This method of investigation showed that the sensory activity of the cortex could be divided into three categories. It is not associated with crude recognition of touch, pain, heat and cold, but endows sensation with three discriminative faculties.

These are: (*a*) recognition of spacial relations; (*b*) a graduated response to stimuli of different intensity; (*c*) appreciation of similarity and difference in external objects, brought into contact with the surface of the body.

These three aspects of sensation can be disturbed independently of one another in consequence of a cortical lesion.

Spacial recognition.

(8) Some loss of power to recognise passive movements of the affected part forms one of the most frequent consequences of injury to the sensory cortex. In fact, it may be accepted for clinical purposes as a leading sign in the syndrome of cortical disease. This test is a means of investigating the appreciation of spacial relationships in three dimensions; the compass test and "spot-finding" (topical localisation), as we have employed them, are explorations in two- and one-dimensional recognition.

Whenever the spacial aspects of sensation are disturbed by a lesion of the cortex, the appreciation of passive movements is most extensively and most gravely affected. Discrimination of two compass points is less severely disturbed and the loss of sensation occupies a smaller number of digits. Lastly, localisation carried out strictly according to our method shows the smallest loss of any of the three tests.[1] (Table on p. 681.)

Intensity.

(9) From the cortical aspect the tests we use for measuring sensibility to touch, to temperature and to pain are not of equivalent value. The tactile hairs demand a high degree of constancy and a strictly graduated response to stimulation. Appreciation of heat and cold, as we are forced in most cases to examine it clinically, depends comparatively little on cortical activity; for whilst it is easy to say whether an object is hot or cold, it requires an intelligent patient and favourable conditions to test the relation of two warm stimuli to one another or to determine the thresholds for heat and cold with approximate accuracy. Similar difficulties occur, to an even greater degree, with all measurable tests for painful stimulation.

At the same time these three qualities of sensation are dependent on the physiological activities of the cortex and optic thalamus to a profoundly different degree. Correct appreciation of the tactile hairs demands a high grade of cortical function, whilst a prick appeals almost entirely to the optic thalamus.

Consequently, the tactile hairs show the greatest and most extensive loss as the result of a cortical lesion. Appreciation of thermal stimuli suffers to a less degree and over a smaller number of digits, whilst sensibility to measured prick is rarely affected. (Tables on p. 686.)

Recognition of similarity and difference.

(10) The tests which come under this category are those for appreciation of size, shape, weight and texture, apart from their purely tactile qualities.

[1] This statement presupposes that the patient is able to recognise touches with some approach to uniformity. The effect of want of tactile appreciation on these tests is dealt with on p. 698.

As far as the cortex is concerned, these aspects of sensory discrimination tend to be disturbed altogether. On subcortical levels, each of them depends on more than one stream of afferent impulses. But as soon as we have to deal with loss of sensibility of cortical origin, we are face to face with destruction of the activities of the centre itself and not with disorders of conduction.

All these tests, the weights, the different shapes and stuffs of various textures, demand the same power of discrimination and are found to fail together. Tests capable of measurement, such as those for the appreciation of weight, will obviously reveal a slighter degree of change than those which consist in recognition of certain fixed shapes and textures.

The faculty of recognising the similarity and difference in objects brought into contact with the body depends upon one of the fundamental functions of the sensory cortex. It can be disturbed apart from the power to appreciate spacial relations and independently of the graduated relation to stimuli of different intensity; it may also be preserved in spite of gross defects in these functions.

Tests which depend on more than one of the fundamental functions of the sensory cortex.

(11) (*a*) The simultaneous compass test demands that a series of contacts can be appreciated with some reference to the intensity of the stimulus. But, granting that tactile sensibility is not affected, the compass points are a method of testing recognition of relations in two-dimensional space. A cortical lesion not uncommonly disturbs both aspects of sensibility, and it is important to determine how each form of sensory loss affects the records of the compass points.

When this test is disturbed in consequence of defects of tactile appreciation, the answers are confused and errors appear, not only in the recognition of two points, but also when the patient has been touched with one point only (p. 696).

If, however, tactile sensibility is not affected, the patient is unable to distinguish single and double contacts and shows a tendency to call them all "one" (p. 697).

(*b*) Topical localisation (or "spot-finding"), as carried out by our method, depends on the due appreciation of relative intensity and is also one aspect of spacial recognition.

Observations in selected cases seem to show that a defective response to contact stimuli appears on the records as a diffuse localisation. The patient may pass his indicating finger up and down the assistant's finger, saying, "The spot seems spread out so that I can't exactly say what part of it you have touched" (p. 700).

When, however, contacts are appreciated perfectly but recognition of spacial relations is disturbed, the loss of localisation may take another form. The patient is unable to decide which digit has been touched; he complains, "I have difficulty in making up my mind." The error takes the form of inability to determine on which finger or on what part of it the touch has fallen (p. 699).

(c) The power of recognising various stuffs by feeling them with the fingers is obviously dependent on the accuracy of tactile impressions. But there is another aspect of this test which demands the essential faculty of appreciating similarity and difference.

By choosing suitable cases this appeal to two sides of cortical activity can be demonstrated. When the orderly response to contact of graduated intensity is disturbed, the patient hesitates and is puzzled by the curious sensory differences in his two hands; he may, however, name the stuffs more or less correctly (p. 702). If the power of appreciating similarity and difference is alone affected, his answer approximates more or less to "I don't know what it is," and he cannot name correctly the various textile substances (p. 701).

Tests which appeal to centres in the cortex and in the optic thalamus.

(12) (*a*) *Measured prick.*—The sensory effect produced by a prick owes something to the physiological activity of the cortex; but this is small compared with the overwhelming part played by the optic thalamus.

A cortical lesion produces no true raising of the threshold to prick unless it is extensive or is associated with subcortical destruction. It may, however, induce a change in the sensation produced by pricking, which is recognised by the patient. The two hands "feel different"; it is "plainer," "sharper," "more distinct," over the normal than over the affected digits. Sometimes the whole character of the sensation is said to be changed, and seems to "tingle" or to resemble "electricity."

(*b*) *Vibration* (*tuning-fork test*).—Disease or injury at lower levels of the nervous system may destroy all power of appreciating vibration. But so grave a loss never occurs in consequence of a stationary lesion of the cortex unless it happens to be associated with epileptiform attacks or other causes of shock; for vibration appeals both to the optic thalamus and to the cortex, although the latter element is the more important in the ultimate sensation.

A tuning fork, beating 128 vibrations in the second, is almost always appreciated for a shorter period over the parts affected by a lesion of the sensory cortex. This loss of appreciation runs *pari passu* with the want of recognition of passive movement (Table, p. 713). From the peripheral end-organs to the cortical centres both tests appeal to the same physiological functions.

Subcortical Lesions.

(13) The nearer the lesion lies to the internal capsule, the more extensive is usually the loss of sensation, and the more certainly does it tend to assume a hemiplegic distribution. Moreover, the sensory disturbance is extremely gross compared with that due to more superficial lesions (p. 703).

The closer a subcortical injury lies to the surface of the brain, the more nearly does the character of the sensory disturbance approximate to that produced by lesions of the grey matter. But the grouping of the dissociated sensibility does not correspond to the three cortical categories, recognition of spacial relations, of graduated intensity and of the similarity or differences of the stimulating object. The loss of sensation still reveals the arrangement of afferent impulses before they have been subjected to integration by the sensory cortex (p. 705).

Hypotonia.

(14) An uncomplicated lesion of the sensory cortex may produce hypotonia. This is closely associated in distribution and degree with the want of recognition of posture and passive movement (Tables on pp. 718 and 721). Both defects are due to a disturbance of those physiological dispositions in the cortical centres which have been called schemata.

(15) This is a completely different condition from paralytic hypotonia, which is associated with gross loss of voluntary motor power (p. 719).

Anatomical Localisation of these Sensory Functions.

(16) Loss of sensation of the cortical type may be produced by a lesion of the pre- and post-central convolutions, the anterior part of the superior parietal lobule, and the angular gyri. These portions of the hemisphere contain the sensory centres.

(17) The form assumed by a cortical loss of sensation is not expressed in anatomical or physiological terms, but in those of the most elementary processes of mind. The anatomical lesion upsets the orderly sequence of physiological processes, and this defect of function is manifested in disturbance of the psychical act of sensation.

(18) Changes in sensibility of cortical origin on the upper extremity do not follow the distribution of axial or radicular lines. Each digit is a unit, which can be used in an isolated act either of motion or sensation: as such it is represented topographically on the cortex. The same rule applies to the palm of the hand, where the changes in sensibility correspond to the proximal extension of the affected digits. The elbow and shoulder are separately represented, because each of these joints is an important centre of the postural activities of the upper extremity.

(19) It is the functions, rather than the anatomical relations, of any one part of the body that are represented. Consequently those portions, such as the hand, which are endowed with the highest powers of discriminative sensibility, are most exclusively represented. Next in order comes the sole of the foot, which constantly exerts a discriminative action in walking.

Hence a cortical lesion may disturb the sensibility of the hand and foot without of necessity affecting the elbow, shoulder or knee.

(20) If the loss of sensation is greatest over the little finger and its neighbouring digits, the foot tends to show some sensory or motor disturbance. But when the loss of sensation reaches its maximum over the thumb and index finger, the face and tongue are liable to be affected; if the lesion lies in the left hemisphere, speech will probably have been disturbed, to a greater or less extent, at some time in the history of the case (Tables on p. 733).

(21) The three aspects of sensibility, due to the activity of the cortex, are

not disturbed uniformly in every instance of a lesion to the surface of the hemisphere. In certain rare cases complete dissociation may occur (Table on p. 738).

(22) This shows that the three fundamental functions of the sensory cortex are not represented to an equal degree in all parts of its extent.

(*a*) Injury anywhere within the sensory area on the hemisphere is liable to cause some loss of appreciation of spacial relationships in the hand or in the foot. But the farther forward it lies within this region, the grosser and more extensive is the disturbance shown by the spacial tests.

(*b*) The power of recognising differences in weight and shape is most severely and most extensively affected by a lesion which falls over the post-central convolution.

(*c*) Those tests which depend mainly on due recognition of stimuli of graduated intensity are more likely to be disturbed, when the injury falls upon the posterior and inferior portions of the sensory area. Any lesion lying mainly within a zone which occupies the foot of the pre- and post-central convolutions, the angular and supra-marginal gyri and the superior parietal lobule, is liable to be associated with disturbances of tactile sensibility. If this is severe and extensive, the patient may be unable to distinguish various degrees of warmth about which he has no doubt on the normal hand.

Theoretical Conclusions.

(23) The sensory disturbance produced by a cortical lesion is not a paræsthesia or a hypoæsthesia, but a definite loss of power to appreciate one or more of the three aspects of sensation, which depend on the physiological activity of the cortex.

(24) Analysis of afferent impulses, on their passage through the central nervous system, tells us nothing of their origin or final fate. If we wish to learn how they arose, we must produce an analogous dissociation in the peripheral nervous system; and their ultimate grouping can only be shown by breaking up those complex physiological activities which directly underlie sensation. At either end of the chain we are brought face to face with elementary physico-physiological and psycho-physiological processes respectively.

(25) If the functions of a lower, more primitive organisation are kept under control by the activity of a higher afferent system, the removal of this dominant mechanism does not exhibit the vital processes of the phylogenetically older organs in all their primitive simplicity. The setting free of a primitive activity from higher control reveals a condition which is part of the complete act. Thus, the reactions of the human optic thalamus, freed from the restraining influence of the cortex, are an almost perfect expression of the non-discriminative aspects of sensation.

(26) When dissociation occurs, either on the physiological or psychical level, the manifestations represent that portion of the complete function which still remains active.

Should the function lost belong to the same level as that which remains, the loss of the one does not materially affect the other (*e.g.* dissociation of the various aspects of cortical sensibility). If, however, the factor which has been eliminated exercised some control over that which remains, primitive characters may appear that are not manifest under normal conditions (*e.g.* the thalamic syndrome).

(27) The simplest physical stimulus, acting on the peripheral nervous system, may produce afferent impulses which are incompatible from the point of view of sensation. These are sorted and re-grouped; some are facilitated, others are repressed, before the final sum is presented to consciousness. Many afferent impulses remain on the physiological level and never form the basis of a sensation: they are destined to control reflex activity or to co-ordinate movements of the body and limbs.

(28) The simplest sensory act is the result, not only of prolonged qualitative integration, but of a constant struggle for functional dominance. On the higher physiological planes, impulses which are precluded from exciting sensation are not wiped out; they may produce a profound and manifest effect, although they cannot excite consciousness.

The closer we come to those centres which directly underlie sensation, the more evident is it that impulses, which fail to excite consciousness, do not of necessity cease to exert any physiological influence. They may be repressed by their successful rivals, but they are not therefore abolished.

(29) Similar physiological processes underlie the afferent integration of a reflex and the co-ordination of two sensations or even of two concepts. But, in each instance, the product of these vital functions is given in terms of the level at which the impulses exert their influence; in the one case it is expressed reflexly, in the other it is manifested in some psychical act, such as sensation.

SHORT ACCOUNT OF SOME ILLUSTRATIVE CASES

This portion of the paper consists of two parts. In the first I have given a short account of a series of illustrative cases [Nos. 2, 3, 5, 6, 8, 15, 18, 19, and 23].

In the second part I have described as far as possible the situation and nature of the lesion in each case. Professor Elliot Smith has kindly localised approximately the site of the injury on the surface of the hemisphere from the data given to him. I am fully aware how difficult it is to judge of the position of a cerebral lesion from a wound on the surface of the skull, but reproduce figs. 3 to 23 with a full consciousness of the uncertainty of such localisation.

(A) Short Account of a Series of Illustrative Cases

Case 2.—An example of injury to the cortex without penetration of the skull. Wounded January 26, 1916, by the fragment of a shell in the anterior part of the left parietal region. Not trephined. Radiograph showed injury to outer but none to inner table of the skull. Examined in the third and fourth *weeks after the wound. Right upper extremity only affected. Grasp of right hand diminished. Individual movements of the fingers were defective. Writing changed. No hypotonia. Right wrist-jerk increased. Other reflexes normal. Sensation most severely affected over the little finger, rapidly improving towards the pre-axial parts of the hand. Passive movement badly appreciated over four digits, the compass test over one; localisation not affected. The tactile hairs, thermal tests and prick showed introspective changes only, confined to the little finger. Weights and the texture of various fabrics were not perfectly recognised over the little finger. He greatly improved, and a set of observations made ninety-four days after the wound showed changes in the little finger only.*

Lieutenant F. W. B., aged 31.

On January 26, 1916, he was hit by the fragment of a shell which burst in the air. He fell, but does not think he lost consciousness. The right arm "dangled loosely and was all pins and needles"; he could, however, move it at the shoulder. He walked to the dressing station and, after a night spent in the field ambulance, was sent to the base next day. On February 5 he was admitted to the Empire Hospital for Officers, under my care. He thought his arm had rapidly improved up to January 31, but since that time its condition had remained stationary. Neither face nor leg had been affected at any time.

On admission, the wound consisted of a stellate bruised tear in the scalp about 2·5 cm. in length, which healed rapidly. The centre of this cut was situated 19 cm. from the nasion and 5 cm. to the left of the middle line. The total nasion-inion line measured 34 cm. A radiograph showed injury to the outer, but none to the inner table of the skull.

The following observations were made in *February*, 1916, *during the third and fourth weeks after the wound.*

He was a most intelligent man, an engineer by profession, and his introspective experiences were unusually definite and well expressed. The examination interested him and he showed no general fatigue. The effects of local fatigue were obvious in the readings from the affected parts, but elsewhere his answers remained remarkably constant from day to day.

Speech was normal. There was some headache at first, but it rapidly disappeared. There was no nausea or vomiting, even when he was first hit. He had not suffered from convulsions or seizures.

Vision was unaffected, and the discs showed no change of any kind. The pupils reacted normally, ocular movements were well performed and there was no nystagmus.

Face, tongue and palate were unaffected.

Reflexes.—The only abnormality in the superficial or deep reflexes was shown by a definite increase of the right wrist-jerk compared with the left.

Motion.—The grasp of the right hand was certainly somewhat affected; for, although he was by nature right-handed, the grasps were equal. Individual movements of the digits of the right hand were less quick than those of the left, and he said, "All the fingers come forward and I have to pick out with the thumb the one I want to touch." This exactly expressed the condition observed. The greatest clumsiness occurred, when he attempted to approximate the tip of the thumb to that of the little finger. When he held out his hands in front of him, there was slight difference only in the alignment of the fingers. But when his eyes were closed the little finger became abducted and fell away, and the inco-ordination of the individual movements of the other digits was greatly increased.

There was no wasting and no change in tone.

All the movements of the right elbow and shoulder were strongly performed against resistance, but he was somewhat clumsy when he attempted to touch his nose rapidly with his right fore-finger. This was not increased by closing his eyes.

He could still throw with remarkable accuracy, but his writing was somewhat affected; this was particularly evident in the curves of such letters as B, M, N, and W. He found it easier to write with a pencil than with a pen, for the nib seemed to catch in the paper.

The lower extremities were in every way normal and the right leg had never been affected.

Sensation (between February 9 and February 24, 1916).

He said he was in every way normal except in the right hand, where his little finger and corresponding parts of the palm and dorsal surface "felt stiff." At first this "feeling" occupied the ulnar aspect of the forearm to the elbow; but this had to a great extent passed away.

	Right (affected) hand.					*Left hand.*
	Little finger.	Ring finger.	Middle finger.	Index finger.	Thumb.	Normal digits.
Measured movement	12° to 25°; gross errors	5° to 8°	6° to 10°	3° to 6°	1°. Normal	1° or under.
Vibration ...	Gross loss	Affected	Affected	Affected	Equal R. and L.	—
Compass test	Perfect at 2 cm.	Perfect at 1 cm.	Perfect at 1 cm.	Perfect at 1 cm.	Perfect at 1 cm.	Perfect at 1 cm.
Localisation	Perfect	Perfect	Perfect	Perfect	Perfect	Perfect.
Tactile hairs	14 grm./mm.²; introspective change	14 grm./mm.²	14 grm./mm.²	14 grm./mm.²	14 grm./mm.²	14 grm./mm.²
Thermal ...	Slight change; introspective	Normal	Normal	Normal	Normal	—
Prick ...	Slight change	Same R. and L.	Same R. and L.	Same R. and L.	Same R. and L.	Threshold, 3 grm.
Weight ...	Slower; introspective change	Perfect	Perfect	Perfect	Perfect	Perfect (twelve tests on each finger).
Texture ...	Defective	Good	Good	Good	Good	Quick at recognising all four fabrics.

The lower extremity was entirely unaffected.

Measured movement.—All the digits of the right hand except the thumb were affected. In the index, middle and ring fingers the extent of the passive movement necessary to evoke recognition was considerably increased, but in the little finger the answers were confused; in three instances he indicated movement in the wrong direction with a range of 20° to 25°. He said, "I appreciate some movement, but cannot tell its direction with certainty."

Compass test.—The little finger alone was affected and the threshold was raised to 1·5 cm. But even at this distance his answers were doubtful, though correct, and it was not until the two points were separated by 2 cm. that he became certain. He complained: "The thing that puzzles me on the little finger is that it seems like an echo. I don't know whether it is two or one with an echo. When they are close together I can't tell whether it is one point, which influences the part around, or two points. When they are wide apart, the second point falls outside this part influenced, and I know it is two."

Tactile hairs.—He gave a perfect series of answers on the little finger even with a hair of 14 grm./mm.², but the response was slower from the right than from the left. He said, "The first two or three touches were fairly clear; but it seemed to become more difficult and I wasn't so certain. I was doing it with an effort on the affected hand, instead of not thinking about it."

Thermal tests.—The only change was discovered in the little finger. The threshold for heat and for cold was not materially different in the two hands, but such temperatures as 30° to 40° C. seemed warmer on the normal than on the affected side.

Prick.—There was a definite introspective change between the sensation in the two little fingers; with 3 grm. he said the prick was "quite clearly felt" on the normal hand, but was "occasionally a slight prick" on the right little finger. On increasing the strength of the stimulus to 3·5 grm., he said it was "clearly a prick" on both hands. No such difference was found between the sensation from the two ring fingers.

Weight.—When various weights of between 20 and 100 grm., covering exactly the same surface, were added and removed, he gave quick and perfect answers on all but the little finger of the right hand. Here I was forced to wait longer and he responded with much less certainty. He said, "I've more difficulty with the little finger. The changes in weight are not so pronounced, and I was not so absolutely sure that I was right as on the other fingers."

This difference came out even more clearly, when he was permitted to lift the finger on which a weight had been placed. When asked to compare 80 and 100 grm. he made no mistakes anywhere except on the little finger of the right hand; here out of six tests he failed in three and was not perfect in his answers when comparing 70 and 100 grm. He said, "On the right little finger it is more of a strain; unless I pick it up at once I can't get it at all. It seems to merge into a confused feeling."

Texture.—For this test on the right hand he invariably used the thumb and index finger, and when forced to use the little finger he said he judged by the sensation of the thumb alone. When the various fabrics were rubbed across the digits, he complained that they "felt different on the right little finger." Here he recognised silk and cotton, but was uncertain about flannel and ribbed velvet, except that he said flannel was "rougher." When each fabric was rubbed over one little finger and then over the other, he failed to recognise that the ribbed velvet was the same substance on the right as on the left hand; the same error occurred with silk.

He was examined again on *April 30, 1916, ninety-four days after the wound.* He still noticed the same difficulty in writing, but found no difference when playing golf.

The arm-jerks were now equal. The grasp of the right hand had greatly improved, but isolated movements of the little finger were still clumsy. When he held his hands out in front of him, the various parts were in perfect alignment, and the little finger no longer fell away when the eyes were closed. There was no hypotonia.

Sensation had improved greatly. All the digits of the right hand gave perfect readings with 1° of *passive movement*, except the right little finger, where from 1·5° to 2° were required. To the *compass test* he had no difficulty at 0·75 cm. on all the digits, except the little finger; here he failed at this distance, but gave a perfect series at 1 cm. He said, however, "On the right little finger I still have the feeling of an echo. It is harder for me to tell whether there are two points, but directly you put them further apart I am certain." *Localisation* was perfect. He could appreciate a *tactile hair* of 14 grm. mm.^{2} on his right little finger, but said the sensation was "duller and fainter, less clear" than on the normal hand. *Weights* and *texture* were now perfectly appreciated.

Case 3.—An instance of dissociation of sensory functions due to a cortical injury. Wounded June 7, 1917, by a rifle bullet. Trephined over the right Rolandic area June 8, when "a large piece of bone and extradural clot were removed." Admitted under my care July 7, 1917, with an unhealed wound in the right parietal region. At that time the lower part of the left half of the face moved poorly and the tongue was protruded to the left. Left arm-jerks were exaggerated. Left lower abdominal reflex defective. Left hand affected; individual movements impossible. Movements of left wrist and elbow less powerful than those of right. No hypotonia at this stage. Sensation showed from the first profound dissociation. The spacial aspects were not normally appreciated, and the power of recognising similarity and difference was diminished, but he reacted perfectly to graduated tactile and thermal stimuli. He remained under observation and was examined from time to time. A series of records, made during the 10th and 12th months after the wound, showed that hypotonia had gradually appeared in those fingers in which the loss of recognition of posture and passive movement was most severe. This hypotonia accompanied the return of motor power and recovery of the reflexes. Sensation showed the same fundamental dissociation as before. This made it possible to work out the form assumed by the loss of appreciation of weight and texture, in the absence of changes in tactile sensibility. It also showed the nature of defects in the records of the compass test, when spacial relationships are disturbed, but touch is not affected.

Bombardier J. W. B., aged 26.

On June 7, 1917, he was hit by a sniper's bullet, which penetrated his helmet. He remembers a singing in his head and a feeling as if two hammers met; then he dropped. He noticed that his left arm was weak, but after about twenty minutes he could walk with help, though his left leg was distinctly affected at first. After his wound was dressed, he walked about 5 kilometres to the motor ambulance. He arrived at Boulogne on June 8, and was trephined over the Rolandic area. The field card states that "a large piece of skull and extradural clot" were removed.

He was admitted to the London Hospital on July 7, 1917, with a deep lanceolate wound, situated from 17·5 to 19 cm. back from the nasion, and from 4 to 8 cm. to the right of the middle line. The total nasion-inion line measured 35 cm. The wound had a granulating base, which pulsated heavily. Cultures grew *Staphylococcus albus* only.

CONDITION IN JULY, 1917, FORTY DAYS AFTER THE WOUND.

The importance of this case lies in the condition, which was present many months after the wound had healed; but I shall summarise first of all the observations made shortly after his first admission to hospital.

His mental state was excellent and speech had not been affected at any time.

Vision was perfect, the fields were not restricted and the discs were normal.

The pupils reacted normally, movements of the eyes were well performed and there was no nystagmus.

The lower part of the left half of his face did not move so well as the right, and the tongue was protruded a little to the left.

Reflexes.—The left wrist-jerk and triceps-jerk were distinctly exaggerated, but the knee- and ankle-jerks were equal and there was no ankle clonus. The plantar reflexes were normal. A reflex could be obtained from all four areas of the abdomen; but, whereas those from the right upper and lower segments were quick and vigorous, the reflex from the left lower quadrant was obtained with difficulty and was of small range.

Motion.—The grasp of the left hand was profoundly diminished and registered on the dynamometer 5, compared with 58, the force exerted by his right hand. He could not carry out individual movements with the fingers of the left hand; they tended to remain passive or to be flexed in a bunch, whilst the thumb moved across to be approximated to the tip of each finger in turn. Movements of the left wrist were feeble and those of the elbow were not so strong as on the other side. The shoulder was not affected.

