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ON THE FUNCTIONS OF THE CEREBRUM

I

Symptomatological Differences Associated with Similar Cerebral Lesions in the Insane

By
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II

Variations in Distribution of the Motor Centers

By
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PREFACE

The two articles which constitute the present monograph deal with the same general topic, the variations in function of corresponding parts of different brains. This matter has received scant attention in neurological literature, notwithstanding the fact that the anatomical variations have been extensively studied. The data recorded in the two articles point to a conclusion which helps to an understanding and to a conciliation of some apparent discrepancies in previous clinical and experimental studies of cerebral function. The theoretical discussion which is given is, however, not due solely to the work now presented, but in great part has been the result of previous personal observations and of various facts which have been recounted in clinico—and physiological—neurological literature.

The experimental data of the second article were collected before the examination of the clinico-pathological data contained in the first article was begun. Many results of the experimental study could not be prepared for publication in the present article, and a number of duties prevented the earlier completion of the article as it now stands, but it is hoped that time will be found for the early presentation of the other collected facts which bear upon the same problem. Part of the first study was prepared for, but was not presented at, the conference on individual differences at Columbia University in celebration of the twenty-fifth anniversary of the professorship of J. McKeen Cattell.

In the experimental part of the present work the author has had the assistance of and is under obligation to a number of former students, and of internes at the Government Hospital for the Insane, too numerous to mention separately. The major part of the assistance was given by Dr. J. Duerson Stout, now associate professor of physiology and pharmacology in the George Washington University and his name appears, therefore, on the title page.

The research on the brains of the monkeys was made possible by reason of a grant to the author, for the purchase and maintenance of animals for the investigation of the functions of the cerebrum, by the Carnegie Institution of Washington, and for making possible this and other similar previous investigations the author here expresses his sense of obligation.

For the convenience of the reader it may be mentioned that summaries of the experimental work appear at the ends of the individual sections of that article (see pp. 102, 105, 132, and 139).

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I

SYMPTOMATOLOGICAL DIFFERENCES ASSOCIATED WITH SIMILAR CEREBRAL LESIONS IN THE INSANE

INTRODUCTION

It is well known that in different diseases similar symptoms are often exhibited. For example, anemia and fever are not more characteristic of one special disease than of a multitude of others. On the other hand, discomfort and malaise are so constantly reported by those who are sick, that they can not be said to be of more than minor diagnostic value. Even pains are so commonly concomitants of different diseases that, except when definitely localized, and not always then, they almost cease to be of diagnostic or prognostic importance. In the mental disease, the individual symptom is often less valuable, if this be possible, as an indication of the special disease. A depression or a sadness, an hallucination or a delusion, defects of retention or of comprehension, and evidences of loose thinking and the like are elements or symptoms in many of the psychoses. Not one is pathognomonic of a special disease, each is an expression of a physiological conflict or of a loss or defect of anatomical, and also functional, cerebral elements.

Although no one symptom or condition can be relied upon for the purpose of diagnosis, the combination of symptoms does give most often plain evidence of the nature of the special disorder. The recognition of the fact that diagnostic reliance may be placed upon the collection or concatenation of symptoms has led to the foundation and the elaboration of a system of knowledge, we might almost say a science, which is called differential diagnostics. The development of this field has also been due to the realization that in the same disease in different individuals the micro-organisms may produce different effects, or the body physiologically

may be affected differently, and there may result different prominent systems in different individuals. Apart from the so-called mildness or the severity of the disease, one individual may exhibit high temperature, another may exhibit a temperature only slightly above the normal. In one individual the diseased condition of one of the heart valves may exist for many years without obvious symptoms which attract the patient's attention because of compensation in both the strength and the size of the heart, while a similar pathological state in another patient gives rise to distress, sharp pains and faintness.

These similarities of symptoms in different diseases and the variations in symptoms in different individuals with the same disease are paralleled by variations in actions of different drugs and by differences in the reactions of different individuals to some foods. In some, the eating of strawberries or of fish is accompanied by disagreeable effects, and in other individuals the effects following the administration of therapeutic doses of certain drugs are not only disagreeable but often dangerous. Small amounts of the derivatives of opium, of arsenic, of antipyrine, and of even generally supposed-to-be-harmless quinine at times give rise to violent physiological reaction, although most people may take small doses of these drugs with impunity and without apparent physiological changes.

In the older psychiatry individual symptoms or concomitant physical conditions were uncritically believed to have major importance and, because of this, dissimilar diseases were considered to be the same. When certain etiological factors were determined and when the symptomatological variations were carefully considered it became apparent that superficially different groupings of symptoms might be and often are essentially similar. Notwithstanding these supposedly fundamental similarities as we see them at present, there remain many prominent points of differences in the symptoms in individuals who suffer from the same disease. These individual differences have been supposed to be due to or to be connected with variations in the normal mental make-up of the patient, or to variations in lesions or in functional disturbances of cerebral centers or connections.

To account for the individual variations in both mental and nervous diseases, the psychoses and the neuroses, it has been most easy and quite satisfying to presuppose functional and structional differences of the lesions, because of our relative ignorance of many of the functions and of the anatomical connections of parts of the nervous system. This is specially true when we deal with lesions or disease of the cerebrum and the basal ganglia. Within recent years, however, there has been growing the realization that a minute lesion in one part of the brain may give rise to a symptom or to a collection of symptoms which is exactly the same as that resulting from a similarly minute lesion in a second or a third portion of that organ. If we liken the cerebral mechanism to the stations and lines of a telephone or a telegraph plant we may readily understand how this can be. If the emissive element or the transmitter be broken or destroyed it is not possible to transmit the message in a particular direction or to a given point. The function is abolished. But we must also keep in mind that a similar abnormal condition of function arises if, instead of having a lesion of the emissive element, there be a break in any part of the conducting line. Such an injury or a disease may be close to or far from the transmitter and may even be in the receiver.