The fingers of the left hand were not in alignment, when the hands were held out in front of him; the wrist became flexed and the whole arm swayed unsteadily. As soon as the eyes were closed the hand dropped and the fingers became irregularly flexed. Even with the eyes open, on attempting to touch his nose, the movements of the left hand were inco-ordinate and unsteady, and when they were closed the ataxy was pronounced.

There was no obvious spasticity and no hypotonia.

The left forearm and hand were distinctly wasted; this was most visible in the interossei and was less evident in the muscles of the thumb. The arm and shoulder muscles were not affected.

In the left lower extremity there was no gross loss of power and no wasting; but the movements were not quite so accurate as those of the right leg. He could, however, stand equally well on either foot with the eyes closed.

Sensation.—The outstanding feature of the sensory disturbance was the considerable want of recognition of measured movement in all the digits and the wrist, together with great loss of discrimination of weights in the little and ring fingers, in spite of perfect sensibility to touch. This is a case where the various sensory activities of the cortex were dissociated from an early stage.

I shall, therefore, pass over his condition during the intermediate period in order to lay stress on the observations made during *March, April and May*, 1918, *ten to twelve months after the wound.*

The scar was firm and did not pulsate. He had been discharged from the Army and was at work, rarely suffering from headache except when tired.

He was remarkably bright and intelligent, handing himself over willingly for examination. His answers were given without hesitation; he made no attempt to interpret his sensations and was not introspective.

Reflexes.—Great improvement had taken place and the two elbow-jerks were almost of equal strength; there was no difference between the triceps-jerks. The abdominal reflexes were equally brisk on the two sides in all the areas.

Motion.—The grasp of the left hand had greatly improved and individual movements could now be carried out by each finger in turn. They were, however, slower and less perfect than those of the right hand, which were quick and precise. The various digits were in good alignment, when he held his hands out in front of him, but they fell away when he closed his eyes and the movements of the fingers of the left hand became distinctly ataxic.

The little and ring fingers of the left hand, and to a less degree the middle finger, were now definitely hypotonic, whilst the index and thumb were normal.

There was no wasting; but the ulnar half of the left hand was soft and toneless to the touch, compared with similar parts of the right.

Sensation.—He was at work but had no necessity to use his left hand except for lifting. He could pick up objects with the forefinger and thumb but complained that he was clumsy with the middle, ring and little fingers.

	Left (affected) hand.					*Right hand.*
	Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.	Normal digits.
Measured movement	1.° Introspective	1° to 2°. Direction defective	1° to 2°. Direction defective	Gross loss	Gross loss	Perfect at 1°.
Vibration ...	Not affected	4 to 6 sec.	4 to 5 sec.	10 sec.	10 sec.	—
Compass test	1 cm.	1 cm.	1 cm.	Gross loss at 5 cm.	Gross loss at 5 cm.	Perfect at 1 cm.
Localisation	Good	Good	Good	Affected	Affected	Good.
Tactile hairs	Normal	Normal	Normal	Normal	Normal	Perfect with 14 grm./mm.^{2}
Thermal ...	Normal	Normal	Normal	Normal	Normal	Can distinguish 35° and 45° C. perfectly.
Prick ...	Normal	Normal	Normal	Normal	Normal	Threshold about 4 grm.
Weight ...	Perfect	Perfect	Distinctly affected	Gross loss	Gross loss	Perfect appreciation of 80 and 100 grm. Perfect answers to addition and subtraction.
Form ...	Perfect	Perfect	Slightly affected	Gross loss	Gross loss	Perfect appreciation of the six tests. Objects rolled over palmar aspect of fingers.
Texture ...	Perfect	Perfect	Affected	Gross loss	Gross loss	Perfect appreciation of ribbed velvet, silk, flannel and calico rubbed over digits.

Passive movement was appreciated within normal limits on the left thumb, but he said it was "less easy" than on the right hand. With the index and middle fingers the readings were slightly raised, and he tended to be somewhat uncertain of the direction of the movement with an excursion of 1° to 2°. Both ring and little fingers were grossly affected; he did not appreciate a movement of less than 20° to 30° and in many instances its direction was wrongly indicated.

The *compass test* gave normal readings over the thumb, index and middle fingers of the affected hand, but over both ring and little fingers contact with two points was invariably called "one," even when they were separated to a distance of 5 cm. He said, "I feel the pressure quite well, but it all feels the same. It is not like the other fingers."

Localisation had throughout remained unaffected on the thumb. In view of the normal state of tactile sensibility, I chose the palmar aspect of the four post-axial digits for a more extended series of observations than usual on topical localisation. Twelve contacts were made, first on the normal and then on the affected side; this was repeated three times on each hand to the number of seventy-two in all. Every touch on the normal hand was correctly localised, but the answers from the fingers of the affected side showed a disturbance increasing in a post-axial direction. Thus, whilst all nine stimuli were correctly localised over both the left index and middle fingers, he made two mistakes over the ring, and six over the little finger. Of these six errors one was placed on the wrong digit, three were more or less distal, and two were proximal to the spot stimulated. Both the mistakes on the ring finger consisted in choice of the wrong digit.

All the digits of the affected hand gave perfect records to the *tactile hairs*, even with 14 grm. mm.^{2}, the smallest strength of stimulus to which he responded constantly on the normal fingers. There was no introspective difference between the two hands. *Thermal sensibility* was equally good on both sides and *prick* was not affected. The whole of this aspect of cortical activity remained throughout untouched by the destructive effects of the lesion.

But the appreciation of relative weights, form and texture was gravely affected in the little, ring and to a less degree in the middle fingers of the left hand. In view of the perfect reaction to varying intensities of stimulation, this was a most instructive dissociation.

Weight.—This case also illustrated the rule that with a cortical lesion inability to discriminate weights is independent of the manner in which they are applied. If the hand was carefully supported, and weights were added or subtracted on each digit in turn, he failed to recognise the direction in which the load had been altered in spite of perfect tactile sensibility. He was also unable to recognise the difference between two weights placed one after the other on the affected fingers, even when he was permitted to move them and to "weigh" each test-object in turn.

Thus, with the method of addition and subtraction, the thumb and index gave normal readings; on the left middle finger he did not reply to five of the twelve changes in weight, on the ring finger he did not answer on six occasions and thought all the weights had been removed, when one of 20 grm. still remained on the hand. On the little finger he failed to appreciate ten out of twelve changes and asserted that there was no weight when 140 grm. still remained on the hand. He also experienced hallucinatory changes of weight, describing addition and removal, when the pile remained untouched. He stated, "The only ones that seem to me bad are the middle, ring and little fingers; the little finger is the worst. The first (index) is all right."

The following observations were made on his power of comparing two weights by "weighing" them; they were placed one upon another, in irregular sequence, on the palmar aspect of the terminal phalanx of the little and ring fingers and of the middle and index fingers. Two digits were chosen so that the movements should not displace the weight, as would have been the case if one finger only had been selected. On the normal hand, and with the left index and middle finger he recognised the difference between 80 and 100 grm. on every occasion. But with the left little and ring fingers he could not even appreciate a difference of 100 and 20 grm. All his answers took the form of "I can't tell, I don't know," or some similar expression of ignorance.

An unusually extensive series of observations were made on his power of recognising *form*, when solid test-objects were rolled over the palmar aspect of each digit in turn; for on the normal hand he was particularly good in recognising the shape of the solid blocks cut to scale. On the left thumb and index he made no mistakes, on the middle he was a little uncertain, but on the ring and little fingers his answers were gravely defective. Thus on the latter he said, "Everything feels alike; except that they scratch or hang on to the flesh; I cannot tell they have any shape at all." Pyramid, ovoid and cube were all said to be "square," whilst a cylinder and cone were called "round" and a sphere was not recognised at all.

The power of appreciating differences in *texture* was gravely affected in the little and ring and, to a less degree, in the middle fingers of the left hand. The ribbed velvet, silk, cotton and flannel were named correctly over all the digits of the normal hand and over the left thumb and index. But on the middle finger velvet was called "silk," flannel was thought to be "cotton," whilst silk and cotton were named correctly. Over the little and ring fingers he either said the fabric was "rough" or confessed he did not know. "Everything seems rough on these fingers and I find it difficult to tell on the middle finger. The first finger and thumb are all right."

But in spite of this profound disturbance, his power of appreciating *roughness*, measured with the Graham Brown apparatus, was identical on the digits of the two hands.

Case 5.—To illustrate the introspective aspects of the sensory loss of cortical origin. Wounded June 6, 1916, by a rifle bullet. A radiograph showed injury to the outer plate of the skull in the left parietal region, but none to the inner surface. He was not trephined. Admitted to the Empire Hospital December 4, 1916. The wound was represented by a fully-healed scar, 3 cm. in length, in the left parietal region, 23 cm. from the nasion and 5 cm. from the middle line. The importance of this case lay in the patient's remarkable power of describing his sensations over abnormal parts. Individual movements of the right hand were good with the eyes open, but clumsy when they were closed. The right thumb and index finger were hypotonic. In the right foot he had lost to a certain extent the extraordinary powers of moving his toes which he still possessed on the normal side. Otherwise it would not have been possible to discover any affection of motor power in the lower extremity. The reflexes were normal. Sensation was most severely affected in the thumb and index finger of the right hand. In the little finger many aspects of sensation showed introspective changes only. The tactile hairs, thermal tests and prick showed the severest and most extensive loss. Sensory changes, similar in quality, but somewhat less severe, were present in the right foot.

2nd Lieutenant R. S. C., aged 28.

In the early hours of June 6, 1916, he was hit by a sniper's bullet. He was not wearing a helmet. He spun round and felt as if some one had stuck a boathook into his head, pulling him backwards. Apparently he fell, but did not lose his senses, and after his wound was dressed he went back to his machine-gun. But "everything seemed so slow; I seemed to have lost touch with my men. I was thinking very slowly." He had a violent headache and felt sick, but did not vomit.

He stopped one day in the Field Ambulance and on June 7 reached the Casualty Clearing Station. Here a piece of the casing of a bullet was removed from the scalp. A radiograph showed injury to the outer surface of the skull, but none to its inner aspect. He was not trephined.

The wound healed, and he was discharged on June 24 from the 3rd London General Hospital, with a scab still present on the site of the injury. He could not sleep and the noise of the gramophones made him feel sick. The next four months he spent in the country, in a most unsatisfactory condition physically. He was easily fatigued and fell into violent rages; when they came on, whether by day or by night, he would leave the house and walk up and down in the garden for hours.

During the first week of November, 1916, he was sent back to light duty. The headache returned and the attacks of "violent feelings" became more pronounced; they were followed by depression and suicidal ideas. He acted as assistant adjutant, working from 9 a.m. till 7 p.m. He rapidly became so ill that he was sent to see me by his senior medical officer, on November 30, 1916, and was admitted to the Empire Hospital for Officers on December 4. Here he rapidly improved, and the following account is based on observations made during *January*, 1917, *seven months after the injury*.

The wound was then represented by a fully healed scar, 3 cm. in length, in the left parietal region. The anterior limit was 23 cm. from the nasion and 5 cm. from the middle line of the skull.

The total nasion-inion line measured 35 cm. A radiograph showed that the outer plate of the skull had been damaged in the region of the injury, but the inner plate seemed to be intact. There was no evidence of a foreign body or dead bone within the cranial cavity.

He was a highly educated man of unusual intelligence. His answers to measured tests were far above the average, especially from the introspective point of view. He tended, however, to interpret his sensations, and this made him slow to reply when an affected part was being tested. He gave himself over most willingly to my examination because, in spite of his repeated complaints, no one had examined into the condition of his right hand. The fact that he had never been examined, even superficially, from a neurological point of view, was one of the most potent causes of his anger and misery. His power of attention was good, but he became tired easily, and care had to be taken to make the examination in short spells, selecting days when headache was absent and he had slept well. Sleep soon improved, and he ceased to dream unpleasantly. His memory was not good on admission, but became much stronger with rest and quiet. There were no hallucinations or delusions at any time. At first he was irritable, but this passed away and he became particularly easy to deal with.

On admission he had a stutter which slowly disappeared; this was a purely psychical manifestation, and speech was not otherwise affected. He had had no seizures or convulsions. The headache was at times severe and was of the same character throughout; it was "like a toothache," mainly on the left half of the head. All nausea had disappeared for some months before admission.

The discs were unaffected. The pupils reacted normally. All movements of the eyes, face, and tongue were carried out well.

Reflexes.—All reflexes, superficial and deep, were equal on the two sides and were normal in character.

Motion.—The grasp of the right hand was certainly less powerful than that of the left, but there was no paralysis. Individual movements of the fingers could be carried out easily so long as his eyes were open, but became very clumsy when they were closed. He could not write so easily as before he was wounded, especially if he was tired, and his handwriting had changed somewhat in character. He could still play the piano, but his right hand "was not so good as it might be."

The right thumb and index finger were definitely hypotonic; the condition of the middle and ring fingers was more doubtful, but the tone of the little finger was certainly not diminished. There was no wasting of the hand.

The wrist, elbow, and shoulder were unaffected.

Had he been brought up under ordinary conditions, there would have been no evidence that the movements of the right lower extremity were in any way affected. But as a child he had lived on a sandy beach in China and his father had not permitted him to wear boots. His agility with the toes of the normal foot was remarkable; he could cross the great toe over the second, could spread the toes and bring them together again, just as we can adduct or abduct our fingers. He had no difficulty in picking up a penny from the bed with his foot. But, with the right foot, he could no longer cross the toes, though he could abduct or adduct them, less perfectly than with the other foot. Individual movements of the right great toe were still possible, but were slower and less accurate than those of the left. There was no gross hypotonia, but it seemed to me as if the right great toe could be passively extended to a greater degree than the left, and he said, "I think the great toe of the right foot is slack like the first finger (index) of the right hand."

Apart from this loss of special aptitude in the foot, there was no want of power anywhere in the right lower extremity.

His gait was normal and he could stand well on either foot with the eyes open; but when they were closed he said, "I don't trust myself so much on the right; I have to plant it more definitely before I begin; whereas I don't mind how I put the left foot before I close my eyes."

Sensation.—He complained mainly of the index finger of the right hand and said, "If I wanted to feel for a pin I should use the first finger of the left hand, but with the right I should use the middle finger, because the first finger felt as if there was a corn on it."

	Right (affected) hand.					*Left hand.*
	Little finger.	Ring finger.	Middle finger.	Index finger.	Thumb.	Normal digits.
Measured movement	1°	8° to 15°	10° to 15°	Gross loss	Gross loss	Perfect with 1°.
Vibration ...	No shortening	Affected	Affected	Affected	Affected	—
Compass test	1 cm., introspective	Not quite perfect at 3 cm.	Not quite perfect at 3 cm.	Gross loss	Gross loss	Perfect at 0·75 cm.
Localisation	Good	Good	One error	Gross loss	Gross loss	Perfect.
Tactile hairs	23 grm./mm.²	23 grm./mm.²	23 grm./mm.²	No threshold	No threshold	21 grm./mm.²
Thermal ...	Introspective	Affected	Affected	Gross loss	Not tested	35° and 40°, perfectly discriminated. Thresholds 30° C. and 27° C.
Prick ...	4 grm.	8 grm.	8 grm.	8 grm.	Not tested	Threshold, 4 grm.
Weight ...	Definite loss	Definite loss	Gross loss	Gross loss	Gross loss	Perfect series on addition and subtraction.
Texture ...	Introspective	Gross loss	Gross loss	Gross loss	Gross loss	Perfect appreciation of four fabrics on each digit.

Measured movement.—The loss of appreciation of passive movement was so gross in the thumb and index finger of the right hand that 40° sometimes evoked no reply. He said, "It is pure guessing; I have no idea which way it is moving." With the middle and ring fingers he not only recognised the movement, but also its direction at a range of between about 8° to 15°, whilst with the little finger he answered correctly in every instance to a movement of 1°.

Vibration exactly bore out the results obtained with the test for passive movement; the little finger was entirely unaffected, whilst the other four digits of the right hand showed considerable shortening of the period during which the tuning fork was appreciated.

Compass test.—Over the thumb and index finger, he failed entirely to recognise the two points at a distance of 5 cm., and frequently thought that contact with one point was "two." In fact, his answers on these digits showed complete confusion. On the middle and ring fingers his answers at 2 cm. were confused, but at 3 cm. they were almost perfect. On the little finger he could discriminate one and two points as 1 cm., and made no mistakes; the sensation was not, however, the same as on the normal little finger. There is no doubt that on this digit, at any rate, the compass test was disturbed by the changes in tactile sensibility.

Localisation was profoundly disturbed on the thumb and index fingers. A single contact might appear to be two, or even three touches, each of which was localised in a different position. He would call out, "Just wait a minute, I want to touch a dozen different places." Then after a pause, "I think it must have been there," indicating a wrong spot. He also said, "Unless I answer at once I am done; I go on wandering about." Now, there can be little doubt that this is an example of a double defect; he had not only lost, to a great extent, his power of appreciating the locality of the stimulus, but the sensation produced by the contact was in itself disturbed. On the middle finger he made one mistake, referring the touch to a proximal point on the ring finger. On the ring and little fingers he made no mistakes.

The greatest disturbance in this case was shown by those tests which demanded an accurate response to stimuli of different intensities. For this aspect of sensibility was certainly affected over all five digits, whilst on the spacial side even measured movement showed no defect in the little finger. Moreover, his own statements with regard to his tactile and thermal sensations throw considerable light on the nature of the changes caused by a cortical lesion.

Tactile hairs.—The thumb and index finger were profoundly affected to this test. No threshold could be obtained, and on first testing with a hair of 23 grm./mm.² he gave as many correct answers as to a series of subsequent contacts with one of 100 grm./mm.² (*vide* p. 689). The patient said: "On the left (normal) side I felt as if you were putting on and taking off a fine wire point. On the right hand it was exactly as if a mosquito drew its leg along the surface. I never felt a distinct pressing on. Sometimes I felt it vaguely as if it was still there, and I wanted you to press it and take it away again, so that I might be certain if it was there or not."

On the middle and ring fingers a threshold was obtained with a hair of 23 grm./mm.², but his answers were slow and he said that he had difficulty in making up his mind. On the little finger the record with 21 grm./mm.² was defective, but he gave perfect replies with 23 grm./mm.² There was, however, a profound introspective difference between the two little fingers: "Sometimes it seems dead and sometimes it is like the brushing of a fly's wing." Throughout these tests, he complained that the serial contacts with the tactile hairs, over affected parts only, set him "on edge." "I feel that, if you went on long, I should become like I am when I am worked up; I seem to want a relief somewhere."

Thermal tests.—The sensibility of the index finger was profoundly affected to all the tests for appreciation of temperature. He could not discriminate heat or cold with certainty between about 26° C. and 40° C., whereas on a bright spring-like day, the temperature of the room being 18° C., the indeterminate zone lay between about 26° C. and 30° C., over the normal index finger. But an even more striking defect was shown by his inability to distinguish two stimuli of the same thermal quality, but of different intensity. So gross was this change that he was unable to discriminate 35° C. and 40° C., 35° C. and 45° C., and even 20° and 25° C. (*vide* p. 689).

When tested with the warm and cold tubes he said: "There is a great difference between the two fingers; the right never changes its mind, whereas with the left (normal) the temperature seems to grow upon it; with heat I feel it growing hotter until it reaches a certain stage and then stops. Cold does the same thing. I was baffled on the right hand; I don't know how to describe it. It sometimes seems ice-cold and sometimes nothing at all; but there was never any difference between the two tubes." The cold tubes were first applied to the affected hand; as soon as the change was made to the normal hand he burst into laughter, saying: "I could not have believed that the difference could be so great. Here I never have a moment's doubt; the first was just off tepid and the second was colder still, or vice versa, as the case might be."

Over the middle and ring fingers the disturbance of thermal sensibility was less severe. He could not discriminate 35° and 40° C. on the affected hand, but there was no such profound difference between the thresholds as on the index finger.

Over the little finger he gave correct answers in every case, when 35° C. and 40° C. were compared, but said that the sensation from the affected hand was "different; on the right hand (affected) it has a dryer feeling, whilst on the normal one it is more liquid." He added: "It does not change on the right as it does on the left (normal); on the left it leaves a definite feeling, which I can think about, a sort of glow, which I feel going off."

Prick.—He complained that a prick did not seem normal on any of the digits of the right hand. The threshold was distinctly raised (4 grm. left, 8 grm. right) on the index, middle and ring fingers. On the right little finger it was 4 grm., the same as on the normal hand, but he said he "felt it more on the left; it seemed softer on the bad hand."

Weight.—Over the thumb and index finger the addition and subtraction of weights was not appreciated; he either failed to reply or his answers were confused. He complained, "Sometimes it feels as if you were rolling my finger round, not as if you were putting things on and taking them off."

Over the middle and ring fingers the loss of sensibility was less pronounced. In a sequence of twelve changes in weight he failed to answer five times on the middle and three times on the ring finger; but there was no confusion.

Over the little finger the sensation was also measurably affected and he said: "I could distinguish when you were putting on and taking off the heavier weights; but there were times when I could not tell what you were doing, it seemed as if you were only touching me."

Texture.—He was unable to distinguish ribbed velvet, silk and flannel over the thumb, index, middle and ring fingers. Over the first three digits the loss was absolute and he said he had "no idea" what I was rubbing over his fingers. On the ring finger he could not determine which of the three fabrics he was feeling, but they seemed different from one another; at the same time they all produced a different sensation from anything he experienced on the normal hand. On the affected little finger all three fabrics were named correctly, but he said there was "a decided difference between the two hands." "When you put the silk on to the left (normal) little finger it comes down softly and I feel it at once. On the right hand it might be anything, until I worked at it to get the definite silk feeling, or until you rubbed it in. With the ribbed velvet, I recognised at once on the right (affected) little finger, that it was a heavier, warmer material; but I could not make out what it was until I thought about it."

Sensation was distinctly affected on the right lower extremity, though to a less degree than on the hand.

Measured movement.—At the normal great toe, ankle and knee, he responded perfectly with passive movements of 1°. But, on the affected side, he required a range of from 3° to 6°, and from 3° to 5° at the great toe and ankle respectively before an answer was evoked. At the knee he appreciated a movement of from 1° to 2°, but he was somewhat slower than on the normal side.

Compass test.—On the normal sole he gave a perfect set of readings at 3 cm., whilst on the right foot he was equally confused at 3, 4, 6 and 10 cm. This confusion was evidently in part due to irregular tactile responses, for he complained: "On the right foot some touches are much duller, some much more lively. Even when they seem two, the two points are quite different in feeling."

Tactile hairs.—On the normal sole he reacted perfectly to a hair of 23 grm./mm.², and to 13 out of 16 consecutive contacts with one of 21 grm./mm.² But on the right sole no threshold could be obtained, even with 100 grm./mm.² During the testing on the affected foot he said: "It seems as if it was on all the time. It's just the difference between a point and a straight line: on the good foot, it has position but no magnitude, on the other one (right) it has magnitude without position. I feel you must press on the part or I could not bear it. It sets me on edge, just as your teeth feel when a knife is scraped on a plate."

Thermal.—The feet are not usually a favourable field for observations on thermal sensibility, especially in the winter, and this case was no exception to the rule. However, he was certain that the sensation he obtained from the two feet was not identical with the same hot or cold stimulus, and he was unable to distinguish 35° and 45° C. on the right sole: they seemed to him the same throughout a series of observations, although they were easily recognised and named correctly when applied to the left sole.

A further set of observations were made in June, 1917, exactly twelve months after the injury, and yielded results which did not differ materially from those detailed above.

Case 6.—An example of the effects of a subcortical injury. Wounded July 3, 1916, by a shell fragment in the left frontal region. Trephined July 4. Came under my care July 17. The observations recorded below were made during March, 1918, twenty months after he was injured. The wound lay in front of the Rolandic area, but had produced subcortical changes in motion and sensation. These affected the right hand and foot. Isolated movements of the fingers were good with the eyes open. No hypotonia. Movements of the toes and dorsiflexion at the ankle were less perfectly performed right than left. Right abdominal reflex diminished; other reflexes normal. Sensation was *affected in the right hand, and the loss lay mainly over the post-axial parts. The records showed the raised threshold and the absence of irregular answers and hallucinations, characteristic of a subcortical lesion.*

Captain R. D. D. C., aged 41.

On July 3, 1916, he was hit in the frontal region by a fragment of a high-explosive shell, which penetrated his helmet. He became unconscious for a few minutes, and then went on with his work. Shortly afterwards he "fainted," but crawled back to the dressing station. The wound was thought to have injured the scalp only, and he was passed on rapidly to Boulogne. Here he was operated on at 7 a.m. on July 4. On July 17 he was evacuated to England, and was for a short time in the Empire Hospital for Officers.

The wound healed before the end of July. It consisted of a surgical flap in the frontal region, bounded by a semi-lunar incision posteriorly, which extended further to the left than to the right of the middle line. This covered an irregular trephine opening in the skull, which began 6·5 cm. from the nasion and extended backwards for 5·5 cm. This opening, which was roughly triangular with the apex posteriorly, extended 2·5 cm. to the left and 1·25 cm. to the right of the middle line. It pulsated heavily, especially when he put his head down. The total distance along the nasion-inion line was 34 cm.

He returned to work in March, 1917, but happened to come under my care again in March, 1918, twenty months after the date of the wound. He was then in an excellent condition for detailed examination, and the following observations were made between *March* 6 *and April* 3, 1918.

The site of the wound now consisted of a deeply depressed area over the opening in the skull which bulged when he coughed, or when he put his head down towards the ground.

His mental state was extremely good; he was a highly intelligent soldier, who had become tired in consequence of too much irritating routine under an unsympathetic commanding officer. Headaches were at first troublesome, but rapidly improved under quiet and rest. He had not suffered from convulsions or seizures of any kind.

Vision was good, and the discs showed no signs of having been affected at any time. The pupils reacted well, ocular movements were normal, and there was no nystagmus.

The movements of the face, tongue and palate were carried out perfectly.

Reflexes.—All the deep reflexes, both of the upper and lower extremity, were equal on the two halves of the body. The plantar reflexes were brisk and the great toes gave a downward response. The only reflex abnormality was distinct diminution of the response from the right half of the abdomen; in both the upper and lower segments the movement was slow, of small extent, and confined to the neighbourhood of the stimulated spot, whereas on the left side a scratch either above or below the umbilicus tended to produce a brisk movement of the whole abdomen.

Motion.—Isolated movements of the fingers and thumb of the affected hand were well performed so long as his eyes were open, but when they were closed the right little, ring and middle fingers moved clumsily and even the index did not move as accurately as the left. He complained that the "little and ring fingers are the worst, the middle finger is somewhat better, but even the first finger is a little difficult." The grasp of the right hand was obviously less than that of the left, and movements of the right wrist were also slightly weaker, but those of the elbows and shoulders were equally strong on the two sides. He used to be a strongly right-handed man, but was now using the left hand for picking up small objects or for turning the handle of a door. There was no wasting and no hypotonia.

Under normal conditions he walked well; but the right foot easily became tired, and, when this happened, he noticed that he did not "clear things" on the ground so easily as with the normal foot. When he got out of bed at night, or was walking in the dark he always used his left foot to "feel the ground."

He could make all movements with the right lower extremity; but flexion and extension of the toes were somewhat slower, and dorsiflexion and plantar extension of the foot less strongly performed on the right than on the left side.

With the eyes open he could stand on either foot, but staggered when he attempted to balance himself on the right with his eyes closed. In testing his co-ordination, the right foot was certainly clumsier than the left; when his eyes were closed, he had distinctly more difficulty in finding the right great toe with the left heel than *vice versa*.

There was no spasticity and no hypotonia.

Sensation (between *March* 9 *and March* 30, 1918, *twenty months after the wound*).

He complained that "the three fingers (little, ring, middle) of the right hand seem as if they were always going to sleep. I have to move them about to make them come to again. When I wake at night I sometimes feel as if I hadn't got these three fingers, and the whole of that part of the hand seems to disappear, too."

I have placed on the following table the results obtained with the ten tests. They are so clear and definite that I shall only comment shortly on each set in turn.

	Right (affected) hand.					*Left hand.*
	Little finger.	Ring finger.	Middle finger.	Index finger.	Thumb.	Normal digits.
Measured movement	Average 19°	Average 14·6°	Average 9°	Average 8°	Average 2·5°	Perfect at 1° to 2°.
Vibration ...	29 sec.	27 sec.	23 sec.	23 sec.	18 sec.	—
Compass test	1 cm.	1 cm.	1 cm.	0·5cm. Slower	0·5. Introspective	Perfect at 0·5 cm.
Localisation	Not affected	Not affected	Not affected	Not affected	Not affected	No mistakes.
Tactile hairs	Not perfect at 110 grm./mm.²	Threshold 110 grm./mm.²	Threshold 70 grm./mm.²	Threshold 35 grm./mm.²	Threshold 35 grm./mm.²	Perfect reading with 14 grm./mm.²
Thermal ...	No differentiation	3 errors	2 errors	Introspective	Perfect	35° to 43° perfectly recognised.
Prick ...	9 grm.	7 grm.	7 grm.	6 grm.	3 grm.	3 grm. thumb, 5 grm. index, 4 grm. other digits.
Weight ...	8 errors	5 errors	"Much more difficult"	2 errors	Perfect	Perfect series of 12 tests on each digit.
Form ...	Defective	Defective	Introspective	Good	Good	Perfect recognition
Texture	3 errors, much doubt	3 errors	Introspective	Introspective	Introspective	Named all 4 tests correctly on all digits.

Measured Movement.—On each finger I have given the average of ten movements. In many cases, with a purely cortical or combined cortical and subcortical lesion, this is not possible, because of the uncertainty of the answers and of hallucinations of movement. In this case, however, among the fifty answers from the affected fingers, the direction was wrongly given in two instances only, and the figures fell within remarkably close limits on any one finger.

Vibration.—The difference between any two digits was considerable, even on the two thumbs. This test did not reveal the same fine differences of appreciation as measured movement, although the same number of fingers were affected.

Simultaneous compass test.—He gave perfect records on the normal digits, when the points were separated by 0·5 cm. only. He was conscious of a difference between all the digits of the right hand and those of the left. But the first obvious change appeared in the index finger, where the answers were slow, although the record was perfect as 0·5 cm. Over the middle, ring and little fingers it was necessary to separate the points to 1 cm. before he could give a perfect series of replies, and the little finger was evidently most severely affected.

Localisation was not obviously disturbed.

Tactile hairs.—This test revealed a condition different from that usually found with a lesion of the sensory cortex. The lighter hairs were not appreciated at all, and each succeeding increase in the strength of the stimulus gave a corresponding increase in the number of replies. The little finger was the only digit where a threshold was not ultimately obtained. There were no hallucinations or gross irregularities of response (p. 706).

Thermal tests.—When two silver test-tubes, containing water at 35° C. and at 43° C., were applied in irregular sequence to the palmar aspect of the terminal phalanges of the normal hand, he answered quickly and correctly in every case. On the right thumb and index finger he made no mistakes; he said that it was less easy over the right index than over the left. Over the middle finger he twice thought that the tubes were of the same temperature, whilst on the ring finger three out of four applications were thought to be the same. On the right little finger he failed altogether to recognise that the tubes were of a different temperature.

When 40° C. was applied to each digit of the two hands in turn, he noticed no difference between the sensation in the two thumbs; but it seemed "easier" on the normal index, and over the left middle, ring and little fingers the same tube seemed "hotter" than on the affected hand.

Prick.—To this test there was a distinct raising of the threshold over the middle, ring and little fingers of the right hand.

Weight.—This test was carried out by adding and subtracting weight on each digit in turn. From the thumbs he gave perfect answers, but on the right index he twice failed to reply, when a weight was removed. This is one of the earliest signs by which a disturbance of this aspect of sensibility is revealed in cases of cerebral lesion. Over the right middle finger he made no actual mistake, but was much slower even than over the index, and complained that he found the test "much more difficult" on the right hand than on the left. The ring and little fingers were more obviously affected, and here he failed five and eight times respectively out of twelve tests on each digit.

Form.—It was very difficult to be certain of the results of this test when the sphere, cylinder, pyramid, cube, cone, and ovoid were rolled over each finger in turn; but he was obviously much slower in his answers from the little and ring finger of the right hand. With the middle finger he made no mistakes, but found it easier to be certain on the left than on the right hand. There was no definite difference between the thumb and index fingers on the two sides.

Texture.—Velvet, silk, cotton, and flannel were named in every case correctly, when rubbed over the normal digits. On the right hand, however, even the thumb seemed to him to be affected, although the only mistakes were found when the tests were applied to the ring and little fingers. Here he either said he "did not know" or spoke of the roughness or smoothness only of each textile fabric.

Case 8.—*This case is cited as an example of disturbed sensibility at the elbow, and to a less degree at the wrist, without obvious affection of the hand or shoulder. Wounded in the left side of the head on December 21, 1915, by shrapnel, he was trephined within a few hours of the injury over the middle, pre- and post-central convolutions. From the first the changes in motion and sensation lay in the neighbourhood of the elbow and wrist. The hand was slightly affected at first, but had recovered entirely six weeks after the injury.*

Lieutenant L. A. D., aged 20.

He was wounded on December 21, 1915, by shrapnel, at Cape Helles. He dropped, and was unconscious for a few seconds only.

On January 5, 1916, he was seen by Sir James Purves-Stewart, who kindly sent me the following account: "The patient immediately lost power in the right upper limb. Within an hour or two he was operated upon at the 17th Stationary Hospital, where a trephine opening was made; the anterior edge was $\frac{1}{4}$ in. behind the Rolandic fissure at a point $2\frac{1}{2}$ in. from the middle line, measured along the fissure. The scalp wound has completely healed. Within a couple of days the right upper limb began to recover and has since improved steadily. There has been occasional left-sided headache. No vomiting.

"His condition on January 5, 1916, was as follows: Speech and articulation were normal. Visual fields were normal and there was no hemianopsia. Pupils and cranial nerves normal. Optic discs not affected. To the lightest cotton-wool touches and to pin-pricks there was no loss of sensation in the face, trunk, or limbs, but light touches and pricks on the right forearm and hand produce a mild sensation of superadded tickling. Similarly with a vibrating tuning fork. The joint-sense was normal at all joints. Compass test normal on both hands (right 2 cm., left $1\frac{1}{2}$ cm.). Stereognosis perfect with both hands and feet.

"Right upper limb slightly feebler than the left, especially the hand and fingers. Slight unsteadiness of right upper limb with finger nose test. Some clumsiness in buttoning his clothes with his right hand and in using a knife at meals.

"Right wrist-jerk and right knee-jerk brisker than left. Ankle-jerks equal. Plantar reflexes flexor; abdominals brisk and equal."

He first came under my care on *February* 1, 1916, *six weeks after the injury.* The wound was firmly healed and consisted of a round opening in the skull, which pulsated strongly. It extended from 14·5 to 18 cm. behind the nasion. The upper border was 4 cm. and the lower border 7 cm. to the left of the middle line. The opening was 3·5 cm. in length and 3 cm. in breadth vertically. The total distance between the nasion and inion was 34 cm.

He was highly intelligent and an excellent subject for examination. He did not suffer from headaches; speech was normal and he had had no convulsions or seizures.

Vision was perfect and the discs showed no signs of past or present changes. The pupils reacted normally, ocular movements were well performed and face and tongue were unaffected.

Reflexes.—The right wrist-jerk was brisker than the left, but otherwise the reflexes were normal and equal. The abdominals were active on all four segments, and the toes went downwards when the soles were scratched.

Motion.—There was no paralysis of any part of the hand and both grasps were strong; but his writing had changed. He used to write quickly a somewhat rounded hand; now the letters had become pointed and jerky, like those of an old man. This he thought was due to the condition of the wrist and not to any fault in the fingers. When he held out his hands in front of him, the fingers were in alignment and individual movements were perfect. There was no inco-ordination with the eyes open, but when they were closed the movements of the limb as a whole were slightly ataxic. The fingers were neither hypotonic nor spastic, and the tone of the arm was not obviously increased apart from the exaggeration of the right wrist-jerk.

His gait was normal and the lower extremity was not in any way affected.

Sensation.—He complained that the right elbow "felt odd and heavy" compared with the left. The hand seemed to him perfectly normal.

Measured movement.—I could find no loss of appreciation of passive movement anywhere except in the right elbow and wrist joint. In all the digits and at the shoulder joint, he responded perfectly to an excursion of 1°. But at the right wrist joint it was necessary for a movement to reach 3° to 4° before it was appreciated. At the right elbow joint he showed all those deviations from normal so characteristic of a cortical lesion; not only was the threshold raised to between 7° and 10°, but hallucinations of movement frequently disturbed the records. This never occurred on the normal side, where he appreciated a movement of 1° or less with extreme accuracy.

Vibration.—The tuning fork showed no abnormality over the digits on the radial aspect of the wrist. But there was profound shortening of from ten to twelve seconds over the right elbow joint. This was appreciable to me; for he called out that the fork had stopped beating on the right elbow long before it ceased to be perceptible to my fingers. This was not the case when it was placed on the left elbow. The shoulder joint gave equal readings on the two sides.

Compass test.—The fingers and palm yielded equally good records on the two sides, when the points were separated to 1 cm. Over the normal (left) forearm he did not give a perfect series of answers until they were 4 cm. apart; 3 cm. was distinctly below the maximum threshold. But on the right forearm he showed complete want of discrimination and confusion between one and two points even at 10 cm. The two soles gave a perfect series of answers at 3 cm.

Localisation was not affected on the hands; but he seemed to be more uncertain in the neighbourhood of the right than of the left elbow. This proved to be the case at a subsequent more detailed examination.

Tactile hairs.—Over the fingers and the palm of the hand he reacted perfectly to a hair of 21 grm./mm.^{2}, but tactile sensibility was obviously affected over the flexor aspect of the forearm. On the normal side the response to 21 grm./mm.^{2} was not quite certain and it required a hair of 23 grm./mm.^{2} before he gave a perfect series of answers. But, over a similar part of the right forearm, even 35 grm./mm.^{2} failed to evoke a sensation with every contact. He said "the left is easier and I can be more certain on the left arm."

The soles gave perfect records with 21 grm./mm.^{2}.

Thermal tests.—The hand was unaffected, and I could find no certain change of sensibility over the forearm in the neighbourhood of the flexure of the elbow. But he said, "It takes some time over the right elbow before I recognise that there is anything there at all. When I have recognised it, I begin to feel the temperature."

Prick.—I could find no difference in sensibility to prick between the two upper extremities.

Weight.—There was no difference between the two hands in the power of discriminating weights.

This patient was examined on several subsequent occasions and all the observations pointed to affection at the right elbow without disturbance of the hand or shoulders. I shall pass on, however, to his condition in *June*, 1918, *two years and six months after the injury.*

He was in excellent physical condition and had had no convulsions or seizure. From time to time, about once a month, he suffered from headache, always connected with some increase of pulsation in the scar. Running upstairs or excessive heat would bring on the headache, which passed off when he lay down.

The scar was firm, tough and somewhat depressed; it did not pulsate as he sat upright in a chair.

Reflexes.—All the reflexes were normal and equal except the elbow- and wrist-jerk, which were distinctly greater on the right than on the left side.

Motion.—The grasps were equal, but his handwriting still showed the same changes, though to a less degree than before. He used to be a good lawn-tennis player, but was now "terribly bad"; "I hit the ball on the wood and sometimes miss it altogether." Golf has not suffered nearly so much.

He is a strongly right-handed man, and, although there is no obvious paresis of the right arm against resistance, the force exerted is not greater than that of the left, when bending or straightening the elbow. He is using his left arm more and more because he finds the right arm clumsy. When he held his arms out in front of him, the fingers were in perfect alignment and did not fall away on closing his eyes; but the arm swayed somewhat and was less steady than the left. He could touch his nose perfectly with the right forefinger when his eyes were open; as soon, however, as they were closed, he became uncertain in aim and struck some part of his cheek or hit his nose too hard. There was no obvious change in tone.

Sensation.—He complained that "the feeling in the right elbow is very peculiar; I do not feel when people knock up against me in a crowd as I do with the left arm. I get a sensation of some sort, but it is not a normal sensation. It would be more accurate to say that some one could bump up against me, and I could not tell what it was that touched me."

Measured movement.—The index and little fingers, wrist and shoulder responded perfectly to 1° of passive movement. The right elbow required from 1·5° to 3°, and he said, "It feels quite different in this elbow."

Compass test.—Perfect readings were obtained with a distance of 1 cm. over the index and little fingers and palm of the right hand. Over the right forearm the threshold was 6 cm., whilst over a similar part on the left side he gave a perfect series of answers at 4 cm.

Localisation was equally good over the two hands, but was affected on the flexor surface of the right forearm in the neighbourhood of the elbow joint. A series of observations were made in which he indicated the spot touched on the arm of an assistant. Out of ten contacts he made two distinct errors on the normal (left) forearm, whilst on the affected limb one only of the stimuli, over approximately similar spots, was accurately localised. Three contacts in the neighbourhood of the right wrist were indicated correctly.

Tactile hairs.—The fingers and palm of the right hand gave perfect readings with 21 grm./mm.^{2}; this hair was also appreciated over the flexor aspect of the normal elbow. But over a similar part of the right arm 35 grm. mm.^{2} was necessary before he responded to every contact.

The difference between the two limbs was evident, when a record was taken with a hair of 21 grm. mm.^{2} in the following manner: First a few contacts were made on the normal, and then a similar number on the affected arm, changing from side to side until sixteen stimuli had been applied to each in turn. The following results were obtained:—

Left elbow ..	l.l.l.l.	l.l.l.l.l.l.	l.l.l.l.l.l.	
Right elbow ..	o.l.l.l.	o.l.o.o.l.l.	l.l.o.o.l.o.	

At the end of these observations he said: "Here again the principal difference is that I am not so certain on the right arm."

Weight, form and *texture* were all perfectly appreciated on the right hand.

Case 15.—*Wounded August* 20, 1916, *over the vertex in the parietal region. The wound extended slightly more to the right than to the left of the middle line. This case is remarkable because the three aspects of cortical sensibility were dissociated; spacial recognition was disturbed in the left foot and ankle, tactile and thermal discrimination were defective in the right foot, whilst the power of appreciating similarity and difference was not affected on either side. The reflexes were normal and individual movements were carried out equally well in both feet. The left great toe was definitely hypotonic.*

Lieutenant E. D. J., aged 22.

He was wounded on August 20, 1916, with a piece of shell-casing which perforated his helmet. He fell and became unconscious for a few seconds. Two hours later he vomited. He had very little headache at the time. From the first the left leg "felt odd"; he wanted to step over a man in the trench and stepped on to him. No operation was performed at any of the hospitals through which he passed before he came under my care.

He was admitted to the London Hospital on September 2, 1916, without a note of any kind.

The wound consisted of a linear cut across the middle line of the scalp, with a suppurating sinus leading down to an extensive area of bare bone. The anterior border of this opening lay 21 cm., and the posterior border 22 cm., from the root of the nose. It extended 1 cm. to the right and 2 cm. to the left of the middle line. The total nasion-inion measurement was 34 cm. A radiograph showed flaking of the inner table of the skull and a small fragment of metal superficial to the bone.

The following observations were made between *September* 2 *and* 20, 1916.

He was an intelligent man, who had been an accountant in civil life. He suffered from little or no headache, and had had no convulsions or seizures of any kind. Speech was normal.

He was slightly myopic, but on correction his vision was $\frac{6}{6}$. The visual fields were normal.

Pupils, movements of the eyes and those of the face and tongue were unaffected.

All the *reflexes* were normal, both superficial and deep.

Motion.—The upper extremities were entirely unaffected.

He could walk well and his gait was not obviously changed, though he complained that the left foot was still clumsy; for instance, he found it impossible to put on his slippers if he was standing up.

There was no paralysis, and all movements of the toes could be carried out as well on the one foot as on the other.

So long as his eyes were open, he could stand well on either foot and there was no obvious inco-ordination. But on closing his eyes he was distinctly more unsteady on the left than on the right foot and movements of this leg were somewhat ataxic.

The most striking difference between the two feet was the hypotonic condition of the left great toe. Thus, when pushed up, it could be extended passively so as to subtend less than a right angle with the line of the dorsum of the foot. The mobility of the right great toe was noticeably less; it could be pushed up to form an angle of about 120° only.

There was no obvious wasting in either lower extremity.

Sensation.—The two feet seemed to him quite different. The left was "clumsy" and there was a "fat feeling under the toes." But this foot was "quicker in picking up a cold feeling" than the right.

The two hands were normal to all the tests for sensation.

Measured movement gave the following results :—

	Right.	*Left.*
Great toe	1 to 2	3 to 5
Ankle	1	2 to 3
Knee	1	1

Vibration.—When the tuning fork was placed over the ball of the great toe, there was a shortening of from 7 to 10 seconds against the left foot; but over the inner malleolus there was no definite difference. This supports the results of examination by means of passive movement.

Compass test.—The records obtained with this test were of great interest; for they showed the difference in the records due to want of two-dimensional discrimination and to unequal tactile appreciation. I give here the actual readings, where a stroke represents a correct and a cross a wrong answer. These have been translated into numbers on p. 698.

Right sole (tactile loss).

3 cm.	1	ll lxl lxlxx
	2	l lxxl lxlxx
4 ..	1	xxxl lxll ll
	2	lxxx lxl lxl
6 ,,	1	lxxl llllxl
	2	xlxx llxxxl
10 ..	1	ll lll l ll ll
	2	lll l l lll ll

Left sole (spacial loss).

3 cm.	1	llll lllll l
	2	lxxl llxxl l
4 ..	1	lll lll llll
	2	ll ll lxll ll

Localisation was unusually good on both feet and I could discover no difference between them; but it must be remembered that our method of testing localisation, applied to the feet, can reveal coarse changes only.

Tactile hairs.—The contrast between the condition of the two soles to this test was striking.

	Right sole (affected).	*Left sole (unaffected).*
21 grm./mm.²	looloooolloooo	
23 grm./mm.²	olololllloooo ⁞ —ol ⁞	
35 grm/mm.²	llollolooooloIll	
70 grm./mm.²	lolollolooloool o	
100 grm./mm.²	oloooollololoIll	
21 grm./mm.²	loooolooloolol ol	
21 grm./mm.²	—	llollolllololll
23 grm./mm.²	—	llllllllllllll

He complained that on the right sole he had great difficulty in knowing when the hair was put on or taken off; "It seemed like a feather rubbed over the foot." On the left sole the sensation was normal.

Thermal test.—I could not find any definite difference between the thresholds for heat and cold, but at this time I carried out no comparative observations on the sole (*vide infra*). The determination of thermal thresholds on the foot is extremely difficult, and often yields unsatisfactory results unless the greatest precautions are taken to prevent exposure. In some patients the feet are naturally cold, even in bed.

Prick.—The threshold for prick was the same on two soles (3 grm.).

Form.—He could recognise all these tests when he was allowed to roll them under his feet against the ground.

On September 27, 1916, Mr Walton trephined over the area of the wound and removed an irregular piece of the inner table of the skull; it lay loose on the dura, which was not perforated. The longitudinal sinus was directly to the right of the situation in which lay the loose fragments. Some pieces of metal were removed from the neighbourhood of the outer table. The wound finally healed on November 18, 1916.

I was able on several occasions to confirm the existence of the remarkable dissociation of sensibility given in detail above; but it will be sufficient to add a short account of observations made during the *last week of February*, 1917, *six months after the injury.*

His general condition was excellent. His memory and attention were good, and he was able to read with interest, and remember what he had read. He was entirely free from headache, and had had no convulsions or seizures of any kind.

The *reflexes* were in every way normal and equal.

Motion.—Movements of the toes were as well executed on the one side as on the other, and the only abnormal condition was some hypotonia of the left great toe. This was, however, considerably less than at the first examination. He could walk seven miles, but after about five miles noticed that his left foot became tired and dragged.

Sensation.—He still had "a curious abnormal feeling" in the left foot, especially "over the toes and pads, where the front of the foot touches the ground."

Measured movement.—He answered quickly and accurately to passive movement of 1° in the right great toe; on the left side he required a range of 2°, and was slow in his replies. The left ankle was now normal, and he responded to movements of 1°.

Compass test.—On the right sole he still complained that "a touch seemed to linger, and it is difficult to find out if it is the one you put on last or the two points together." He gave an almost accurate reading, however, at 6 cm.

On the left sole he responded with a perfect series at 3 cm., the smallest distance that can safely be applied in clinical examination.

Localisation was equally good on the two feet; he made no mistakes on either side.

The *tactile hairs* revealed exactly the same changes as before. He complained: "I seem to be longer in feeling it on the right foot. My difficulty was the uncertainty of contact."

On the right sole a good reading was obtained with 70 grm./mm.^{2}, marred, however, by a tendency to hallucinations; all hairs of lower bending strain showed obvious defects of sensibility. On the left sole the condition was exactly as before; 23 grm./mm.^{2} was perfectly appreciated, whilst with 21 grm./mm.^{2} he did not recognise all the sixteen stimuli. He was certain that, as far as this test was concerned, the left foot was normal.

Thermal tests.—I devoted one sitting to a series of observations on thermal sensibility. I could find no definite change in the thresholds for heat and cold, but the foot is so unsatisfactory a situation for tests of this kind, and his answers were so much slower from the right than from the left sole, that I carried out a series of comparative observations. He had no difficulty in recognising the relative warmth of two silver tubes at 35° and 44° C. on the left sole; but on the right, out of seven observations, he was wrong four times, once doubtful and twice correct in his answers. Not only was he slower, but said, "I feel uncertain in the right foot; it takes me longer to grip it."

Prick.—I could find no difference in the threshold on the two soles.

Weight.—On a previous occasion a careful series of observations had been made by adding and subtracting weights, placed on the dorsal aspect of the basal phalanx of the great toe; the soles rested flat on the bed and were fully supported. He was remarkably accurate in his replies when the test was carried out in this manner, and I could find no difference between the aptitude of the two feet.

Form.—He had no difficulty in recognising the various test-objects when he was allowed to roll them under either foot. He could discover no difference in the sensations from the two soles.

Case 18.—This case is a remarkable example of dissociated sensibility due to a lesion of the cortex. The tactile hairs showed distinct sensory loss over the thumb, index and middle fingers, although the power of appreciating passive movement and vibration was perfectly preserved. The compass test was defective in consequence of the loss of tactile sensibility. Individual movements of the three preaxial digits were clumsy. There was no hypotonia.

Colonel M., aged 46.

On October 4, 1914, he was hit in the right parietal region by a rifle bullet. It must have been a glancing blow, for the bullet was found beside him.

He was admitted to the Allied Forces' Base Hospital, and Mr. Whitehall Cole kindly furnished the following report:—

"The patient was fully conscious on admission, but showed definite signs of cerebral irritability. He was hemiplegic, chiefly in the left arm and face; the leg was slightly affected only.

"At the operation on October 23, definite cerebral substance could be seen to protrude through the scalp. Several small fragments of bone lay loose in the wound. The dura showed a small lacerated wound from which there was slight exudation of cerebral substance. All loose fragments of bone were removed and the osseous opening was slightly enlarged sufficiently to ascertain that no depressed bone remained. The wound was closed except for a gauze drain passed down to the dura.

"Recovery was steady and uneventful. The leg cleared up rapidly. The face began to improve after the operation and progressed steadily. The arm made very little progress until the last week or ten days of his stay, when his grip became stronger. There was no return of movement at the elbow and wrist."

The leg recovered completely and his general condition became normal; but the thumb and index finger of the left hand showed no improvement.

On June 23, 1915, he had an epileptiform attack associated with an abnormal "feeling" in the left arm, followed by a short period of unconsciousness.

On June 28, 1915, he was admitted to the Palace Green Hospital for Officers under my care.

The following observations were made *between July 14 and July 20*, 1915, 283 *to* 289 *days after the injury.*

The wound was perfectly healed; it was represented by a small opening in the skull 2 cm. horizontally and 1·5 cm. vertically in the right temporal region. The anterior border of this trephined area corresponded with a point 15 cm. back from the nasion and 10 cm. to the right of the middle line. The total nasion-inion line was 35·5 cm. in length. The opening was depressed and did not pulsate. A radiograph showed no abnormality beyond the opening in the bone.

He was an unusually intelligent man of intellectual tastes and an excellent subject for examination.

Speech was normal. He suffered from no attacks or seizures beyond the one already described. He was free from headache, nausea or vomiting.

Pupils and ocular movements were normal.

There was slight weakness of the lower portion of the left half of the face and the tongue tended to turn to the left on protrusion.

Reflexes.—The left arm-jerks were brisker than those from the right upper extremity. The left knee-jerk was slightly more active than the right. The plantar reflexes were normal, but the response from the left lower segment of the abdomen was undoubtedly sluggish compared with that from the right.

Motion.—When he held both arms in front of him, the digits of the left hand were not in alignment. On attempting to abduct them they fell into great disorder. Isolated and individual movements of the fingers and thumb were badly executed; they were slow, clumsy, and ineffective.

All movements of the wrist and elbow were strongly performed against resistance.

When the hands were held out and the eyes were closed, the left wrist became slowly flexed and the fingers fell out of place. There was definite ataxy, when he attempted to bring his left forefinger to his nose.

No hypotonia and no tonic rigidity could be discovered in any part of the left upper extremity.

There was no wasting of the hand or arm.

The left lower extremity was in every way normal.

Sensation.—

	Left (affected) hand.					*Right hand.*
	Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.	—
Measured movement	Perfect at 1°	Perfect at 1°	Perfect at 1°	Perfect at 1°	Perfect at 1°	Perfect at 1°
Vibration ...	Perfect	Perfect	Perfect	Perfect	Perfect	—
Compass test	Affected at 3 cm.	Affected at 3 cm.	Affected at 3 cm.	Perfect at 1 cm.	Perfect at 1 cm.	Perfect at 1 cm.
Localisation	Perfect	Perfect	Perfect	Perfect	Perfect	Perfect
Tactile hairs	Threshold with 35 grm./mm.²	Gross loss with 100 grm./mm.²	Threshold with 23 grm./mm.²	Perfect with 21 grm./mm.²	Perfect with 21 grm./mm.²	Perfect with 21 grm./mm.²
Thermal	Not tested	Defective	Not tested	Not tested	Not tested	Perfect appreciation of 35° and 40° C.
Prick ...	Not affected	Not affected	Not measured	Not measured	Not measured	—
Weight ...	Not tested	Gross want of appreciation over these two fingers together		Perfect appreciation over these two fingers together		—

The left lower extremity was in every way normal.

These observations are remarkable for the perfect readings given by the test for passive movement and vibration in spite of the obvious affection of tactile sensibility. The compass test was disturbed from the latter cause.

I had the opportunity of examining him carefully on several subsequent occasions, but shall only append a short summary of observations made on *September* 26 *to* 28, 1915, 357 *days after the injury.*

He had had no further attacks, and had suffered from no headaches.

There was still slight weakness of the left angle of the mouth, and the tongue tended to deviate to the left on protrusion.

Reflexes.—The left wrist-jerk was distinctly brisker than the right, but the knee-jerks and ankle-jerks were normal. The plantar response was normal, and the left lower segment of the abdomen responded briskly to stimulation.

Motion.—He complained that he could not use his fork properly, and could not use his left hand to do up his boot-laces. "I have no grip between the thumb and first finger, and have to hold my fork between the middle and ring fingers."

He could abduct, extend and flex the thumb, but the movements were clumsy and were nearly always associated with motion in some other digit. The same want of co-ordinate sequence was seen in movements of the index and middle, but not in those of the ring and little fingers.

There is no increase or decrease of tone and no wasting.

Sensation.—

	Left (affected) hand.					*Right hand.*
	Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.	—
easured movement	Perfect at 1°	Perfect at 1°	Perfect at 1°	Perfect at 1°	Perfect at 1°	Perfect at 1°
ibration	Perfect	Perfect	Perfect	Perfect	Perfect	—
ompass test	Affected at 3 cm.	Affected at 3 cm.	Not quite perfect at 3 cm.	Perfect at 1 cm.	Perfect at 1 cm.	Perfect at 1 cm.
ocalisation	Perfect	Perfect	Perfect	Perfect	Perfect	—
actile hairs	Threshold with 23 grm./mm.^{2}	Threshold with 23 grm./mm.^{2}	Slow with 21 grm./mm.^{2}	Perfect 21 grm./mm.^{2}	Perfect 21 grm./mm.^{2}	Perfect 21 grm./mm.^{2}
rick ...	Not affected	Not affected	Not affected	Not affected	Not affected	—
Veight ...	Not tested	Gross want of appreciation over these two fingers tested together		Perfect appreciation over these two fingers together		—

Case 19.—*This is an example of the third form of sensory dissociation, which may occur in consequence of a cortical lesion. The power of recognising similarity and difference of weight and form was not disturbed in spite of considerable loss of the other two sensory groups. Wounded December* 6, 1917, *with a machine-gun bullet which produced a gutter fracture in the left parietal region. Trephined four hours later, when the dura was found to be intact but bruised and blue. It was incised and blood-clot and brain-pulp evacuated. Isolated movements of the right hand perfect with his eyes open. Distinct hypotonia of little and ring fingers. Reflexes unaffected.*

Second Lieutenant D. P., aged 23.

On December 6, 1917, he was shot down from the air, when patrolling over the lines. He must have been unconscious for about two minutes, but when he came to himself his machine was flying normally; on trying to control it he found his right hand was useless. He saw his hand upon the lever, but thought it belonged to his observer; he then appreciated that it was his own, and replaced it by his left hand. The foot and leg was not affected in any way. He brought the machine down safely and walked to the dressing station. His head was bleeding very little, he did not vomit, and suffered from no headache.

He arrived at the Casualty Clearing Station about four hours later, and was operated upon at once. The dura was perforated; blood-clot and brain matter were evacuated. Wound closed.

This was followed by much headache and some vomiting. Speech was not affected.

On December 12, 1917, the incision was opened up and some blood-clot washed away. The dura was pulsating and was not tense. The wound was left open for drainage.

On February 23, 1918, he was admitted to the R.F.C. Hospital, Bryanstone Square, and came under my care. At that time the wound had healed except for a minute spot which required dressing for three days only.

The wound was represented by a longitudinal incision on the left side of the head extending from the parietal eminence forwards almost into the frontal region of the scalp. At the posterior end of this line was a gutter in the bone. This began posteriorly 21·5 cm. from the nasion; in front it ceased 17·5 cm. from that point. It lay from 4 to 4·5 cm. to the left of the middle line. His head was unusually long, and the total nasion-inion line measured 36 cm. The scar was not pulsating, and the total extent of loss of bone measured not more than 4 cm. longitudinally and from 1 to 1·5 transversely.

The following observations were made *between March 10 and 24, 1918, from 94 to 108 days after the injury.*

His mental condition was excellent and he was an accurate and most willing observer.

He was entirely free from headache, and had not suffered from convulsive attacks or seizures of any kind.

The pupils were normal. Movements of the eyes, face and tongue were perfect.

All the *reflexes* of both upper and lower extremities were normal, and equal on the two sides.

Motion.—The grasp of the right hand was distinctly weaker than that of the left, but all individual movements of the fingers could be performed perfectly with the eyes open; when they were closed the tip of the right thumb was not approximated to that of middle, ring or little finger with the same precision as in the left hand.

All movements of the right wrist, elbow and shoulder were extremely powerful.

If the hands were held steadily in front of him there was no want of alignment of the fingers even when his eyes were closed.

There was distinct hypotonia of the little and ring fingers of the right hand. The other digits seemed to be normal. There was no wasting. The right lower extremity was in every way normal.

Sensation.—He said, "I can use the thumb and first finger; the trouble is mostly in the three other fingers. It is a slight stiffness or numbness, as if I had a tight glove on." He could not play the piano with the right hand: "The fingers won't get on to the right notes." He was able to button his clothes, but found it somewhat difficult with the right hand.

	Right (affected) hand.					*Left hand.*
	Little finger.	Ring finger.	Middle finger.	Index finger.	Thumb.	—
Measured movement	15° to 20°	10° to 15°	4° to 8°	2° to 3°	1° to 2°	Perfect at 1°.
Vibration	8 sec.	8 sec.	8 sec.	5 sec.	2 sec.	—
Compass test	Gross loss at 3 cm.	Threshold 3 cm.	Introspective, 1 cm.	Perfect at 1 cm.	Perfect at 1 cm.	Perfect at 1 cm.
Localisation	One error: very slow	Slow	Normal	Normal	Normal	No errors.
Tactile hairs	23 grm./mm.²	23 grm./mm.²	21 grm./mm.²	14 grm./mm.²	14 grm./mm.²	Perfect with 14 grm./mm.²
Thermal ...	Gross loss	Slow; one error	Normal	Normal	Normal	Perfect appreciation of 35° and 43° C.
Prick ...	10 grm.	9 to 10 grm.	8 grm.	8 grm.	8 grm.	8 grm.
Weight ...	Perfect	Perfect	Perfect	Perfect	Perfect	Perfect series.
Form ...	No loss with these two together		—	No loss with these two together		—
Texture ...	Affected	Affected	Introspective	Perfect	Perfect	Perfect recognition.

The right lower extremity was in every way normal.

Measured movements.—All five digits of the right hand were affected; the loss of sensibility was extremely slight in the thumb, but increased until it reached considerable proportions in the little finger.

Vibration.—This test corroborated the results obtained by passive movement.

Compass test.—There was gross loss over the little finger, when the points were 3 cm. apart; but over the ring finger a threshold could be obtained at this distance. The change in the middle finger was introspective only; he found it harder to make up his mind, although his replies were correct. The index and thumb were not affected.

Localisation.—He made one definite error only, which consisted in localising a touch over the basal phalanx of the little finger on the same phalanx of the ring finger. But in this case the slowness of answering over the little and ring fingers compared with his quickness over the other digits gave a better idea of the disturbance of localisation than the records. He himself said, "I have difficulty in making up my mind; when you touch me on the ring finger I cannot be certain whether you are touching me on the ring or middle finger." But he finally succeeded in choosing the correct phalanx and the right digit, except once on the little finger.

Tactile hairs.—With a 14 grm./mm.² hair he said there was no difference between the sensation on the thumb and index fingers of the two hands. On the middle finger the threshold was raised to 21 grm./mm.², and he said it was "clearer" on the left than on the right hand. When a hair of 21 grm./mm.² was applied in the usual way to the ring finger he not only failed to recognise the contact eight times out of sixteen, but said, "It doesn't seem like a sharp point at all; it is as if you were touching me with your finger." The condition was similar over the little finger of the right hand.

Thermal.—When two silver tubes containing water at 20° C., and at 40° C., were applied to the little and ring fingers of the two hands in varying order, he did not fail to name them correctly, but said that 20° C. was "colder" and 40° C. "warmer" on the normal than on the abnormal digits.

Two tubes containing water at 35° and 43° C. were correctly recognised over the thumb and index finger of the right hand. Over the middle finger his replies were also accurate, but he complained that it was "much easier" on the normal than on the affected hand. Over the right ring finger his answers were slow, and he made one mistake in four observations. Over the right little finger he could detect no difference between the two tubes, but named them correctly on the little finger of the normal hand.

The threshold was raised on the right little finger both for heat and for cold. For cold it was about 25° C. on the right and 27° C. on the left hand, whilst for heat it was about 36° C. on the right, and 29° to 30° C. on the normal side. Thus, the changes consisted in a considerable enlargement of the neutral zone. A similar condition, to a less degree, was present over the right ring finger; but on the middle fingers the thresholds were identical.

Prick.—Unfortunately, the threshold over the tips of the normal fingers was rather high to this test, and he did not recognise the painful element in the prick under about 8 grm. on our algesimeter. But, although there was no difference between the thumb, index and middle fingers of the two hands some loss of sensibility was present in the ring and little fingers on the right side. This came out particularly well when the instrument was set at 8 grm. and a series of pricks were made over the right and left little and ring fingers; they were said to "prick" on the left, but to be "blunt" on the right hand.

Weight and Form.—The striking feature of this case was his perfect sensibility to these tests. He was not conscious of any difference between the two hands, even over the little and ring fingers.

Texture.—Over the thumb and index finger there was no difference between the two hands. Over the right middle finger the four textile objects were named correctly, but he complained that he had some difficulty in being certain, "because they were not so sharp" on the right hand. Over the ring finger he made several mistakes, and said, "I can tell it's a bit of cloth, but I can't feel if it is rough or smooth so well on the right hand." On the right little finger he said it was "very difficult to tell what kind of thing it was," but named two out of the four stuffs correctly. Evidently this is one of the cases where the accuracy of this test suffers through defects of tactile sensibility.

Case 23.—An example of a combined cortical and subcortical injury. Wounded November 14, 1917, by a rifle bullet in the right parietal region. Cerebral abscess evacuated on December 8. The wound had healed before he was admitted to the London Hospital on February 6, 1918. The main feature of the case was the hypotonic condition of the left hand, associated with a peculiar change in its contours and general appearance. The maximum loss of sensation lay over the index and middle fingers.

Private J. H. W., aged 22.

On November 14, 1917, he was hit by a rifle bullet, which penetrated his helmet. He dropped and became unconscious for a few minutes, but was then able to walk about 200 yards to a dug-

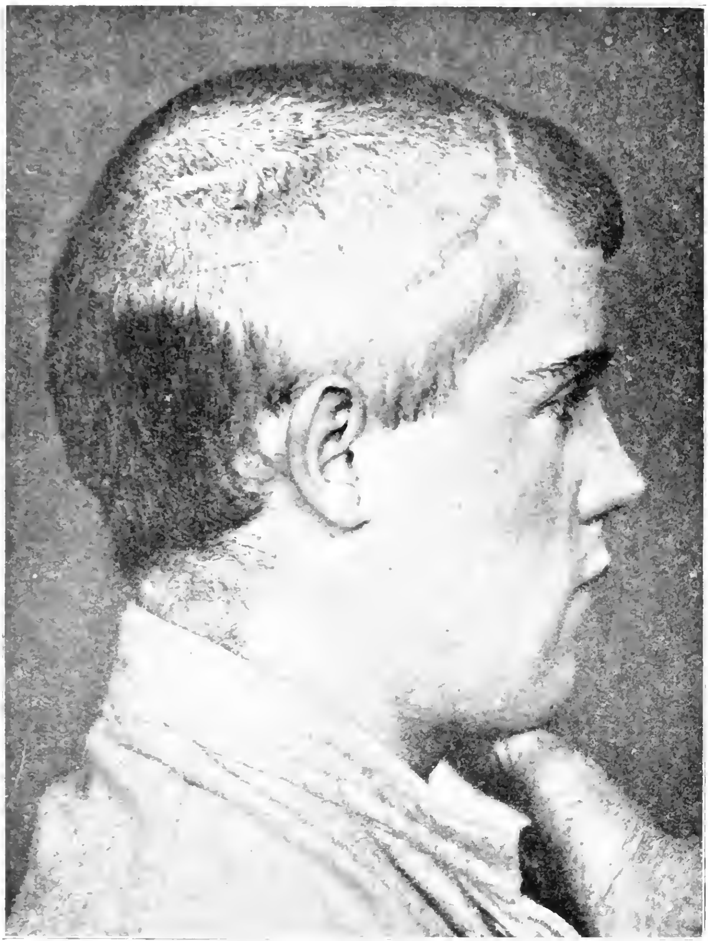

Fig. 160.

out. He reached the Base Hospital about nine hours later, and the wound was excised and sutured at once. Vision and speech were not affected, and he suffered little from headache during the first twenty-four hours. But the headache then became very severe, and by December 4 he had begun to vomit. Four days later the note on the field card said: "Going wrong. Cerebral abscess. Headache and vomiting. Weakness of left face and arm. Slow pulse; subnormal temperature." On December 8 he was operated upon, and a very small fissured fracture exposed. When the bone was removed, pus welled up through a hole in the dura mater. A small tube was inserted, and the flow of pus became profuse. From this time his progress towards recovery was uninterrupted.

He was admitted to the London Hospital on *February* 6, 1918, *eighty-four days after the injury* and sixty-four days after evacuation of the cerebral abscess.

All the wounds were healed, and the trephined area was somewhat depressed. The site of the original injury was represented by an almost horizontal scar, 8 cm. in length, in the right parietal region (Fig. 160). This was bisected by a short transverse cut, apparently the result of the first operation. The central portion of the wound, which lay directly over the trephined

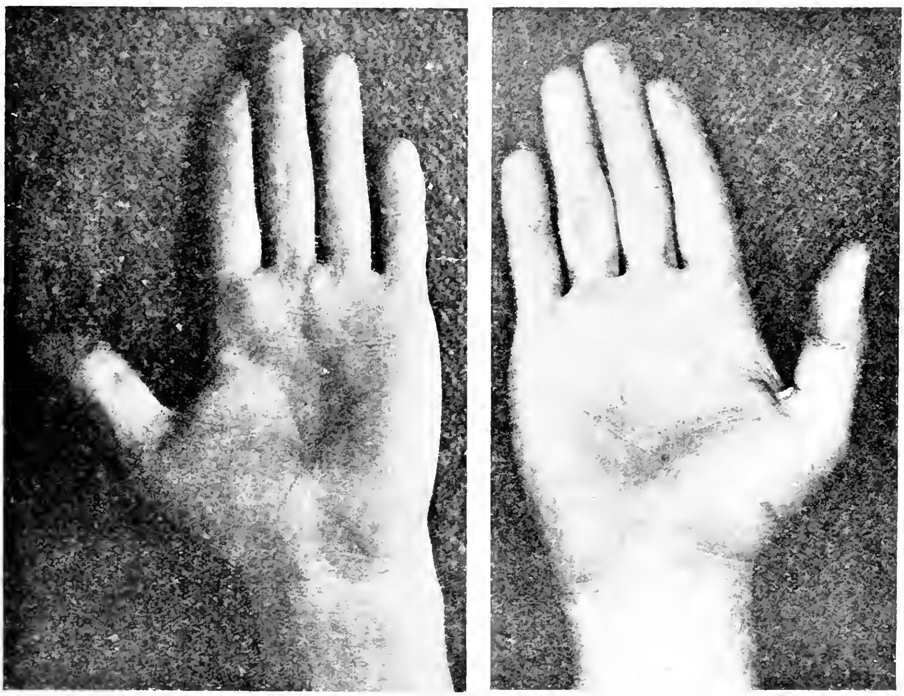

Fig. 161.—To show the condition of the right and left hands in No. 23.

area, was 18·5 cm. along the nasion-inion line and 9 cm. to the right. His head was remarkably big, measuring 37 cm. from the root of the nose to the level of the external occipital protuberance. The trephined area was 5 cm. in length and 4 cm. in breadth, and of an oval shape; measured along the nasion-inion line, the anterior border of the opening was 17 cm. and the posterior 22 cm. It pulsated heavily.

His mental state was remarkably good, speech was unaffected, and he had little or no headache so long as he was kept in bed. The headache became somewhat severe after he was allowed to get up, and he would suffer from a severe attack every two or three days. There was no nausea or vomiting, and he did not suffer from convulsions or seizures.

The discs, pupils, and ocular movements were in every way normal. Movements of the face, tongue, and palate were unaffected.

All the reflexes were equal and normal on the two sides.

Motion.—The grasp of the left hand was somewhat weaker than that of the right in the relation of 30 to 50, but all individual movements could be carried out by each digit in turn so long as the eyes were open. When they were closed, however, individual movements became clumsy: he succeeded in approximating the thumb to each finger by holding the fingers together in a flexed position and bringing the thumb into contact with the tip of each in turn. Moreover, the thumb slid off one finger to assume its position on the next, and the rhythm of the movement was defective. When the hands were held out in front of him, the fingers were in alignment, but, on closing the eyes, the little finger drooped; the other digits were abducted and adducted irregularly, and were no longer under perfect control. He could bring his finger to his nose perfectly with his eyes open; but when they were closed it was liable to strike the cheek, or to arrive clumsily on the spot at which he was aiming.

There was no gross wasting, but the difference between the two hands was profound (Fig. 161). The left hand resembled that of a woman, and was soft and rounded with delicate fingers; the right was that of a man capable of hard manual work. Its surfaces were squarely modelled, the palm broad and flat, and the fingers had an appearance of shortness in relation to the hand as a whole. The left hand, on the contrary, was rounded and soft; its lines were less deep. The fingers seemed to be longer and thinner than those on the normal side, although by measurement they were actually a little shorter. This illusory appearance was due to the smaller width of the left palm, which measured 8 cm. compared with 9 cm. on the right hand. The tips of the fingers were spatulate on both hands, but less so on the left than on the right. The interosseous spaces were not wasted; they seemed, however, on the affected side to be occupied by smaller and softer muscles. The patient had done no manual work for nearly four months, when the photographs were taken, and both hands were white and free from corns. The difference between them was immediately evident on contact. In the act of shaking hands, the right grip was firm and well sustained. I was conscious of the elastic pressure of the contracting muscles of the palm and of the tension of the fingers; I had the feeling that if the patient chose to increase his grasp it might become painful. But when I gave my left hand into his, it was like the impression received from the hand of a woman. My fingers seemed to be in contact with something soft, and without resistance; the pressure was orderly, but gentle and harmless.

All the digits of the left hand could be bent back passively one by one to an abnormal extent; even the thumb seemed to be hypotonic.

	Left (affected) hand.					*Right hand.*
	Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.	Normal digits.
Measured movement	10° to 20°	10° to 20°	20° to 30°	15° to 25°	20° to 30°	1°
Vibration	Affected	Affected	Affected	Affected	Affected	—
Compass test	Gross loss at 3 cm.	Gross loss at 3 cm.	Gross loss at 3 cm.	Gross loss at 3 cm.	Gross loss at 3 cm.	Perfect at 1 cm.
Localisation	Not affected	Affected	Affected	Not affected	Not affected	No mistakes
Tactile hairs	23 grm./mm.^{2}	Not perfect 100 grm./mm.^{2}	No threshold 100 grm./mm.^{2}	Not perfect 70 grm./mm.^{2}	Not perfect 70 grm./mm.^{2}	Perfect 21 grm./mm.^{2}
Thermal ...	Affected	Affected	Affected	Affected	Affected	Perfect recognition of 35° and 40° C.
Prick ...	5 grm.	Gross affection	Gross affection	8 grm.	8 grm.	4 grm. threshold.
Weight ...	Affected	Gross loss	Gross loss	Considerable loss	Considerable loss	Perfect appreciation of the series of changes in weight
Texture ...	Affected	Affected	Affected	Affected	Affected	Perfect recognition

There was no paralysis of the lower extremities, and movements of the left hip and knee could be carried out strongly against resistance; but dorsiflexion, and to a less degree plantar extension, of the left foot were not so forcible as on the right side. All movements of the toes were possible. He could walk well and could stand on the right foot, both with his eyes open and shut; on the left foot he could stand unsteadily but fell when his eyes were closed. I could find no definite signs of hypotonia in the left foot. There was no spasticity.

Sensation (between *February* 11 *and March* 10, 1918, 89 *to* 116 *days after the injury*).

He complained that the left hand "felt numb," and this abnormal sensation was worse over the palm and forefingers than over the thumb and thenar eminence. When he woke at night it seemed to him as if he had lost the index and middle fingers; "this part of the hand seemed gone altogether." He did not recognise any abnormality in the left lower extremity.

The results obtained were the usual sensory tests at this time, as shown in the following table :—

He was sent to a convalescent home, and, on his return, the following observations were made between *May* 6 *and* 12, 1918 (173 *to* 179 *days after the injury*).

His headache had almost entirely ceased; he had given up smoking, and, with the disappearance of the chronic cough, the most potent cause of his headache was removed.

Motion.—Individual movements of the left hand could be carried out so long as his eyes were open, but, when they were closed, the fingers became somewhat ataxic, especially the index and middle. These two digits were still hypotonic, but the thumb, ring and middle fingers could also be bent back to a somewhat greater extent than similar parts of the right hand.

Sensation.—The condition had improved considerably, but the index and middle fingers still showed the greatest loss of sensation.

	Left (affected) hand.					*Right hand.*
	Thumb.	Index finger.	Middle finger.	Ring finger.	Little finger.	Normal digits.
asured movement	1°	5°	5°	1°	1°	Perfect at 1°.
bration	No difference	6 sec. shortening	5 sec. shortening	No difference	No difference	—
mpass test	1 cm.	5 cm.	Lost at 5 cm.	1 cm.	1 cm.	1 cm.
ealisa-tion	Perfect	Affected	Affected	Perfect	Perfect	Perfect
etile hairs	Normal 21 grm./mm.²	Not perfect at 100 grm./mm.²	Not perfect at 100 grm./mm.²	35 grm./mm.²	23 grm./mm.²	21 grm./mm.² perfect
ermal ...	Not affected	Gross loss	Gross loss	Not affected	Not affected	Perfect recognition of 35° and 40° C.
ick ...	4 grm.	8 grm.	8 grm.	4 grm.	4 grm.	4 grm. threshold
eight ...	Perfect	Affected	Affected	Perfect	Perfect	Perfect series
rm ...	Perfect	Slow and uncertain	Slow and uncertain	Perfect	Perfect	Perfect recognition
xture ...	Perfect	Gross loss	Gross loss	Introspective	Introspective	Perfect recognition.

(B) APPROXIMATE POSITION OF THE LESION IN EACH CASE CITED IN THIS PAPER.
(For use with Chapter VIII.)

It is impossible to determine with accuracy the position of the injury to the brain from the situation of the wound on the surface. But certain rough conclusions can be drawn, and Professor Elliot Smith has kindly attempted to localise the main incidence of the lesion in each of my cases. My sincerest thanks are due to him for the trouble he has taken and the encouragement he has given me in this matter.

Case 1.—Lieutenant A. A., aged 26. Wounded October 8, 1915, by a fragment of a high explosive shell. He was not wearing a helmet.

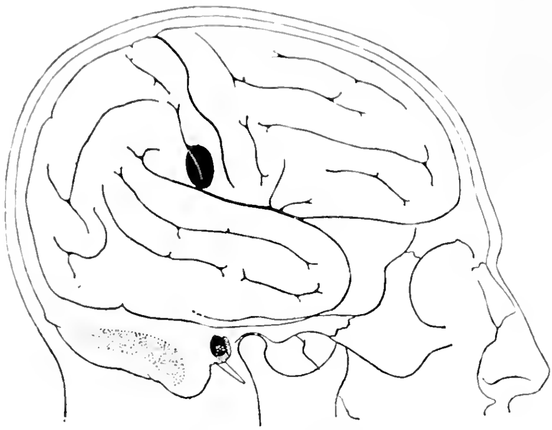

Fig. 162 (Case No. 1).

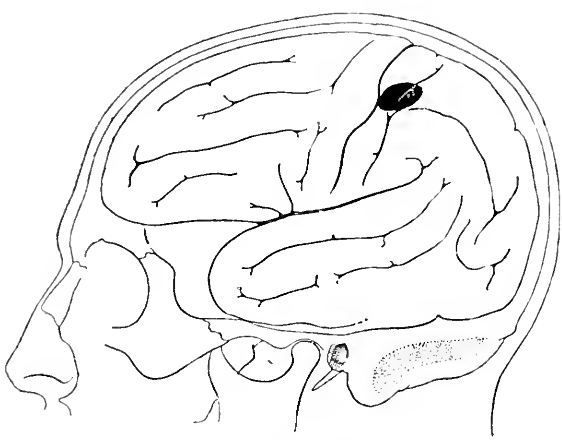

Fig. 163 (Case 2).

He was admitted to the Empire Hospital for Officers on December 22, 1915, with the following note: "Operation on October 9, 1915, by Major Austen. Depressed bone removed. A large fracture passed forwards towards the right eye. Dura mater opened widely and 2 to 3 oz. of subdural blood and brain matter escaped.

"The brain at first formed a slight hernia, about the size of half-a-crown; but, after about fourteen days, it sank away and left a hollow below the level of the bone."

The opening in the skull extended from 15 to 17 cm. back from the nasion and 10 cm. to the right of the middle line. The total nasion-inion line measured 34 cm. (Fig. 162).

The wound healed completely at the beginning of April, 1916.

My observations were made at various times between January 2 and July 22, 1916.

Case 2.—Lieutenant F. W. B., aged 31. Fully reported on p. 761 (Fig. 163).

Case 3.—Bombardier J. W. B., aged 26. Fully reported on p. 764 (Fig. 164).

Case 4.—Private F. B., aged 18. Wounded January 7, 1916, by a shrapnel bullet. No helmet. The note which came with him said: "Compound fracture of the skull. On January 8, 1916, the edges of the long ragged scalp wound were excised. Usual trephine operation to enlarge

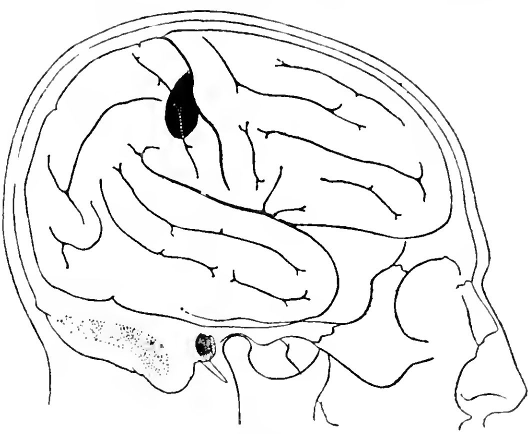

FIG. 164 (Case 3).

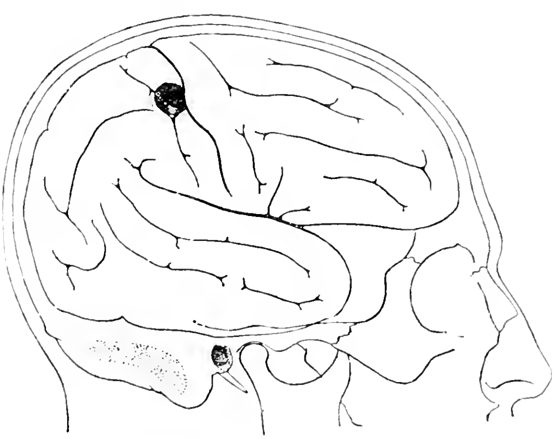

FIG. 165 (Case 4).

opening and remove depressed bone. Brain substance was oozing through. Blood-clot and brain washed away with a gentle stream of eusol.

"Had hernia cerebri, which disappeared under eusol dressings. At first there was complete paralysis of the left arm and leg. Now recovered as to coarse movements; fine movements still lack co-ordination. The ulnar fingers show most impairment."

He was admitted to the London Hospital on April 4, 1916. The wound was healed and consisted of a crescentic scar on the right side of the head, extending from the anterior temporal to the posterior limit of the parietal region. The greater part of this was a scalp injury only; but in the centre of the wound the bone had been removed over an area 3 cm. in length horizontally and 1·2 cm. in breadth. Here the scar pulsated.

This area of removed bone extended from 18 cm. to 21 cm. back from the nasion. Its upper limit was exactly 5 cm. from the middle line. The total nasion-inion line measured 34 cm. (Fig. 165).

My observations were made between May 9 and July 23, 1916.

Case 5. 2nd Lieutenant R. S. C., aged 28. Fully reported on p. 768 (Fig. 166).

Case 7. Lieutenant H. J. C., aged 39. Wounded July 17, 1915, by a rifle bullet. No helmet. He was admitted to the Empire Hospital for Officers on October 27, 1915. No notes of any kind.

On July 18, 1915, some operation was performed, and he said he was trephined.

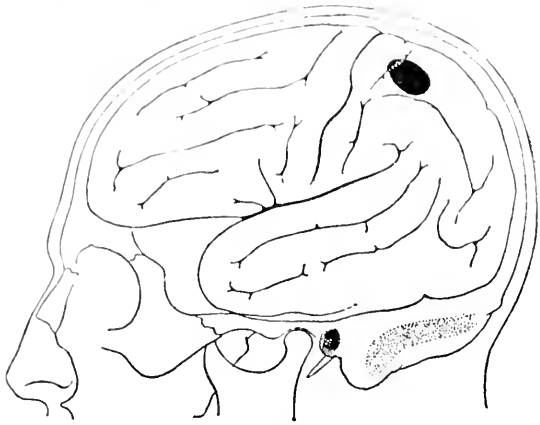

Fig. 166 (Case 5).

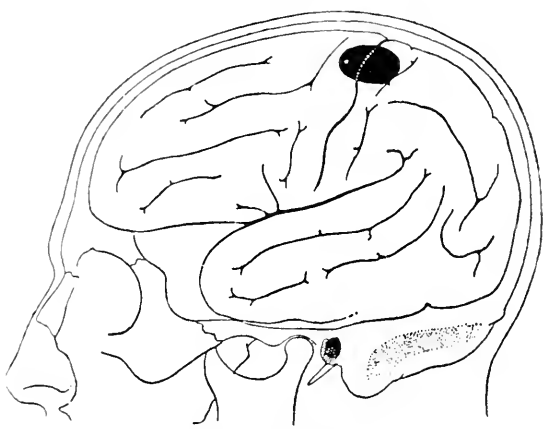

Fig. 167 (Case 7).

When he entered the Empire Hospital there was a long irregular scar on the left side of the head; in the centre was a minute granulating area, which was situated over the small trephine opening in the skull. This opening was oval in shape and measured about 2·5 cm. by 1·5 cm. in the two diameters. It was situated 18 cm. back from the nasion and 2 cm. from the middle line. The nasion-inion line measured 35·5 cm. (Fig. 167).

On November 10, 1915 Mr. Walton removed two small pieces of bone, which lay in the brain substance about 1·5 cm. from the surface, but entirely closed off. The dura was intact except for the sinus.

The wound healed on December 23, 1915.

Exactly a year later the wound was found to be covered with a minute crust, and on November 18, 1916, Mr. Walton removed three small pieces of bone from the fibrous tissue on the surface of the brain. The wound healed finally November 29, 1916.

In this case the foot was most severely affected, and the injury had produced a definite right hemiplegia. Not only did the right plantar give an upward response, but the left was at first also abnormal in the direction of the movement.

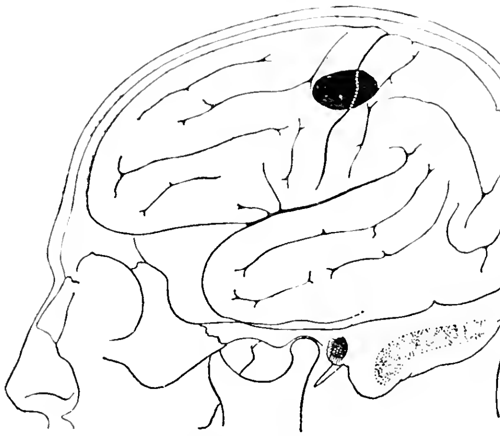

Fig. 168 (Case 8).

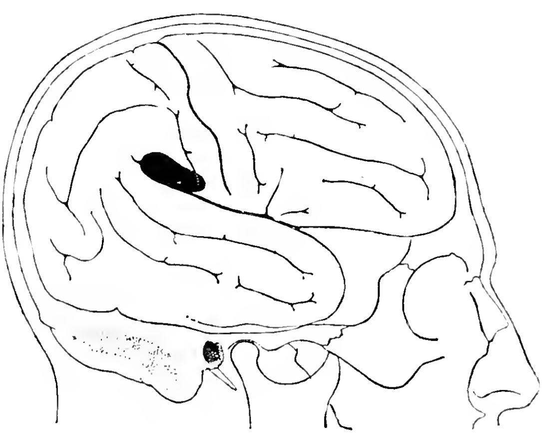

Fig. 169 (Case 10).

The little finger showed more severe sensory changes than any other part of the hand.

Case 8.—Lieutenant L. A. D., aged 20. Fully reported on p. 775 (Fig. 168).

Case 10.—Private C. H. E., aged 23.

Wounded at 6 p.m. on March 2, 1917, by a rifle bullet. He was wearing a helmet.

He says he was placed on the operating table in the early hours of March 3, 1917. No notes of any kind.

On March 6, 1917, he arrived at Rouen. The notes are as follows: "No notes, but trephine opening in the right parietal region. Small entrance wound, apparently not touched, in centre of flap. Large fluctuating hernia under flap, presumably large decompression."

He was admitted to the London Hospital on March 15, 1917. The incision and entrance wound had healed.

The scar of entry was situated from 18 to 20 cm. back from the nasion and 11 cm. to the right of the middle line. It measured 2 cm. in length horizontally and 0·75 cm. in breadth. Beneath it lay an irregular opening in the bone about 4·5 cm. by 2·5 cm. The nasion-inion line measured 35 cm. (Fig. 169).

Case 11.—Lieutenant J. P. S., aged 29.

Wounded on May 3, 1918, by a rifle bullet. He was wearing a helmet.

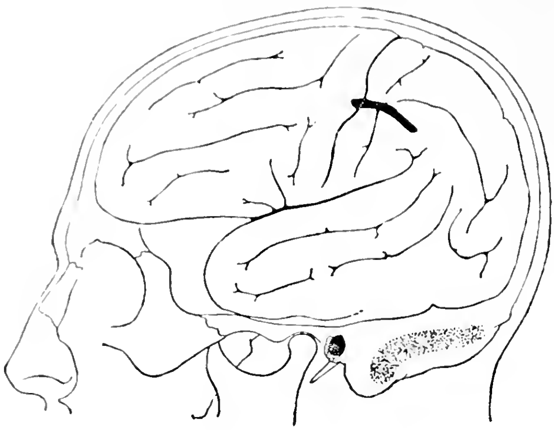

Fig. 170 (Case 11).

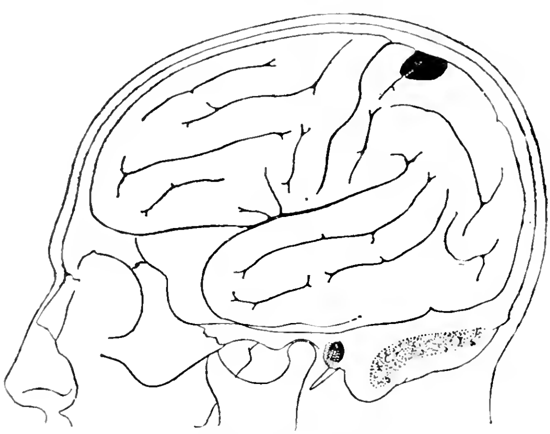

Fig. 171 (Case 12).

On May 4 the wound was excised, but he was not trephined.

No further operation.

Admitted to the London Hospital May 9, and was transferred to my care June 26, 1918.

The scar was an irregular incision in the left parietal region 8·5 cm. in length. It reached in front to within 14·5 cm. of the nasion, and posteriorly to 23 cm. back from the same point. The scar was throughout 8 cm. from the middle line. The bullet had evidently travelled from behind forwards. The total nasion-inion line measured 35 cm. (Fig. 170).

A radiograph showed no fracture of the skull.

This was a case of injury to the cortex without penetration of the skull.

The condition of the right hand was in every way characteristic. The maximum affection lay over the thumb and index finger. The index finger was definitely hypotonic.

Case 12.—Captain H. N. F., aged 22.

Wounded March 12, 1915, by a rifle bullet. No helmet.

He was operated upon by Mr. Robert Milne on March 15, 1915. The skull was fractured and a small irregular trephine opening was made. The wound healed entirely in ten weeks. All headaches disappeared by the middle of April.

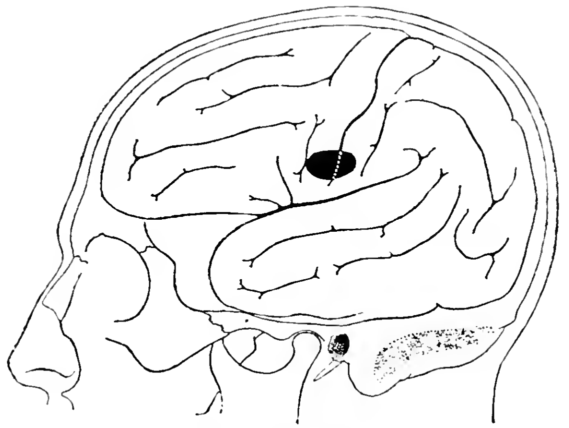

FIG. 172 (Case 13).

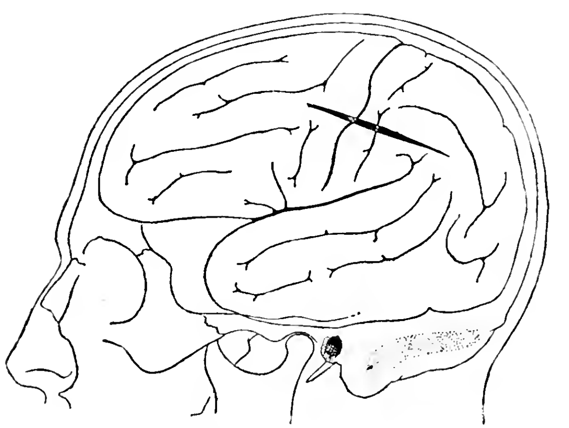

FIG. 173 (Case 14).

The leg had never been affected and two months after he was wounded the hand and arm had reached the condition in which I saw him.

He was brought to me by Mr. Milne in June, 1916, fifteen months after the injury. The wound was represented by a well-healed, somewhat depressed scar, which did not pulsate unless he lowered his head; there was no pulsation in the erect position.

The opening in the bone was irregularly rhomboidal, 3 cm. in diameter from opposite angles. It was situated from 21·5 to 23·5 cm. back from the nasion, and the superior angle was 2 cm. from the middle line. The total nasion-inion line measured 35 cm. (Fig. 171).

My observations were made between June 12 and June 25, 1916.

Case 13.—Lieutenant G. O. H., aged 21.

Wounded May 20, 1917, by a fragment of high-explosive shell. He was wearing a helmet.

At 9 p.m., May 20, "the gaping wound was excised. Depressed fragments removed. Dura open, discoloured and tense. Opened by a linear incision. Blood-clot and ruptured brain expressed."

On May 28, the note states, "Patient had motor aphasia and some slight impairment of the right hand."

When admitted to the London Hospital on June 14, there was a large area on the left half of the scalp covered with a network of healed plastic flaps. At a point in the centre of this labyrinth the skin was somewhat depressed and pulsated heavily. The site of the original wound could be seen, and it lay over a small irregular trephine opening. This was situated 16 cm. back from the nasion, and 5 cm. to the left of the middle line. It was roughly oval, 3 by 2 cm. in diameter. He had a tall head with a short posterior portion, and the total nasion-inion line measured 34 cm. (Fig. 172).

Case 14.—Lieutenant E. C. H., aged 29.

Wounded at about 4.30 p.m. on October 1, 1916, by a rifle bullet. He was wearing a helmet.

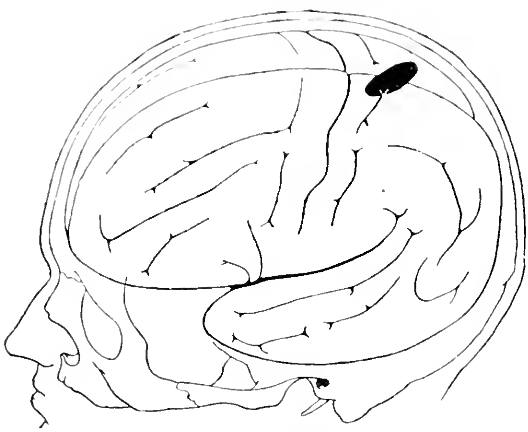

Fig. 174 (Case 15).

The right hand was affected, and the right side of the face was numb. The leg was not affected at any time.

He was operated upon the same day, but was told "Nothing was found in the wound, which had not touched the bone."

He was admitted to the London Hospital on October 6, 1916, with a healed longitudinal scar of a surgical incision in the temporal and parietal region. There was no defect of bone. The anterior end of this scar was 13·5 cm. back from the nasion, the posterior end 23 cm. It lay as a straight line, somewhat obliquely to the middle line of the scalp: the anterior end was 6 cm., the posterior 9 cm. to the left. Its total length was 9·5 cm. The nasion-inion line measured 35 cm. (Fig. 173).

The maximum affection of sensibility was found in the thumb and index finger. The index finger was somewhat hypotonic. Speech was affected at first. The lower extremity was in every way normal.

Case 15.—Lieutenant E. D. J., aged 22. Fully reported on p. 778 (Fig. 174).

Case 16.—Private W. J., aged 38.

Wounded February 23, 1917, probably by a shell fragment. He was sniping behind a steel plate when it was hit.

The interchange of information card sent out by the Medical Research Committee stated:

"Date of wound February 23. Could be roused to answer questions. Headache, vomiting, pain in eyes. Paresis and paræsthesia of left arm. Operation under local anæsthesia. Linear fracture of right parietal. Inner table fractured. Small laceration of dura. Active bleeding from vessel in dura. Bleeding controlled. Salt cigarette drain."

"March 17, 1917, paræsthesia all gone. Still paresis of fingers. Headache much better."

He was admitted to the London Hospital on March 22, 1917. There was a deep, pitted wound in the right parietal region, roughly triangular in shape. No formal operation had been carried out and the loss of bone was extremely small. It measured about 3 cm. by 1 cm., and was situated

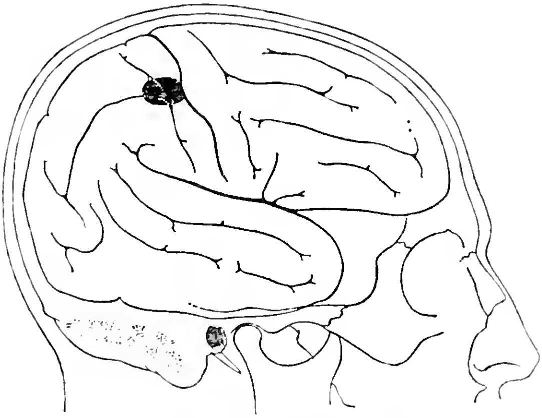

Fig. 175 (Case 16).

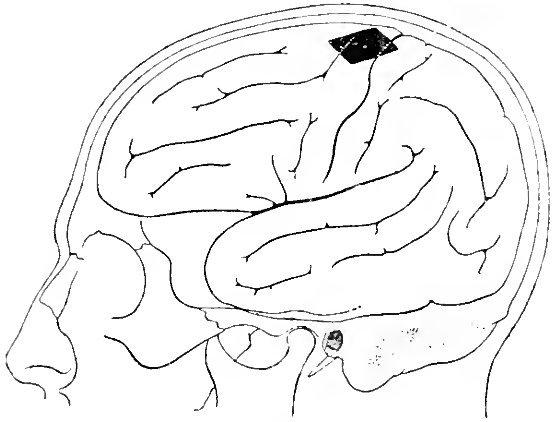

Fig. 176 (Case 17).

from 18 to 20 cm. back from the nasion and 5 cm. to the right of the middle line. The total nasion-inion line measured 35 cm. (Fig. 175).

The wound healed by May 8, 1917.

My observations were made between April 27, and June 4, 1917.

The remarkable condition in this case was the widespread sensory disturbance of the whole of the left hand; but tactile, thermal and painful sensibility were entirely unaffected. The loss of sensation to the tests for weight and form was particularly gross.

Case 17.—Private F. L., aged 29. Fully reported on p. 672 (Fig. 176).

Case 18.—Colonel M., aged 46. Fully reported on p. 781 (Fig. 177).

Case 19.—2nd Lieut. D. P., aged 23. Fully reported on p. 783 (Fig. 178).

Case 20.—Private J. G. S., aged 21.

Wounded on July 18, 1917, by a fragment of a high-explosive shell. He was wearing a helmet.

Operated upon at 11 a.m. the same day. "Fracture of the skull. Dura not penetrated. Wound excised. Large fracture. All loose fragments of inner and outer table removed and bone chipped round evenly. No gross injury to dura."

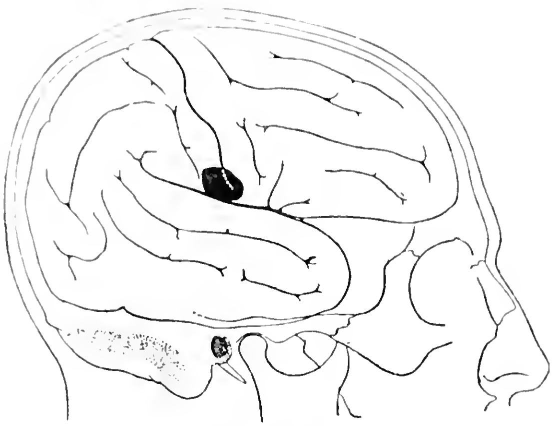

FIG. 177 (Case 18).

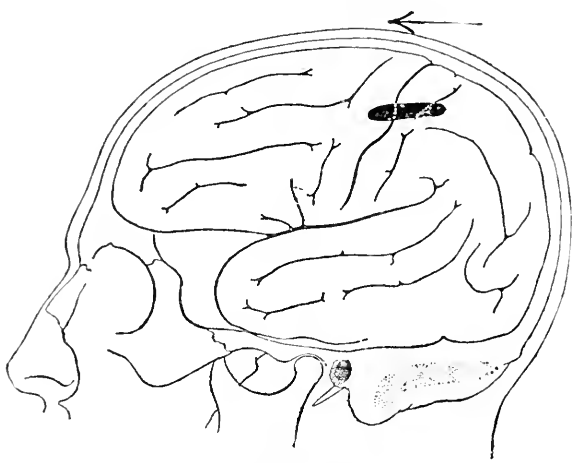

FIG. 178 (Case 19).

July 24, 1917, arrived at the base by barge. "Had convulsions. Slow pulse. Motor aphasia. No optic neutiris. Slow cerebration. At 9 p.m. wound explored and a quantity of serum evacuated. Convulsions at 11 p.m. Lost use of right arm and leg."

"July 26, more fluid evacuated."

"July 27, use of shoulder, elbow and wrist recovered in this order. Use of leg returned, toes last. Abdominal reflex returned. Motor aphasia has cleared up."

When admitted to the London Hospital on August 8, 1917, with a scar in the left parietal region, which was healed except for a small sinus discharging clear fluid. This healed entirely on August 17.

There was an irregularly oval opening in the bone 4·25 cm. in largest diameter. It was situated 20 cm. back from the nasion and was 5 cm. to the left of the middle line. A radiograph showed a definite removal of bone with smooth edges. The total nasion-inion line measured 34 cm. (Fig. 179).

All the digits were affected, but the grossest loss was in the little, ring, and middle fingers.

Case 21.—Private J. H. T., aged 24.

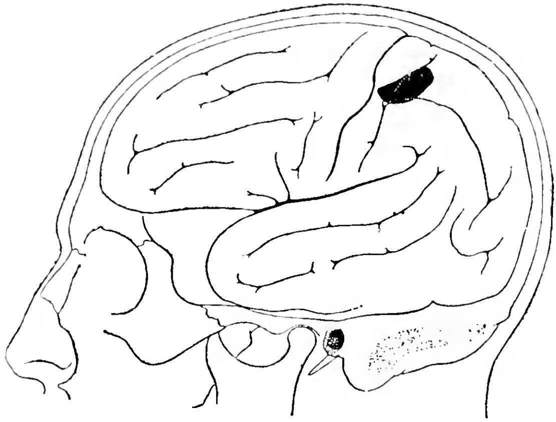

Fig. 179 (Case 20).

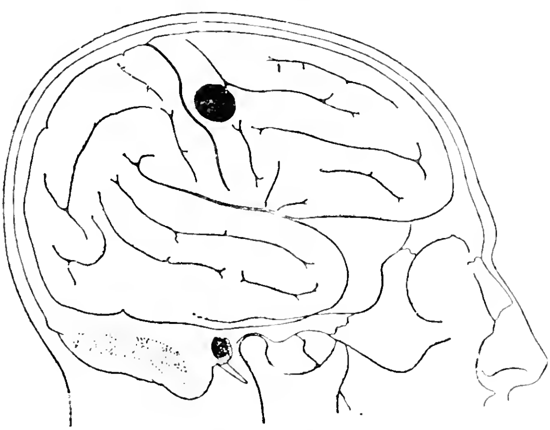

Fig. 180 (Case 21).

Wounded on June 16, 1915, by shrapnel. No helmets at this time.

He was admitted to the London Hospital on July 8, 1915, with no notes of any kind. A large flap had evidently been turned down and in the centre the site of the original wound was obvious as a ragged hole. This was from 15 to 18 cm. back from the nasion and 8 cm. to the right of the middle line. The patch was 3 by 2 cm. and was pulsating. The total nasion-inion line measured 3·45 cm. (Fig. 180).

Case 22.—Corporal H. U., aged 29.

Wounded September 25, 1917, by shrapnel. No helmets at this time.

The same day a piece of shell casing and a shrapnel bullet were extracted.

The wound healed in the early part of December, 1915.

He came under my care on May 15, 1916.

There was an irregular rectangular removal of bone 4 by 1·5 cm. in the right parietal region. It extended from 16 to 20 cm. back from the nasion. The anterior edge was 4·5 cm. and the

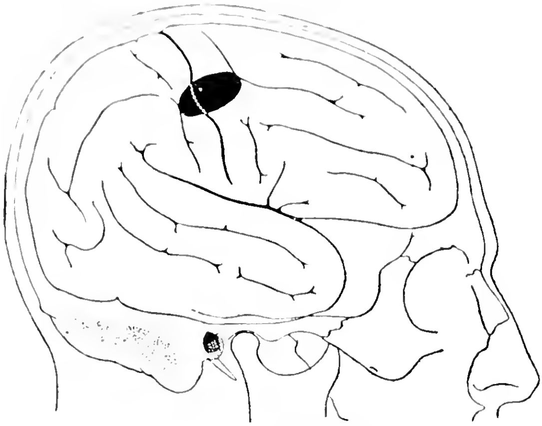

FIG. 181 (Case 22).

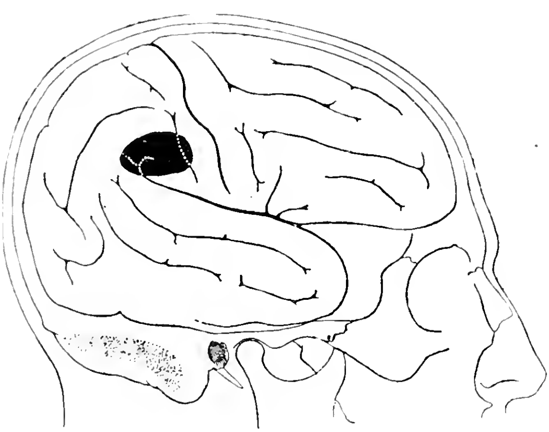

FIG. 182 (Case 23).

posterior edge 8 cm. to the right of the middle line. It was thus placed somewhat obliquely and pulsated in the centre. The total nasion-inion measured 34 cm. (Fig. 181).

In this case the index finger showed the grossest sensory changes.

Case 23.—Private J. H. W., aged 22.

Fully reported on p. 786 (Fig. 182).

EPILOGUE

In the course of this work we have traced the physiological processes produced by various physical stimuli from their origin at the periphery of the nervous system to the moment when they excite sensation. We have shown that they are subjected to far-reaching changes during their passage through this zone of physiological activity, which in many cases give the key to the evolution of function in the nervous system. Our observations have both a practical and a theoretical bearing: thus, for example, the discovery of the nature of protopathic sensibility and of the significance of the mass-reflex are some aid to clinical diagnosis. This practical aspect of our researches we can safely entrust to our neurological colleagues with the certainty that they will adopt whatever they find to be of use in practice.

But before closing this book I should like to call attention to the wider theoretical bearing of our work. It is essentially a study in function by clinical methods in man. Physiological processes have been investigated, not by anatomical or post-mortem examination, but by careful correlation of functional states revealed by dissociation.

Interest in the functions of the nervous system, as revealed by disease, is steadily growing. The English school has always been essentially physiological, from the days of Marshall Hall onwards; but this growing attention to function is mainly due to the teaching of Hughlings Jackson. He sprang from the physiologists of the middle of the last century, and was deeply imbued with the principle of evolution, not only of structure, but of function. But his contemporaries became increasingly obsessed with the study of anatomical and topographical details. As years passed by, the teaching of the day moved away from Jackson's conception of an evolution of function, still demonstrable in the activities of the nervous system. Finally, his doctrines were scarcely comprehensible to those of us who were brought into daily contact with him in the wards, seduced as we were by the glib generalities of more popular teachers. But, when we came to think for ourselves, we found that his conception of a functional hierarchy, in which one form of activity was dominated by another, standing higher in the evolutionary scale, explained much that was otherwise inexplicable in the phenomena of nervous disease. This swing back to the physiological aspect was quickened by the exquisite researches of Sherrington, and the issue of his *Integrative Action of the Nervous System*, in 1906, marks an epoch in the progress of neurology.

We then began to appreciate, that the existence of the central nervous system was due to the necessity of producing coherent action in a plurisegmental organism. Out of the primitive materials at her disposal, Nature was forced to develop a mechanism capable of integrating the physiological forces evoked by relations with the external world. As the animal rose in the evolutionary scale, the functions required of the nervous system became more and more complex, and out of the anatomical structures of a lower organism had to be developed a machinery capable of exercising these higher activities.

This was only possible by integrating the crude physiological processes excited by external stimulation, or arising in response to the action of internal forces. A prick excites a universal tendency to withdraw the part exposed to stimulation: it can also evoke a highly organised movement, such as the scratch-reflex, capable of removing the noxious object.

But such reflexes are preordained and admit of no choice. It became necessary, therefore, to develop a controlling mechanism that would permit the animal, either to attack the stimulus locally, or to evade its action by flight. Finally, with the development of the neo-pallium was given the power of voluntary choice: the reaction was no longer unconscious, but could be preceded by a definite act of discrimination.

This adaptation to a clearly determined end demands a multitude of adjustments, and such integration is the business of the central nervous system. It can only be carried out by utilising, in a modified form, functions originally developed for a somewhat different purpose. Thus, the withdrawal movement, which forms the basic reaction to pricking the sole of the foot, is controlled by higher centres in the mid-brain and forms the flexor aspect of the stepping reflex. Flexion may still occur as a defensive reaction, but it is regulated in such a way that energy does not overflow into visceral channels. When this higher influence is removed, as, for example, by certain injuries to the spinal cord, the lower reflex may become manifest in its primitive form as a pure movement of withdrawal, accompanied by evacuation of the bladder and rectum.

Structure is anchored in the past and may express, in its anatomical arrangements, functions which have been transmuted. Many of them have been carried up to centres of more recent origin, whilst others are exercised normally, in a refined form, under the control of those higher in the evolutionary scale. But nothing remains in its old form, unless it is of utility to the organism under some possible conjunction of circumstances.

Thus the afferent impulses from the viscera do not normally enter consciousness. The eupeptic knows nothing of the processes of digestion, beyond a certain gentle sense of well-being. But, under abnormal conditions, afferent impressions from the internal organs are capable of arousing pain and discomfort. When this occurs, one form of this sensory disturbance is referred to the superficial structures of the body and is associated with areas of tenderness, corresponding to a segmental arrangement of the central nervous system.

This is not a "hyperæsthesia," but a tendency to react more violently to any stimulus capable of evoking discomfort. The threshold is not materially lowered, but the vehemence of the response is greatly increased.

Now this over-reaction is associated with reflexes, which still reveal their old defensive character. As an answer to visceral pain, the abdominal muscles become tonically contracted, and the leg is drawn up on the affected side. The sufferer is forced to creep into some sheltered place, and to lie curled up, till he either dies or recovers. All capacity to move as a whole is abolished; the reactions of the part affected now dominate the activity of the complete animal. Visceral reflexes, of this order, are antagonistic to general movements, and this is expressed, not only in muscular immobility, but in the mental attitude which accompanies visceral pain.

Pain is the oldest defensive reaction, and potentially painful stimuli are the basis of all primitive reflexes. It is therefore of importance for higher development, that these impulses should be rendered less effective in favour of those impressions which lead to a more general and discriminative response. But, although they are controlled and even abolished, the mechanism underlying the production of pain must remain in full physiological activity, ready to play its part should occasion arise, in the defence of the body against noxious influences.

The functions of the central nervous system are not a palimpsest, where a new text is written over an earlier manuscript, partly erased. The more primitive activities have been profoundly modified by the advent of the new centres, which utilise some of the faculties originally possessed by the older mechanism. In many cases the higher function could not be exercised, without the existence of these lower powers which it dominates and controls.

When, however, the higher mechanism is thrown out of action the functions of the lower centres are free to exhibit their activity unchecked. Jackson insisted that the manifestations, due to a lesion of the central nervous system, must be considered from a negative and a positive aspect. Injury to the pyramidal system was shown, negatively, in the loss of the finer voluntary movements; but the activity of the lower centres, released from control, was evident in the spastic rigidity of the paralysed parts. In the same way, removal of the control, normally exercised by the cortex over the activity of the optic thalamus, leads to the remarkable condition known as thalamic over-reaction; all stimuli capable of evoking discomfort, and in some cases even pleasurable excitation, cause an exaggerated response on the affected half of the body. This is not due to "irritation"; it is due to release. It is the direct consequence of loss of that control normally exercised by the cortex over the activities of the optic thalamus. Once this control is removed by disease, the lower centre reacts unchecked to any stimulus capable of exciting a response.

It has been the custom to call upon a hypothetical "irritation" to explain all such positive manifestations of nervous energy. The violent flexor spasms and the outbursts of excessive sweating, which occur when the spinal cord is injured, have been attributed to this cause. In reality, they are the expression of a diffuse and massive response to stimuli, applied to parts below the level of the lesion; they are manifestations of a primitive mode of reaction, due to removal of control from above. Involuntary movements in hemiplegia, automatic acts following an epileptic attack, the emotional utterances in aphasia, are all examples of the same phenomenon. The condition of sensibility, during the protopathic stage of recovery from a peripheral nerve lesion, is another instance of a primitive mode of reaction, released from control by the tardy restoration of the epicritic mechanism. Normally the massive "all or nothing" response of the more primitive system is held in check by the localised and discriminative sensations, due to excitation of the epicritic end-organs. But, when the one set of afferent impulses is permitted to play on the ultimate sensory centres unchecked by those arising in the higher mechanism, the response becomes massive and diffuse, and extensity becomes of greater import than intensity.

Had we applied Jackson's law, that the functions of the nervous system are integrated on evolutionary principles, neurology would not have made so many excursions into the wilderness. He taught us that a lesion of the cerebral cortex caused disorder of movement, not paralysis of the muscles. This lesson, however, was not applied to the other functions of the cortex. Much time was wasted on topographical localisation of various sensory centres, before the nature had been determined of the functions exercised by the cortex. Now we know that, as far as somatic sensibility is concerned, the cortex is responsible for the appreciation of spacial relations, for the power of responding to different intensities of stimulation, and for the capacity to recognise similarity and difference in external objects, brought into contact with the body. The cortical centres are not concerned with the crude appreciation of touch, pain, heat and cold.

Such principles are not only of theoretical importance; they are perpetually thrust before the neurologist in his daily work. Clinical diagnosis is a by-product of scientific investigation. It is impossible to expose every patient to laborious scientific examination, nor would it serve any useful purpose to do so: but the simple tests, employed in the wards, are valueless until they have been calibrated by more elaborate investigations. The man who says he can obtain all the information he wants, in cases of injury to peripheral nerves, by means of a pin and a piece of cotton wool, depends on some one else to teach him the significance of these empirical tests. They have no scientific value, until the data they yield are correlated with results, reached by methods capable of measurement.

The charm of neurology, above all other branches of practical medicine, lies in the way it forces us into daily contact with principles. A knowledge of the structure and functions of the nervous system is necessary to explain the simplest phenomena of disease, and this can be only attained by thinking scientifically.

Let us, then, consider some of the leading principles which have emerged from our researches.

(1) When any level [1] of activity is attacked, the most complex functions, and those which have appeared most recently, are the first to suffer; they are also disturbed to a greater degree, and to a wider extent, than those which are simpler or more inevitable in their expression.

An excellent example of this rule is seen in the effect of a lesion of the sensory cortex on the appreciation of the spacial aspects of an external stimulus. Tests, which demand recognition of movement in three dimensions, are more gravely affected than such a comparatively simple one as localising the position of the stimulated spot: for, with the precautions we habitually adopt, this is an exploration in one dimensional space. Division of the spacial aspects of sensation according to one, two and three dimensions is obviously arbitrary; but the tests we apply become more or less complex and difficult according as they demand recognition of relations in space of three, two or one dimensions. Consequently, the records obtained by measuring the extent of passive movement, which can be appreciated in the affected limb, are more gravely and extensively affected, than those yielded by our method of testing localisation.

(2) The negative manifestations of a lesion appear in terms of the affected level.

Thus when the sensory cortex is injured the change in sensation is not shown as a loss to touch, pain, heat or cold, but as inability to recognise spacial relations, relative intensity or similarity and difference in the various test objects. Any one of these factors may suffer or may escape independently of the others; for they are all functions of the same level and stand to one another in no hierarchical relation.

So, with disturbances of speech of cortical origin, the consequences are manifested in terms of defective speech. They do not appear as an affection of some totally different function, such as visual and auditory images. In the same way morbid conditions at the reflex level appear as changes in the reflexes, and a disturbance of cerebellar activities is seen in inco-ordinate movement.

(3) A negative lesion produces positive effects by releasing activities, normally held under control by the functions of the affected level.

Every study in this book contains illustrations of this law, first enunciated by Hughlings Jackson. The phenomena of the mass-reflex after injury to the spinal cord and of spastic rigidity in hemiplegia are examples on the motor side. Protopathic sensibility and thalamic over-reaction are due to similar conditions amongst afferent activities. For with the release of the essential centre of the optic thalamus from control, all sensory impulses capable

[1] The word "level" is employed throughout in a strictly functional sense. Any one anatomical organ of the central nervous system may exercise functions of more than one physiological level. Thus the optic thalamus contains, not only the termination of the fillet, but also the centre for the affective aspects of sensation. For the same reason, a lesion of the post-central cortex not only produces loss of certain sensory faculties, but may also cause hypotonia in the affected parts of the body.

of exciting affective reactions exercise a preponderating influence. Sensation becomes overloaded with feeling-tone and pleasure or discomfort are evoked to an abnormal degree. In this case the physiological activity of the cortex possesses a direct controlling effect on that of the optic thalamus, so that simple disconnection of the two organs leaves the latter free to exercise its functions unchecked.

(4) The functions of the central nervous system have been slowly evolved by a continuous process of development. The methods, by which this gradual progress from lower to higher efficiency has been reached, are still manifest in the phenomena of its normal activity.

Although localisation of the stimulated spot is the simplest spacial aspect of sensation, observation has shown that it is the product of a struggle between various impulses with diverse sensory potentialities. During the protopathic stage of recovery of sensation, after division of the nerves to a considerable area of the skin, any stimulus capable of arousing a sensation is localised at a distance from its point of application. If care is taken to avoid pressure and the hairs are gently stroked, a widespread tingling may be evoked which seems to lie over some remote area. In the same way a drop of ether causes an extensive sensation of cold, and an interrupted current one of pain in the same parts of the limb. This erroneous localisation is not fortuitous; it remains the same, whenever the stimulus is effective, provided it does not evoke sensations of pressure.

But, with the return of the higher forms of sensibility to the skin, this diffuse radiation ceases, and is replaced by that form of cutaneous localisation with which we are normally familiar. The older extensive response gives place to one more consonant with discrimination.

This is not surprising, when we consider that the sensory mechanism of man has been evolved from that of lower organisms. The primitive method of response produces movements of withdrawal which permit of no choice and are admirably fitted to defend the animal from noxious influences.

But, with the higher development of function in the nervous system, these impulsive reactions are replaced by sensory activities, which permit of discrimination and choice. The response ceases to be diffuse, and becomes confined to the neighbourhood of the stimulated spot; it no longer has the "all or nothing" character of the primitive sensation, but comes to bear some relation to the intensity of the stimulus. Two or more spots can be discriminated, and recognition of the relative size and shape of the external object follows as a necessary corollary. The character of the sensory projection has changed. Impulses from the surface of the body are no longer concerned with producing an indiscriminate reaction of repulsion or attraction, but reveal the position and relative characteristics of objects in contact with the skin.

Thus the lowest reflexes give the most definite response; there is little or no choice, the answer is inevitable. They are, as Jackson expressed it, highly organised. But further development of the needs of the animal demanded a reaction that was less fixed: some variation must be permitted. This led finally to the domination of many reflex manifestations by consciousness. What at lower levels appeared a variable response, became, with the progress of evolution, voluntary control.

(5) Integration of function within the nervous system is based on a struggle for expression between many potentially different physiological activities.

It must not be forgotten that sensation, as known to the normal individual, is the result of innumerable changes, which have been integrated on the physiological level. The diverse effects produced on the living organism by a stimulus are sorted, combined or inhibited on their passage through the central nervous system, and the ultimate results of the integration finally act on the appropriate receptive centres. The most elementary sensation is based on innumerable physiological changes.

Let us consider the following example, drawn from the afferent side. A metal test-tube, containing water at 45° C., normally evokes a sensation of pleasant heat. But it is easy to show that this temperature, suitably applied, stimulates the cold-spots and then appears to be cold. If, by chance, both the end-organs for the reception of heat and cold are absent, pain is produced. Thus the same temperature is capable of exciting heat, cold and pain; and yet under normal circumstances it evokes a sensation of pleasant warmth. Evidently, the incompatible impulses, due to stimulation of the cold- and pain-spots, are prevented from reaching consciousness.

Such integration occurs at several stages, during the passage of afferent impressions through the central nervous system. Those, alike in their qualitative potentialities, are gathered together, whatever may have been their origin at the periphery. Thus all impulses capable of arousing pain come together in the spinal cord. In the same way, there are separable paths for those associated with sensations of heat and cold. Finally, on higher physiological levels is fought out the struggle for final dominance, and, of the warring impulses, one group only excites a conscious response.

The processes by which this integration is rendered possible are three in number. First of all, those impulses potentially of a like sensory quality are gathered together. Secondly, all impulses capable of exciting sensations of a different quality are rejected by the receptors, which guard each functional level. The third method is manifested in the phenomena of adaptation. Water at 30° C. may appear under suitable external conditions to be neither hot nor cold. But, when the hand has been previously soaked in water at 45° C. for some time, a temperature of 30° C. will seem to be cold. Conversely adaptation to water at 15° C. converts 30° C. into a warm stimulus. This power of adaptation to the conditions of the environment, and consequent shifting of the neutral point, is one of the most important factors in the mechanics of integration. No stimulus acting over a long period can remain continuously at the same level of efficiency; it leads to a state increasingly favourable to the appearance of the opposite phase of activity. This is the essential condition underlying the tendency to biphasic reaction so characteristic of the central nervous system.

These three processes, acceptance by similarity, rejection by difference, and biphasic dispositions, form the main features of the physiological functions of the central nervous system. They are factors which lead to integration, whether we are dealing with reflexes or with such psychical acts as sensations.

They are interposed between the vital consequences, produced by the impact of a physical stimulus on peripheral end-organs, and the final processes of consciousness. We have no right to speak of psycho-physical parallelism; we ought rather to consider on the one hand physiologico-physical responses, and on the other psycho-physiological relations.

Thus, between the impact of a physical stimulus on the surface of the body and the movement or sensation it evokes, lie the innumerable reactions of the physiological level. Here the form assumed by the conscious response is prepared to a degree scarcely suspected until recently. Many of the impressions produced by a single external stimulus are incompatible with one another, and some of them must give way in the conflict. But the result of the struggle is not fixed or preordained; it may be reversed by some previous occurrence, which has changed the disposition of the central nervous system. The form assumed by a reflex may be determined by the character of the movement which preceded it, and the phenomena of sensory adaptation depend upon the active influence of the past in present events.

Moreover, the general resistance of the central nervous system to certain impulses varies greatly at different times and in different persons. This is particularly evident in the case of pain. We are all subjected to innumerable painful impressions, which under normal conditions never reach consciousness; but if the resistance, either local or general, is lowered, these impulses may underlie definite sensations of pain.

From a study of the reflexes and the facts of dissociation, it would seem that sensation, in its primitive form, must have been a vague undifferentiated state, aroused by afferent impulses whose primary purpose was the production of impulsive reactions. Any spacial elements, inherent in such impulses, were intended to guide and control these automatic movements. This crude method of response was refined, not only by improvement in the functions of the original sense-organs, but also by the development of further sensory mechanisms capable of more discriminative activity.

These sense-organs, belonging to various stages of development, are still active, even in man. Their co-existence leads to the production of incoherent and incompatible impulses, which must be integrated before they can form the basis of a sensation. This is the task of the central nervous system. Some of the more primitive modes of reaction are repressed, others are utilised to a greater or less extent in the production of more highly developed responses.

This co-ordination is carried out through the steadily increasing control exercised by higher and more recently developed centres over those on a lower evolutionary level.

Primitive sensation was probably a condition of "awareness," endowed with but slight qualitative or discriminative characters. Out of this undifferentiated state have been evolved the highly developed sensory functions of man. This gradual growth of the sensory faculties was associated with increased specialisation of the physiological processes upon which they ultimately depended. Finally, each of the two great receptive centres became almost exclusively occupied with the underlying basis of either the qualitative or projectional aspect of sensation.

But, although the physiological elements of spacial discrimination can be affected apart from those concerned with the qualities of sensation, they demand the existence of some kind of afferent basis, in order that they may be able to exercise their functions. In the same way, the power to respond adequately to stimuli of different intensities can be destroyed, without affecting qualitative sensibility; but abolition of all awareness to stimulation leaves nothing on which the power of responding to relative intensity can act. Some physiological activity must always occur in the lower centre, before the higher one can exhibit its discriminative and projectional functions.

With the high development of his cerebral cortex, man acquires a cumulative knowledge of the world around. He examines himself and, out of what he finds by introspection and physical measurement, constructs his conceptions of Time, Space, and Material. But, ultimately, the fabric of his philosophy depends on the nature of physiological reactions produced by the impact of physical stimuli on his sense-organs. These have been formed out of the lowliest materials, and the human nervous system is engaged in a perpetual struggle to integrate and control these incoherent responses, so that they may endow consciousness with discriminative sensations of Quality, Space, and Time.

APPENDIX

SOME CRITICISMS OF OUR WORK

Throughout these Studies in Neurology our aim has been to give a coherent account of the phenomena excited by a physical stimulus and to follow them within the nervous system to the physiological centres, where they underlie sensation. In the course of this work we have described several conditions new to physiology and medicine, and these we tried to explain by certain fresh conceptions with regard to the action of the nervous system.

It is to our views of the functions of the peripheral nerves that the most serious criticism has been directed, and it is impossible to close this book without considering the experiments of Trotter and Davies and of Boring, together with the critical objections of von Frey. We felt that it would be less confusing to the reader, and juster to these observers, if we considered their work together at the end of the book, rather than by the addition of foot-notes to the original text.

When we began our researches, peripheral sensibility was universally supposed to be due to the activity of four groups of end-organs, those for touch, pain, heat and cold, corresponding to the four qualities of somatic sensation. This view was rooted in the pre-evolutionary period of physiology, when man was thought to be created fully armed to respond specifically to the various qualities of sensory experience. But we attempted to explain the extraordinary facts, which follow division and restoration in a peripheral nerve, by the conception of functional evolution.

The physiologist showed a natural repulsion from deserting the easy explanation of one end-organ for each of the main sensory qualities, in favour of a theory which seemed to complicate the problem unnecessarily. Moreover, the older hypothesis appeared to coincide so exactly with the experiences of the clinician, when dealing with lesions in the spinal cord, that the views we expressed seemed to stand self-condemned. He failed to recognise that this simple solution neither explained the facts of dissociation at the periphery, nor in the highest receptive centres.

Both the physiologist and the clinician were set against our views, not only because they were based on a new principle, but because they disturbed the simplicity of the traditional explanation. This has led to an unfortunate blindness to the existence of problems which must be faced by any worker in the sensory field. Disputes as to the value of our theoretical views have obscured recognition of the facts. Trotter and Davies carried out a large number of observations on nerves divided in themselves. They criticised our views and threw doubt on some of our statements; but in the main they confirmed the physiological problems, offered for solution by the destruction and recovery of function in peripheral nerves.

I shall, therefore, begin this account of the criticisms on our work by showing in how far the experimental results of our critics agree with our own. I shall then deal with the points in which their observations directly contradict the statements made by us. After marshalling the facts, I shall attempt to summarise their criticism of our views and give a short account of the hypotheses by which they explain the experimental facts, which are new and of fundamental importance both to physiology and clinical medicine.

[124] EXPERIMENTAL STUDIES IN THE INNERVATION OF THE SKIN. By Wilfred Trotter and H. Morriston Davies. [*Journal of Physiology*, 1909, vol. xxxviii, pp. 134–246.]

[125] THE PECULIARITIES OF SENSIBILITY FOUND IN CUTANEOUS AREAS SUPPLIED BY REGENERATING NERVES. By Wilfred Trotter and H. Morriston Davies. [*Journal für Psychologie und Neurologie*, 1913, Bd. 20, S. 102 E–150 E.]

These observers separate the phenomena, following nerve division, into those which appear before regeneration can have occurred and those which are due to recovery of function. I shall, therefore, begin this account of their observations with the condition of the affected area some ten to fourteen days after division of the nerve.

We were able to show that when the skin was rendered entirely insensitive, the deeper parts responded to contacts that would commonly have been called "light touches." Thus it was evident that there were two mechanisms for the production of sensations of "contact," one of which was situated in the skin and the other in the deeper structures. With this statement Trotter and Davies are in complete agreement. They say ([124], p. 203), "At the beginning of his paper, Head shows that it is of cardinal importance to recognise that not only the skin, but the deeper structures also are sensitive to contacts, so that in testing the sensibility of the skin it is essential to know whether the impression to which the subject is responding is coming from superficial or deeper parts. All the work we have done tends to confirm the importance of this view and to show that the investigation of the problems of sensation in the abnormal is not possible without the recognition of it. To make sure that he is obtaining responses to impressions of purely cutaneous origin, Head uses one of what we have called the minimal pressure methods, that is to say, he makes use of a stimulus which is supposed to be too light to stimulate the subcutaneous structures. . . . We are able to confirm most thoroughly his statement that such a method, for example, that of cotton wool or the camel's-hair brush, gives an extremely definite outline which is very easily obtained and remarkably constant. It does moreover, on the whole, correspond fairly closely with the outline of the area which the subject distinguishes as distinctly numb."

As a matter of fact we calibrated the rough empirical stimuli such as cotton wool against von Frey's hairs and were able to show that parts of the arm and hand, endowed with deep sensibility only, did not respond to hairs exerting less pressure than 23 grm./mm.^{2} (8 grm./mm. tension); some areas, such as the dorsum of the hand, required an even stronger stimulus.

Trotter and Davies ([124], p. 163) also found " no evidence that sensibility to heavy pressure and to vibration is in any way affected by loss of sensibility confined to the skin."

Thus they confirm the crude fact that, when the skin is rendered completely insensitive by section of a purely cutaneous nerve, the patient still responds to contact, pressure and vibration. At the same time they agree that the denervated area is insensitive to prick, heat and cold.

A superficial reader might suppose that their observations on the condition of the intermediate zone were in fundamental disagreement with the statements made by us. It is true that they object to our theoretical explanation and set up an hypothesis of their own; but the facts they observed correspond remarkably with those we have described.

This " intermediate zone " does not appear after division of every nerve; but after section of certain trunks, such as the median or the ulnar, the area insensitive to prick is smaller than that of the anæsthesia to light touch. There is an intermediate zone between the borders of loss to touch and to prick. This is not only sensitive to painful and thermal stimuli, but shows certain remarkable peculiarities in its mode of reaction.

Here we are in complete agreement: but in reading the first paper of Trotter and Davies [124] it is important to remember their attitude to what we have called " over-reaction." We recognised that parts which responded more vividly to pain, heat and cold might have a high threshold to the very stimuli which produced this apparently " intense " reaction. We fixed our attention on the threshold value necessary to evoke a response and, if it was raised, spoke of the part as one of diminished sensibility, in spite of the vividness of the sensation. Trotter and Davies, attracted by this excessive reaction, spoke of a " hyperalgesia," although their own measurements showed that they were frequently face to face with a raised threshold. " We came to the problem " they say, ([124], p. 167), " in the full expectation of finding a central area of analgesia separated from the surrounding region of normal sensibility by a zone of hyperalgesia, and this, in fact, is what in a general way we found. We could not, however, fail to be struck with the anomalous character of the production of an increased sensibility by what appeared to be a purely destructive lesion. . . . It was at any rate essential, before we could accept the occurrence of a true hyperalgesia, that we should secure a means of applying constant or graduated stimuli. For this purpose we invented the algometer already described. Investigation of the affected area with this instrument did undoubtedly show that we had been accepting an exaggerated estimate of the extent of the increased sensibility to pain; certain spots which with the free hand use of the needle had yielded abnormally unpleasant sensations of pain, had proved to be inexcitable by a stimulus fully capable of producing a distinct prick on many spots in the normal skin."

Thus they confirm our statement that the intermediate zone is an area of lowered sensibility (raised threshold) from which the response may be peculiarly vivid, or, as they say, "intense."

This condition is developed as a rule within the first fortnight after nerve section, provided the extent of the area insensitive to the lighter tactile stimuli exceeds that of the absolute analgesia to prick. Trotter and Davies say, "Between the tenth and twelfth days, however, and as a rule rather suddenly, a very distinct hyperalgesia became evident. . . . It always lay in part outside the area of anæsthesia to the brush, extended usually up to the wound, but never above it, and might often crop up in patches in the middle of regions which were otherwise profoundly analgesic" ([124] p. 168). "About the eleventh day after the operation the subject notices that the affected area of skin has begun to attract his attention once more through an unpleasant quality in the sensations produced by accidental touches. This increase of sensitiveness is quite distinct when the part is rubbed with the finger, and tends to form a broad band surrounding the analgesic part and roughly corresponding with what we have called the zone of transitional tactile hypoæsthesia" ([124] p. 169).

"The recognition of the fact that touch is a sensation sui generis opens up the intermediate zone to investigation. Before referring to the results of such examination, a few words are necessary to define precisely the nature of this zone. According to the statement of Head, the area inside the cotton wool line is sensitive to painful stimuli in its outer parts and analgesic only in its central parts, so that outlining the affected area according to sensibility to pin-pricks gives a very different result from outlining the area according to sensibility to cotton wool. This observation we have been able to confirm in the area of each of the seven nerves we have cut" ([124], p. 204).

Our contention that the intermediate zone was insensitive to temperatures in the middle of the thermal scale is also confirmed ([124], p. 206). "The statement of Head, that in the intermediate zone there is anæsthesia to temperatures between 20° and 40° C. and sensibility to temperatures outside this range, we can in a general way confirm . . . on the whole we may say that the range of temperatures which cannot be felt is about fifteen to twenty degrees centigrade, and lies in that part of the thermometric scale which contains what have been called by Head 'intermediate' temperatures (22° to 40° C.). The second character of this thermo-hypoæsthetic zone is that, as has been pointed out by Head, it is sensitive to temperatures higher and lower than these 'intermediate' temperatures" ([124], p. 165). Trotter and Davies put forward the suggestion that this is due to a general diminution in the thermal sensibility, and add later ([124], p. 207), "We should like to call attention to the fact that the view expressed here does not in any way conflict with the actual observations reported in Head's work, for he says there merely that the intermediate zone is sensitive to extremes of temperature, but he does not say that this sensibility is of normal acuteness." Actually, we stated that it was usually profoundly diminished.

Thus they confirm the fact that division of a peripheral nerve may be followed by an area of complete loss of cutaneous sensibility surrounded by an intermediate zone, sensitive to pain, heat and cold. Shortly after nerve section "hyperalgesia" may appear. "The characters of it point to its being a complication due to the presence of an irritative change rather than to its being due to any kind of sensory loss" ([124], p. 236).

Here we have the difference between our views expressed in a succinct form. To Trotter and Davies the vivid reaction of areas, demonstrably hyposensitive to pain, heat and cold, is produced by "irritative changes"; to us these phenomena are due to release of a more primitive mechanism from control. When the higher, more discriminative aspects of sensation are removed from the skin over a wider area than sensibility to pain, heat and cold, impulses generated from the intermediate zone pass on to the highest receptive centres, uncontrolled by the simultaneous activity of their normal companions. This condition is not established immediately on nerve section, but is in full activity long before any regeneration can possibly have occurred.

Such delay is in harmony with the effect of acute lesions in other parts of the nervous system. Abnormally vivid responses, associated with loss of sensibility, gradually appear as the immediate consequences of the injury pass away, but once established may last indefinitely. We have seen cases where a nerve trunk was proved by operative exploration to have been divided for years, and yet the intermediate zone yielded abnormally vivid responses to pain, heat and cold, though demonstrably "hypoæsthetic" to such stimuli. This alone would render the theory of "irritation" improbable.

The description given by Trotter and Davies of the phenomena of recovering sensation agrees even more closely with our observations. They insist on the importance of "intensification" and "reference," two facts which cannot be reconciled with any theory commonly held by physiologists and clinicians. "However great may be the differences between the observations of Head and of ourselves—and we have shown they are considerable—the fact is established by both series of investigations that during recovery after section of a cutaneous nerve, the affected area shows very remarkable peculiarities of sensibility. These peculiarities can, as we have shown, be narrowed down to the phenomena of intensification and peripheral reference. In addition to their directly practical importance, intensification and peripheral reference are matters of great theoretical interest. To the subject of them they present a series of sensations entirely new and entirely outside his previous sensory experience, and yet they are surprisingly definite and unmistakable. No one who has not experienced them can appreciate the intense vividness with which they present themselves to the subject; and the investigator with no direct knowledge of them is likely even to be wearied by the importance their brilliance makes them assume in the subject's mind" ([125], p. 121). This exactly expresses our feeling on the matter. To discuss critically protopathic sensibility, without having experienced this remarkable condition, is as futile as to dogmatise on the experiences of aerial flight without ever leaving the ground.

By "intensification" Trotter and Davies signify "that qualitative change in the sensations elicited from a recovering area which makes them abnormally vivid. . . . Intensification frequently accompanies defects in sensory acuity. . . . For example, in the early stages of recovery, when the threshold for pain is still high, it would obviously be incorrect to describe the area as hyperalgesic, however unpleasant the sensations elicited might be. On the other hand, when the pain threshold has come down to the normal and a stimulus which just produces pain in the normal skin produces a much more intense pain on the abnormal, the latter might fairly be described as hyperalgesic. In our earlier contribution we did in fact describe it as such, but we now think that the use of the term hyperalgesia is better avoided in this connection, because it is accurate only during a certain period of recovery" ([125], p. 127).

This "intensification" occurs with touch, pain, heat and cold provided the stimulus is capable of evoking a sensation. Thus they fully confirm the existence of that remarkable condition, in which the threshold to the stimulus may be raised, but the sensory experience be more vivid. For this state no physiologist or clinician has attempted to give an adequate explanation.

With regard to "reference," the second fundamental peculiarity of what we have called protopathic sensibility, Trotter and Davies confirm our observations detailed on pages 297 to 305. "We use the term peripheral reference," they say, "to indicate the peculiarity of recovering areas whereby sensations, instead of, or in addition to, being felt at the place stimulated, are felt in the distal part of the affected area" ([125], p. 127). At first they thought that "reference" always occurred in a distal direction and that it was not evoked with heat; but later they recognised that the sensation might be referred to proximal portions of the area affected. In the case of my hand, there was also cross-reference between the index knuckle and the dorsal aspect of the thumb (p. 302). Moreover, they found that "with the use of a large stimulating surface heat sensations are found to behave as regards reference as do cold, touch and pain" ([125], p. 128).

Thus with regard to the sensory condition of the intermediate zone, and of an area of recovering function, our observations are in substantial agreement. The one fundamental contradiction concerns sensibility to the compass test. Trotter and Davies agree that there is "a definite reduction of the discriminating capacity" in the intermediate region, but they discovered "no specific loss of the capacity to discriminate two points, that is to say, that wherever the compass can be felt, some power of appreciating the distinctness of the two contacts remains" ([124], p. 161). We, on the other hand, found that, over an area supplied with deep sensibility only, contact of the compasses was appreciated, but the two points were not discriminated, when applied strictly simultaneously. We have repeatedly confirmed this observation when some accidental lesion had rendered the skin totally insensitive, and it is beautifully illustrated by cases where the whole hand has recovered its sensibility to prick, but not to cotton wool or to a hair of 5 grm./mm. In spite of the recovery of sensation, the power of discriminating two points applied simultaneously remains as defective as it was over the intermediate zone, although the whole of one half of the hand may have become available for testing (cf. p. 150). We can only suggest, therefore, that the contradiction between the results obtained by Trotter and Davies and by ourselves must rest on some diversity of method.

On the other hand, we believe that the contradiction between our statements, as to the return of tactile sensibility, depends on a diverse interpretation of our observations, and not on a contradiction of fact. Trotter and Davies believe that sensations of touch and of pressure differ so profoundly that they can be discriminated in every case subjectively. They depend on this subjective difference to determine whether a given test-hair evokes a sensation of touch or pressure, and confidently employ, for tactile purposes, hairs capable of evoking deep sensibility. We, on the other hand, have restricted ourselves to hairs with a tension of at most 8 grm./mm., because we found that those exerting a greater force stimulated subcutaneous end-organs. It must not be forgotten that most parts of the normal hand and forearm respond to contacts with hairs of from 2 to 5 grm./mm., and on the palm any area sensitive to cotton wool reacts with certainty to a hair of 5 grm./mm. or less.

Now it is true that sensation might be so greatly diminished that the subject did not respond to any of these tactile hairs, although he was not completely insensitive to touch. This is the contention of Trotter and Davies. But we have not found that the sensations of touch and pressure are sufficiently different to justify the use of stimuli, demonstrably capable of exciting deep sensibility. This is certainly the case with many of the hairs used by Trotter and Davies as tests for touch. Thus they state ([124], p. 161), "The various grades of hypoæsthesia may be conveniently classified into three groups according to the pressures which are necessary to elicit a sensation of touch. The first grade, which we call minimal hypoæsthesia, is scarcely distinguishable from normal sensibility. It will correspond to hairs of pressures varying between 70 and 400 milligrammes, according to the natural sensitiveness of the part. . . . The second grade we call that of transitional hypoæsthesia; such a zone will respond to hairs of pressures between 500 and 1200 milligrammes. The third grade, that of maximal hypoæsthesia, responds to pressures between 1700 and 4000 milligrammes. Corresponding with these grades of hypoæsthesia the groups of hairs to which they respond may be referred to as light, medium and heavy respectively." Now we have shown that all these "heavy" hairs and many of the "medium" ones are capable of evoking a response in areas which have been completely deprived of cutaneous sensibility. Under such circumstances it is scarcely safe to assume that the sensations produced are not due to the action of pressure upon deeper parts.

All the areas denervated by Trotter and Davies were covered with hairs, and we believe that this is a second cause for the difference in our views with regard to the return of sensibility to touch. We are fully in accord that some form of sensation can be evoked from the hairs eighty to ninety days after the operation. In our experiment a few hairs reacted to pulling on the eighty-sixth day; Trotter and Davies add, "This corresponds closely to what we ourselves found in regard to the first appearance of tactile sensation in response to gross stimulation of the recovering area. Such stimulation, for example, yielded tactile sensations in two of our areas at eighty-two and ninety days respectively after nerve section" ([125], p. 113).

The reaction obtained by brushing the hairs, during this stage of recovery, has exactly the same vividness, and is referred into the same remote parts of the affected area, as the other qualities of sensation evoked by any effective stimulus. Trotter and Davies contend that these sensations are due to normal tactile sensibility in a "hypoæsthetic" form. They agree that the affected area in this stage of recovery loses its sensibility to cotton wool after shaving and to von Frey's hairs of less than "360 milligrammes" (corresponding probably to our hair of 5 grm./mm.); but they point out that they can obtain a response with hairs exerting higher pressures. They hold that our measured tactile stimuli are incapable of revealing hypoæsthesia, whilst we suggest that the response they obtain over carefully shaved parts with their heavier hairs is due to deep sensibility, which was manifestly not affected by any of our experimental lesions.

On the other hand, the peculiar vivid referred sensation, produced by stimulating the hair-clad surface of an area of recovering sensibility, seems to us utterly unlike a normal tactile response. It corresponds more closely to tickling or itching, and does not occur over parts of the affected area devoid of hair (p. 273). We believe that this is not simply a manifestation of tactile "hypoæsthesia," but is the result of the unrestrained activity of end-organs residing in the roots of the hairs; it has a high threshold and after shaving, the affected area becomes insensitive to cotton wool and to normal cutaneous tactile stimuli. In our view, the peculiar response evoked from the hairs is closely analogous to the other sensations, pain, heat and cold, that can be aroused from the same area: all show "intensification" and are referred into identical parts of the limb. Moreover, this abnormally vivid response may be excited from areas that are still measurably "hypoæsthetic."

But apart from these differences of interpretation, we are agreed in our observations on the time and manner of return of contact sensibility to hair-clad parts; we are at one in our description of the vividness of the response ("intensification") and of the peculiar reference of the diffuse sensation into remote portions of the affected area. These facts are entirely incompatible with any of the orthodox views on the mechanism of peripheral sensation, and we think that the attempt made by Trotter and Davies to explain them is scarcely adequate to the importance of the problem. They contend ([125], p. 149) that these manifestations must not be looked upon as stages in the advancing process of regeneration, but must be considered as accessory and accidental phenomena in the actual restoration of function; they probably depend on an abnormal irritability of regenerating nerve fibres.

Many of our observations are entirely inexplicable on such an hypothesis. For instance, we found that, when the phenomena of over-reaction and reference had ceased during the process of recovery, they could be brought back temporarily by cooling the hand. We also showed that the characteristic tendency to localise the sensation in some remote area might be inhibited by simultaneous stimulation of adjacent normal parts. If the base of a cold tube was placed just within the affected area on the back of my hand, cold was referred to the thumb, whilst, if the stimulus lay partly on the normal side of the border, the sensation was localised correctly. Our observations on the comparative want of adaptability to heat and cold in areas of recovering function (p. 292) find no solution in such an hypothesis. There are many other phenomena described in the previous pages which we believe can only be explained as manifestations of release from control of a mechanism of inferior, but specific sensory aptitudes.

Throughout this criticism we have been able to touch on the more important points only in the work of Trotter and Davies; but we have attempted to show that, under a completely different interpretation of the experimental results, lies a remarkable agreement concerning the facts observed. These manifestations, on which we are agreed, are a formidable problem for the orthodox exponent of somatic sensibility. Trotter and Davies prefer to embark on no comprehensive theoretical explanation, but insist on the remarkable character of the phenomena. We, on the other hand, have attempted to bring them into connection with the facts of dissociated sensibility in other parts of the nervous system.

[39] THE DISTRIBUTION OF AFFERENT NERVES IN THE SKIN. MAX VON FREY. [*Journal of the American Medical Association.* Sept. 1, 1906, vol. xlvii, pp. 645–648.]

[39*a*] "PHYSIOLOGIE DER SINNESORGANE DER MENSCHLICHEN HAUT," I. DER TEMPERATURSINN. MAX VON FREY. [*Ergebnisse der Physiologie,* 1910, Bd. 9, S. 351–368.]

[39*b*] "PHYSIOLOGIE DER SINNESORGANE DER MENSCHLICHEN HAUT," II. DER DRUCKSINN. MAX VON FREY [*Ergebnisse der Physiologie*, 1913, Bd. 13, S. 96–124.]

The first of these papers, a short address delivered before the American Medical Association in 1906, contains some general criticisms of our views based on our two first communications. But the detailed description of our experiment had not yet appeared, and I suggested to Professor von Frey, from whom I had received many kindnesses, that he should examine my hand at leisure by his own methods. In April 1908 I therefore spent a week at Würzburg and submitted to a long series of tests in the physiological laboratory. The records made at that time confirm certain of our statements in so remarkable a manner, that I shall deal with them first before considering von Frey's two later papers, which contain purely literary criticism of our work.

During these sittings his observations were confined to the back of my hand, which was marked out into centimetre squares as on p. 300. At that time the thumb and a considerable portion of radial aspect of the dorsal surface had become sensitive to a hair of 5 grm./mm. tension and to cotton wool after shaving; but the skin adjoining the ulnar border of the affected area was still in a purely protopathic condition (*vide* Fig. 62). Sensations evoked from this part of the hand by superficial stimuli were localised in the thumb, a most fortunate condition for the study of the phenomena of reference.

Professor von Frey's examination proved that this area was insensitive to 5 grm./mm. (21 grm./mm.^{2}); but 8 grm./mm. (23 grm./mm.^{2}) was appreciated in several places as a "weak, diffuse, well-localised, but not punctate pressure." Brushing the skin, or contact with its hairs, caused a vivid tingling referred to the thumb. Evidently the threshold for contact stimuli was high, and this portion of the dorsal surface was insensitive to all those measured hairs relied upon by von Frey to test superficial touch.

The conflict between the localisation of pressure and of referred pain was beautifully shown by some experiments with the heavier test-hairs: 110 grm./mm.^{2} was painless on both sides and evoked a well-localised sensation of pressure over the affected area. But 120 grm./mm.^{2} caused pain on both hands; on the protopathic portion it was "more intense," and was localised definitely over a widely diffused area on the thumb. In this case reference dominated localisation at the site of impact. When, however, the stimulus was increased to 200 grm./mm.^{2}, I experienced a definite sensation of pressure, localised correctly at the point of contact, and, at the same time, a widespread stabbing pain in the thumb.

Graduated thermal stimuli showed that the protopathic area did not respond to temperatures above 25° C. on the lower half of the scale, whilst 27° C. seemed definitely cold over the normal half of the dorsal surface. After the whole hand had been adapted for five minutes to water at 45° C., 28° C.

was distinctly cold to the ulnar side of the border, whilst the threshold over the abnormal area remained unaltered (24·5° C.). A similar set of experiments were made on another day with temperatures on the warm side of the scale. The threshold over both halves of the hand was about 40° C.; but after it had been soaked in water at 20° C. for five minutes, 36° C. was definitely warm over the normal parts, whilst the protopathic portion still did not respond to a temperature below 40° C. This shows that protopathic parts are less capable of adaptation than the normal skin.

These observations confirmed our statement that the threshold for tactile stimuli may be considerably raised over a recovering area and yet the sensation evoked be abnormally vivid. In the same way, the protopathic parts failed to respond to temperatures to which the normal skin was sensitive, and thermal adaptation was defective; and yet they reacted " more intensely " to any degree of heat or cold capable of exciting sensation. Finally, these experiments furnished a good example of a conflict in localisation between sensations of pressure and referred pain.

With this experience behind him, it is difficult to account for the complete failure of von Frey to grasp the problems presented by nerve section and recovery. In his first contribution to the *Ergebnisse der Physiologie* (1910), dealing with thermal sensibility, one page only is devoted to the experiments of Trotter and Davies and of ourselves. He does not even mention the fact that, before recovery can have begun, an abnormally vivid sensation may be evoked from parts with a raised threshold to the same stimulus. Of referred sensations he says, " Es handelt sich anscheinend um eine abnorme Erregbarkeit der Nervenfasern durch thermische Reize." (" We have to deal apparently with an abnormal irritability of the nerve fibres to thermal stimuli "). All the other phenomena of recovery are dismissed with the bewildered comment, " Auch sonst berichten Head, so wie Trotter and Davies über eine Reihe merkwürdiger Erscheinungen, deren weitere Aufhellung sehr zu begrüssen wäre " ([39*a*], p. 358). (" Head, as well as Trotter and Davies, also describe a series of remarkable phenomena, of which a further elucidation is much to be desired ").

He is obsessed with the old idea that man is endowed with specific sense organs capable of responding fully to each known sensory experience. " Most physiologists agree," he says ([39], p. 2), " that the sensory functions of the skin are based on four fundamental qualities mediating sensations of warmth, cold, touch and pain. Careful investigations have placed it beyond a doubt that corresponding to these functions the nerve supply to the skin must be a four-fold one." No believer in evolution would grant this postulate, nor do the " careful investigations " bear out his contention. Von Frey himself showed that an area on my hand, innervated by heat-spots and capable of an abnormally vivid response, was insensitive to temperatures between 25° and 40° C. Moreover, in his account of the glans penis ([34], p. 175), he spoke of the corona and neck of this organ as the most sensitive parts of the body to temperature, although they do not respond to heat and cold between 26° and 37° C. Here again a high threshold to thermal stimulation is associated with an abnormally vivid sensory response. According to the view of von Frey and to the orthodox psychologists, such parts are either "hyperæsthetic," as judged by the vividness of the sensation, or "hypoæsthetic" because the threshold is raised. Directly it is conceded that they can be both at the same time, the whole *a priori* structure falls to the ground and some other explanation must be found to account for the phenomena.

The second contribution to the *Ergebnisse* (1915) deals with the "Drucksinn," or "sense of deformation, by which consciousness becomes aware of the position, weight, size, form, surface characters and state of movement of objects which press upon the skin at rest" ([39*b*], p. 99, translated). Our demonstration of a form of subcutaneous sensibility, capable of producing well-localised sensations of contact and of pain, fell with disruptive effect on to this preconceived idea of a "sense of pressure." Von Frey makes no attempt to face the problem squarely; he talks of wide-spreading deformation of the skin and the picking up of the stimulus by adjoining normal parts. He makes no mention of the fact that during the period when the affected areas of my arm and hand were innervated from the deep afferent system only, pulling the hairs caused no sensation of any kind. Deformation outwards produced no effect, whilst pressures, so light that they would ordinarily have been called "touches," were appreciated and well localised. Then, again, he does not even mention the problem of the existence of deep pain, independent of any "pain-spots" or other mechanism in the skin.

The phenomena of reference into remote parts is treated as follows: "Sehr bemerkenswert sind die Beobachtungen während des lang ausgedehnten Zeitraumes der Restitution. Hier treten die Erscheinungen austrahlender Erregung (Radiation) und falscher Lokalisation (Reference) in den Vordergrund. Die erstere wird von v. Frey und ebenso von Langley aufgefasst als Ausdruck zentraler Veränderungen in Folge des operativen Eingriffs. Die falsche Lokalisation dürfte ihre einfachste Elklärung in der Annahme finden, dass die aus dem zentralen Stumpf des durchschnittenen Nerven ausgewachsenen Achsenzylinder falsche Wege einschagen" ([39*b*], p. 119–120). ("The observations made during the long-drawn-out period of recovery are most worthy of attention. Here the phenomena of radiation and reference come into the foreground. The former is explained by von Frey and also by Langley as an expression of central changes due to the operation. Erroneous localisation is probably explained most simply by the assumption that axis cylinders growing out of the central stump of the divided nerve follow false paths.") Here the puzzled physiologist invokes hypothetical changes in structure to elucidate what is in reality a superb problem in disordered function. No wandering axis cylinders which have lost their way can form an adequate explanation of the phenomena of systematic cross-reference of all qualities of sensation into remote parts.

[9] CUTANEOUS SENSATION AFTER NERVE-DIVISION. By EDWIN G. BORING. [*Quarterly Journal of Experimental Physiology*, 1916, vol. x, No. 1, pp. 1–95.]

We destroyed the sensibility of the skin over the greater part of the preaxial half of the forearm and back of the hand, and Trotter and Davies divided seven nerve branches without ill effects. In the face of these experiments, it is difficult to understand why Boring selected for section a small nerve twig, which could only produce an area of defective sensibility measuring no more than 6·2 cm. in maximum length and 1·6 cm. at its broadest part.

Had he divided both branches of the internal cutaneous nerve above the elbow, together with the fibres of the lesser internal cutaneous so as to eliminate this source of proximal overlapping, he might have obtained an area of sufficient size to exhibit the phenomena of sensory loss and recovery. Even then he would not have had the advantage of working on the hand, which derives its postaxial supply mainly from the ulnar nerve. But by dividing the anterior branch of the internal cutaneous alone, he produced a condition most disadvantageous to the success of his experiment. For, on either side of the axial line of the forearm, the overlapping of the various cutaneous branches is so great, that the analgesia due to the destruction of any one of them is incomparably smaller than the distribution of its nerve fibres. No part of this area could have shown even an approximately definite border, for it is overlapped in every direction by other branches arising from the same main trunks or roots. So great was the accessory nerve supply in Boring's experiment that, on the thirteenth day after the operation, no part of the area was completely analgesic over an extent of 2 cm. in both directions. From the beginning, his observations were confused by the preservation of normal sensibility to prick in the middle of parts where sensation was recovering.

But, in spite of this almost wilful neglect of the conditions necessary for the success of such an experiment, Boring was able to confirm some of the phenomena described by Trotter and Davies and ourselves.

First of all, he found (p. 95) that " deep sensibility to pressure and pain was not altered " and localisation to pressure remained unaffected. Thus all the observers who have actually produced cutaneous insensibility in themselves, unite in rejecting von Frey's *a priori* objections.

It was obvious from the nature of Boring's experiment that he could not have produced that " intermediate " zone which so commonly follows division of trunks such as the median or ulnar nerves. He therefore contents himself with assuring us there was no such area, confirming the confident anticipations of all who have worked with more than one divided nerve.

When describing the phenomena of recovery, he insists that " warmth and cold passed from hypoæsthesia to hyperæsthesia and hence towards normal " (p. 73), and " in limited scattered regions pain also showed a tendency toward hyperæsthesia as measured by the intensity of the sensation though not as measured by its threshold " (p. 73). Thus he confirms the existence of that remarkable condition, where a part, manifestly defective in sensibility to stimulation as measured by the raised threshold, reacts with a "more intense" sensation than normal portions of the skin. "We have used the word 'hyperæsthesia,'" he says (p. 92), "to denote an abnormal intensity of sensory response. Head has maintained—and we have partly confirmed the facts—that this hyperæsthesia is not associated with a lowering of the threshold. There is no evidence that the threshold is ever less than normal." We can only regard him as fortunate in being able to see so much of the truth through the medium of his miniature experiment.

He also confirms the peculiar sensation, or "flutter," produced by contact with the hairs during the stages of recovery. "It now appeared that arousal of this complex was related to stimulation of the hairs. The lifting or the bending of a single hair would bring it out" (p. 33).

This "flutter" was referred to remote parts, or was diffusely localised, like pain, heat and cold, during the process of recovery. But the area of sensory loss in Boring's experiment was too small to permit of anything more than the demonstration of the fact.

Much is made of the long preparation, extending over more than a year, to which he submitted himself before the operation. But when exposed to the astonishing experiences, which follow excitation of an area of recovering sensibility, he is completely baffled. Although "it is doubtful whether Head, Trotter and Davies were possessed of the introspective training which in the psychological laboratory would be considered adequate to their problem" (p. 2), it is inconceivable that any of these observers could have written the following description of the effects produced by cold stimulation (p. 52): "This 'protopathic' complex is unique. It is a good fusion, and it would probably be taken as simple (not complex) if an especial effort were not made to analyse it. As a complex it is without doubt something new in my experience. Description of it is distressingly baffling," and (p. 53), "This 'protopathic' cold resembles cold on the glans penis; but the glans cold is more like cold, is less stingy (hence less burning) and is not quite so complex (*e. g.* it has no pressury puckers)." We have cited this passage more for what it reveals than as an adequate description of an entirely new sensory experience.

Boring believes that the "greater intensity" of "unpleasant quality" in protopathic cold is pain; this no one would doubt, since he uses 2° C. as his cold stimulus; but he does not explain how protopathic warmth is associated with excessive pleasure. Punctuate stimulation of an active heat-spot in an area of recovering sensibility with a temperature between 38° and 42° C. may evoke, not only a vivid sensation of warmth radiating widely and referred into some remote part, but also extreme pleasure. If the temperature is raised to between 45° and 55° C. this is replaced by pain, ranging from a "stinging" to a "burning feeling." We do not think that these facts are made clearer by the following statement (p. 53): "The cold stimulus is adequate to pain as well as to cold, just as we have seen a hot stimulus may also be.

The problem for pain is one thing, the problem for cold is another; and there is no evidence that this problem extends beyond the explaining of a hyperæsthesia in the organ and a high intensity of sensation. It is not a qualitative problem."

Thus, as far as the phenomena are concerned, Boring confirms our statements with regard to deep sensibility; he allows that sensations to pain, heat and cold pass through a stage of "hyperæsthesia" on their way to recovery. He also observed reference and double localisation. But he denies that "new qualities of sensation were experienced at any time. Many unique experiences were found to be merely unusual combinations of familiar qualities."

Passing from observation to theory, Boring sums up his criticism and conclusions as follows (p. 95): "The hypothesis of Head and others, which assumes that cutaneous sensibility may be divided into 'protopathic' and 'epicritic' groups, is open to criticism: (*a*) because it is inconsistent to its evolutionary aspect with the hypothesis of development of other modes of sensation; (*b*) because it cannot replace other hypotheses of cutaneous sensibility, since it is applicable only to a particular group of facts; (*c*) because it is not sufficiently thoroughgoing to constitute a true theoretical formulation; and (*d*) because it indicates generalities which admit of exceptions or are of doubtful status."

He then proceeds to formulate his views as follows: "A more satisfactory theory is one which assumes that single sensory spots are innervated by more than one nerve fibre, that the multiple innervation is projected upon the central nervous system as multiple excitations, which depend for their degree upon their relative strengths, their separations in the region of projection, and a limitation of the available amount of central energy. Under these conditions, multiple innervation may be effective as summation or as inhibition of the excitations involved. The division of inhibiting fibres may result in hyperæsthesia or in abnormal localisation; the gradual appearance of these forms of abnormality is due to the gradual effect of practice in the assumption of vicarious function." Such an invocation of purely imaginary anatomical conditions sounds oddly from the mouth of a psychologist; but I have quoted this summary to show the grounds upon which Boring rejects our conclusions and the theory he proposes to erect in their place.

Conclusion

In the preceding sections of this Appendix an attempt has been made to present the attitude of our principal critics, as far as possible in the words of the authors themselves. I have attempted to correlate their observations with our own, and to illuminate the causes which have led us to diverse conclusions. Before closing this portion of the work, I should like to put forward our views concerning certain of these problems in peripheral sensibility, so far as they can be deduced from the facts on which we are all agreed.

(1) *Deep Sensibility.*

All those who have actually experimented with lesions of the larger nerve trunks are united as to the main facts of deep sensibility. It is unaffected by destruction of a purely cutaneous nerve, and is dependent on afferent fibres, which run with the muscular, articular, and subcutaneous branches. It endows the part with the power of responding to tactile and painful pressure, and vibratory sensations are not appreciably affected. Contact of any stimulus capable of evoking sensation is well localised, and posture and passive movements can be recognised without difficulty. But the denervated area is insensitive to cutaneous painful stimuli and to all degrees of heat and cold; even extreme heat is incapable of producing pain or discomfort. Recognition of these sensory potentialities on the part of subcutaneous structures destroys at a blow the à priori conception, that peripheral sensibility is due solely to a fourfold specific mechanism. The existence of both cutaneous and subcutaneous end-organs which respond to contact and to painful stimulation, necessitates integration of these various impulses in the central nervous system, and a "simple" specific sensation is the result of synthesis and recombination.

(2) *The Character of the Sensory Borders produced by Division of Cutaneous Nerves.*

Considerable misunderstanding has arisen as to the nature of the borders which bound areas of defective sensibility. As a rule there is so much overlapping between the various twigs of a peripheral nerve, that division of any one of them could not be expected to produce more than an ill-defined sensory loss; the defective areas merge gradually into parts of normal sensibility.

But under certain conditions the threshold between the two portions of the skin changes so sharply, and the difference is so profound that a distinct border can be marked out with all forms of cutaneous stimuli. This is particularly liable to occur, when the territory supplied by one group of nerves adjoins that of branches arising from a different set of posterior roots. Thus, the border on the flexor aspect of my forearm could be defined with ease, and was almost exactly coterminous to touch, prick, heat and cold. For the affected half of the flexor aspect of the forearm is supplied by preaxial branches arising mainly from the fifth and sixth cervical roots, whilst the normal postaxial portion is innervated by branches of the internal cutaneous nerves, which originate mainly from the eighth cervical and first thoracic. Such nerve groups have little in common, and do not overlap to any considerable extent.

But the conditions are entirely different when the injured and intact branches belong to the same complex. Thus the defective area on the back of my forearm, due to division of the external cutaneous branches, merged gradually into parts of normal sensibility, owing to the fact that we had not destroyed the long branch of the musculo-spiral nerve, which also belongs to the preaxial group. A similar "soft" border to all forms of cutaneous stimulation appears on the postaxial half of the hand, when the ulnar nerve has been divided, but its dorsal branch remains intact. Under such conditions destruction of a single branch cannot produce an area of sensory loss with well-defined borders. The overlapping between nerves of similar origin is too great to permit of anything but an indefinite boundary, if one is divided and another is left. But where two trunks or nerve-groups of different origin meet one another, destruction of the whole of one complex produces a border easy to define by any form of purely cutaneous stimulation.

(3) *The Relative Distribution of the Cutaneous Loss of Sensibility to Touch and to Pain produced by Lesions of the Peripheral Nervous System.*

In any one peripheral nerve the fibres which supply the skin with the finer degrees of tactile sensibility do not, as a rule, overlap to the same extent as those for pain. This is particularly the case at the termination of the limbs. Thus after division of either the ulnar or the median nerve, it is easy to define the boundary on the palm between normal parts, which respond to test-hairs of from 1 to 3 grm./mm., and the affected area where 5 grm./mm. cannot be recognised. As far as such light tactile stimuli are concerned, the supply of the two nerves overlaps to a small extent only, and the threshold falls rapidly on passing from the anæsthetic area to the normal half of the hand.

But the fibres which endow the skin with sensibility to prick, usually overlap to a much greater extent, and the majority of analgesic areas, due to division of a peripheral nerve, merge gradually into normal parts. Thus, within the borders of the sensory loss, it is not uncommon to find an intermediate zone, which is more or less sensitive to prick, but not to the tactile hairs or to cotton wool.

To this rule there are certain rare exceptions, even with lesions of the peripheral nerves. For example, division of the whole of the radial and external cutaneous nerves is liable to produce a small triangular area at the wrist, which is entirely insensitive to prick, but responds to the lighter forms of tactile stimuli.

When, however, the loss of sensation is due to division of the posterior roots, this condition, far from being exceptional, tends to be a common form of sensory dissociation, especially in the upper extremity. The analgesia to prick is usually more extensive than the loss of sensibility to the lightest tactile stimuli. Thus, when the lesion lies on the peripheral side of the brachial plexus, the cutaneous tactile loss tends to exceed in extent the analgesia to prick, whilst, when several posterior roots are divided, the reverse is the case.

Now these two forms of dissociated sensibility differ fundamentally from one another, not only in the specific quality of the residual sensation, but in the general behaviour of the affected parts to stimulation. When the loss of sensibility to prick exceeds in extent the tactile anæsthesia, the intermediate area responds to light contacts, with a sensation accurately localised and graduated according to the relative force exerted by the test-hairs. If conversely the want of response to such tactile stimuli is more extensive than the complete analgesia to prick, sensations evoked from the intermediate zone seem to be abnormally painful, and are widely diffused although the skin is demonstrably "hypoæsthetic."

Thus, an area insensitive to prick, but responding to light contacts, shows no abnormality, as far as these two stimuli are concerned, beyond the negative phenomenon of analgesia. When, however, the skin is deprived of its lighter tactile sensibility, but remains sensitive even in a diminished degree to prick, the response is not only painful, but is more diffuse and badly localised.

(4) *Over-reaction.*

This abnormally vivid response of demonstrably "hypoæsthetic" parts is a new and indisputable fact which demands explanation. Although the sensory reaction is excessive, the strength of the stimulus required to evoke it is never less, and is frequently greater, than that necessary over the normal skin. It tends to occur whenever a peripheral lesion produces a more extensive cutaneous loss to touch than to prick, and is peculiarly evident during one stage of returning sensibility. During this period of recovery we are all agreed that this "intensification" occurs with prick, with heat and with cold. Thus, during the restoration of function, the affected area may gradually pass from a condition of gross loss of cutaneous sensibility, to one in which the response is more vivid, although the threshold is still raised to each specific stimulus. This excessive reaction increases steadily up to a certain point with returning function; it then diminishes rapidly as the nerve resumes its normal sensory activity. But for many years after successful union of a divided peripheral trunk, a prick or thermal stimulus may tend to evoke a more vivid response from the affected area.

This excessive response to painful stimuli is not due to incomplete restoration of the peripheral mechanism responsible for this specific aspect of cutaneous sensibility. For with the gradual recovery of function, the threshold to prick may return to normal; and yet this only increases the vividness of the over-reaction and reference into remote parts. But, as soon as the finer degrees of contact sensibility show signs of restoration, this abnormal response diminishes, and may finally disappear altogether.

According to our view, this damping down of the over-response during the last stage of recovery is due to restoration of the more discriminative aspects of sensibility. Both the vehemence and wide extent of the reaction are controlled by the production of more delicate tactile sensations, which correspond to the relative intensity of the stimulus and are localised in the neighbourhood of the stimulated spot. Our hypothesis is essentially physiological; it is the impulses generated in one system that are controlled by the simultaneous activity of the other; Trotter and Davies believe that the progress of recovery is associated with "irritation," which subsides as the normal structure of the nerve is restored.

But if the over-response were due to structural changes, inherent in the act of recovery, it is difficult to see why they do not always occur when nerve fibres conducting painful impulses undergo regeneration. The return of painful sensibility to an area of the skin, that retains its power of responding to light touches, is not associated with any such "intensification." This was peculiarly evident within the triangular area on my wrist, and we watched it in other cases under similar conditions. If over-response were characteristic of structural recovery in the "pain-fibres," it should be independent of the presence or absence of other sensory activities; but this is not the case.

Moreover, it is important to remember that the over-reacting parts are limited to areas which have lost the more discriminative aspects of tactile sensibility. We know that the cutaneous pain-fibres of the ulnar nerve extend into the "median area" on the radial half of the palm; in a similar manner a portion of the so-called "ulnar area" is innervated by fibres from the median nerve. But the extent of the protopathic over-reaction, which may follow division and reunion of a peripheral nerve, is strictly limited by the borders of the tactile loss; it does not spread over on to those parts of the palm, which we know to be supplied with pain-fibres from the injured trunk.

When, however, the excessive reaction to prick is really due to irritation, as in certain cases of "causalgia," the extent of the cutaneous tenderness is not limited by the loss of tactile sensibility, but spreads across the palm on to all those portions innervated with pain-fibres from the injured nerve.

We therefore explain the peculiar method of response we have called "protopathic" as due to release of painful impressions from the control normally exercised over them by the more discriminative aspects of tactile sensibility. In consequence of the absence of these higher impulses an area with a demonstrably raised threshold to prick, to heat, and to cold is capable of evoking a more vivid sensation than normal. Such an hypothesis alone can explain why such over-reaction should be limited to the parts devoid of the more discriminative forms of tactile sensibility.

(5) *Referred Sensations.*

Another fundamental peculiarity of protopathic sensibility is the tendency to refer any sensation evoked to some remote part of the affected area. This is not simply an erroneous localisation of the stimulated spot, but depends on a radical change in the mode of response. Under normal conditions, a stimulus is localised with more or less accuracy, in the neighbourhood of the point to which it has been applied. But, when the skin is in a protopathic condition, a strictly local stimulus in one part may be followed by a widespread sensory disturbance in some remote portion of the affected area. Thus pricking or effective thermal stimulation of a certain portion of the flexor surface of my forearm was followed by a radiating sensation of pain, heat, or cold, over the region of the first metacarpal. Any one of these stimuli applied to the dorsal aspect of the thumb produced a diffuse but specific sensation around the region of the index knuckle; conversely, when this area on the back of the hand was excited, the effect was referred to the thumb.

But whenever this abnormal form of localisation appears after injury to a peripheral nerve, the referred sensation always lies within the affected area, and is limited to parts that no longer respond to the lighter contact s imuli. It does not accompany returning sensibility to prick, if the skin has remained throughout sensitive to light touch. Thus, this peculiar phenomenon was not present at any time within the triangular area in the neighbourhood of my wrist; here, localisation remained normal throughout recovery of sensibility to prick.

Attempts have been made to explain reference into remote parts by supposing that it is due to a diffuse outgrowth of nerve fibres, which make abnormal connections. If this were the case, it is difficult to understand why this peculiar condition should be limited to parts insensitive to the lighter tactile stimuli. It should occur wherever the skin is supplied even in part with regenerating fibres responsible for sensibility to prick, heat and cold. But this is notoriously not the fact. For example, during recovery of the median and ulnar nerve after complete division, the distribution of this sensory condition coincides strictly with the extent of the anæsthesia to cotton wool, and to the finer test-hairs. It is not found to the normal side of the border of the palm, although we know that fibres of the injured nerve, responsible for cutaneous sensibility to prick, heat and cold, considerably overlap this boundary.

Moreover, reference increases greatly in vividness up to a certain point during the process of recovery; then, with the further return of sensation, it diminishes rapidly and may finally disappear entirely. The response ceases to be diffuse and becomes confined to the neighbourhood of the stimulated spot. This change coincides with the reappearance of the finer and more discriminative forms of sensibility, and we suggest that it is the restoration of these afferent impulses which inhibits the diffuse reference of the protopathic stage of recovery.

(6) *Extensity and Intensity.*

No one can any longer doubt that division of a peripheral nerve may be followed by a condition in which the threshold is raised to all cutaneous stimuli, but the response is more vivid and of greater extent. This is a new fact in the physiology of the senses. Careful experiments show that this want of correspondence between the strength of the stimulus and the sensation it evokes is due to the explosive response of the end-organs of the skin: the intensity of the stimulus is of comparatively little importance, provided it is effective. But, on the other hand, an increase in the extent of the area excited, has a profound effect on the vividness and massive value of the sensation. If, for example, five cold-spots are exposed to 20° C., the effect produced is said to be "colder" than when one active cold-spot is stimulated with ice.

A response of this character is admirably adapted to evoke a protective reaction, but it is obviously insufficient for sensory discrimination. Consequently it tends to disappear with the return of the higher afferent functions to the skin, and the extent of the stimulus ceases to be of greater importance than its intensity, so long as it remains within moderate limits.

We believe that the skin is furnished with specific end-organs for pain, heat, cold, and certain crude forms of contact, which belong to a more primitive sensory apparatus. The function of this system is to evoke a massive response followed either by repulsion or attraction. This reaction is impulsive rather than discriminative, and the extent of the stimulus is of greater sensory importance than its actual intensity.

But higher development of "awareness" demanded a more discriminate reply to stimulation, and extensive referred sensations were replaced by those more definitely associated with the position and intensity of the stimulus. These allowed no choice, and the animal was no longer compelled to act impulsively.

At a time when an area of recovering sensibility reaches its acme of vivid response ("intensification") it is devoid of the finer discriminative faculties. With their return the impulsive reaction is controlled, and the sensory response becomes more closely related to the site and relative intensity of the stimulus; finally cutaneous sensibility may re-assume its normal character.

Any theory that may be adopted with regard to the nature of peripheral sensibility, consonant with the experimental facts, demands, as a corollary, the integration of afferent impulses. Impulses of similar quality originating in different structures must be brought together before they can subserve a specific sensation; impressions produced by contact on the skin and on the subcutaneous tissues are regrouped within the spinal cord, and those capable of evoking pain become united to pass on in a single tract. After the tactile, painful and thermal elements of peripheral sensibility have been filtered off into secondary tracts, certain spacial impulses still continue to be conducted by the long fibres of the posterior columns of the spinal cord, which in this way come to form almost specific paths. One of the principal functions of the spinal cord is to unite impulses with similar sensory potentialities, whatever their peripheral origin, so that finally the afferent tracts become approximately specific paths.

This qualitative regrouping is not the only influence exerted by the central nervous system on sensory impulses. The activity of one centre is controlled and modified by that of another; for example, the widespread explosive response of the optic thalamus, to stimuli capable of exciting pleasure or discomfort in any form, is regulated by the discriminative activity of the cortex.

Our critics explain the final disappearance of the over-reaction and referred sensations, which accompany recovery of function in a peripheral nerve, by structural changes in the nerve-fibres conveying painful and thermal impressions. We, on the other hand, have attempted to show that the cessation of these remarkable reactions coincides with the reappearance of the more discriminative aspects of sensation.

This conception agrees with the facts exhibited by the mutual relations of higher centres. When the optic thalamus is released from the discriminative control of the cortex all potentially affective stimuli produce an exaggerated response; not only does the abnormal half of the body react more vividly to pain, but warmth may be unusually pleasant. Even with normal centres the response to any painful or thermal stimulus may be increased, if the number of impulses making a thalamic appeal is excessive compared with those subserving the more discriminative aspects of sensibility. This is the case with any part of the surface in a protopathic condition. Consequently the response resembles in its vividness and explosive character thalamic over-action. Not only are painful impressions exaggerated, but the pleasure evoked from the heat-spots by suitable thermal stimulation is peculiarly intense. But with the return to the skin of the more discriminative elements of peripheral sensibility, the balance tends to be redressed and the response becomes more nearly related to the intensity and spacial conditions of the stimulus.

Our conception of the mechanism of somatic sensibility is fundamentally opposed to all previous psychological and physiological teaching. We believe that the physical forces of the external universe produce within us a number of impressions, which are in many cases incompatible with one another from the sensory point of view. These are sorted, combined and controlled within the central nervous system until they are sufficiently integrated to underlie sensation; the final product is simpler than its constituent elements. There are no basic physiological activities corresponding to "primary sensations." The afferent impressions produced by the action of an external stimulus are highly complex, and are subjected to the integrative action of the central nervous system, before they can become fitted to subserve sensation. Qualities such as pain, heat and cold, are abstracted from the psychical response and spoken of as "primary sensations"; but they have no exact physiological equivalent in the vital reactions of the peripheral mechanism. A "primary sensation" is an abstraction. Afferent physiological processes are most complex at their origin; they become continuously more specific and simpler as they are subjected to the modifying influence of the central nervous system.

Primitive sensation was probably a condition of "awareness" endowed with but slight qualitative or discriminative characters. Out of this undifferentiated state have been evolved the highly developed sensory functions of man by increased specialisation of the physiological activities on which they depend. Our aim has been to study the effects produced by dissociating these processes at various levels of the nervous system, in the hope of obtaining some insight into the lines along which they have developed to form one aspect of human sensibility.

This conception has the advantage of explaining functional states by a physiological hypothesis. It indicates a method by which the highly developed sensory activities of man may be evolved from more primitive states, and by invoking the control, exercised by discriminative responses, over those of a more impulsive character, it shows the way along which man has developed and indicates the path of his individual progress.

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