Lesions in the nervous system minute enough to embrace an individual nerve cell or its processes are never found. The smallest always involve many elements. But even though this be true, it has been shown that such lesions in different parts may result in similar physiological disturbances. Lesions of such widely separated parts of the nervous system as the frontal lobes and the cerebellum are known to produce similar symptoms, and in many cases a definite diagnosis can be made only after death. Usually, however, concurrent with the main, or with the more prominent, symptoms other symptoms are found. These additional symptoms point to disturbances of structures anatomically allied to the one which is chiefly involved or which is entirely destroyed, and they permit fairly accurate neurological diagnostic localizations in many cases during life. Thus, for

example, we find it possible to predict the localizations of lesions in individuals with paralyses because of the association of several paralyzed segments, or because of concomitant sensibility disorders.

The reverse state of affairs is seldom considered. Is it, we may ask, possible that anatomically similar lesions of the cerebrum give rise to dissimilar symptoms in different individuals? The consequences of a positive or a negative answer to this question are of great importance. If similar cerebral lesions do not always produce similar symptoms, there is opened a series of problems regarding the "why" and the "how" of cerebral function which are fundamental. If similar cerebral lesions are always accompanied by similar mental changes, our conceptions of cerebral mechanics may remain simple and our explanations of the relations of mental and cerebral functions become less difficult.

Because of these considerations it appeared desirable to make a special study of possible differences in symptoms accompanying similar cerebral lesions. For this purpose there were available autopsy and clinical records of nearly 3,300 patients who had been in the Government Hospital for the Insane. The clinical records of many were so meagre that attempted correlations of the cerebral lesions with the clinical symptoms would, in these cases, have been futile, and it appeared would have resulted in a loss of time. For this reason only those cases have been considered in which there were recorded the results of fairly complete mental examinations as well as the autopsy examinations. These considerations resulted in the primary rejections of all but the last 950 autopsy cases, representing roughly those autopsies which had been performed during the past six or seven years. It was also found that about one-third of these must also be rejected on account of insufficient clinical examinations, and because of indefinite diagnostic data. The cases which were eventually selected were of all kinds of mental diseases, but the series is particularly strong in the organic psychoses, such as paresis, arteriosclerotic dementia, senile dementia, and the like.

The brains of these individuals showed a great variety of lesions, inflammatory, atrophic, hemorrhagic, and the like. These were divided into two general groups, one in which there was a single or unitary lesion, the other in which there was a combination of cerebral lesions. Those in which there were two kinds of lesions, *e. g.,* softening and atrophy, were excluded. The cases which showed atrophy were the most numerous and these were selected for the present study. These were separated into two general classes: (1) Those in which the atrophy was general but in which there might be a greater atrophic condition in one portion of the cerebrum, and (2) those in which the atrophy was well localized in one special region of the cerebral cortex. The second group is the one which has been more carefully studied at the present time. From this group, as has been stated above, there have been omitted almost all those cases in which there were other gross lesions of parts of the cerebrum or of the nervous system in general. A few cases in which the only additional lesions were recent cerebral hemorrhages, that resulted in the death of the patients, were included, because whatever mental changes had been observed during the major part of their hospital residence could not have been due to these lesions. It might also have been possible to include certain cases in which localized softenings accompanied the atrophy, because in a number of cases these additional pathological conditions were due to comparatively recent cerebral insults. Since, however, definite dates could not be assigned to some of them, they have been excluded from the present report.

The atrophies which are dealt with here are those which, as defined by Blackburn[1], imply "reduction in size and weight of an organ which has been at one time of greater volume and weight, though the organ may not have been orginally up to the normal standard. It also implies that this atrophy is the result of degeneration and diminution of the elements of the tissue and not merely the result of pressure or gross loss of substance." In old age this condition of atrophy of the cerebrum is met with as

[1] Blackburn, I. W. Atrophy of the Brain in the Insane. *Govt. Hosp. for the Insane Bull.,* 1911, 3, 45-50.

a common concomitant of the general bodily degenerative changes, and it may be due solely to these degenerative tendencies of the body as a whole. The condition of cerebral atrophy is also to be found in a variety of other mental diseases besides that of senile dementia, and it is particularly noticeable in many cases of general paralysis of the insane. The atrophies may, it has been shown, be primary, *i.e.,* due to degenerations of the cells, without concomitant changes in the blood vessels, or they may be the result of partial blocking of or difficulties in the course of the blood flow. The atrophies which accompany cerebral arteriosclerosis are allied, some think, to the atrophies which are found in general paralysis of the insane, in that they are atrophies of a secondary nature, whereas the atrophies which are found in senile dementia, and possibly also in dementia precox, are more frequently primary atrophies. In many cases the atrophies are so distributed that it is apparent they do not depend upon changes in the arterial supply. In fact, in many instances the gross and also the histological examinations may fail to show any sclerotic changes in the blood vessels. In this connection, it may be noted that Blackburn has pointed out that in certain cases there may be a complete preservation of certain cortical areas with an atrophy of surrounding or neighboring zones which are supplied by the same vessel.

In many cases the cerebral atrophy is general, but regional atrophies are frequently met with, such as those of the frontal, or parietal or temporal lobes. In paresis it is not uncommon to find such localized atrophies, and these are more frequent in the frontal lobes. There is, however, an atrophy of the parietal region, circumscribed in character, which has been described by Lissauer. Although the symptoms due to this circumscribed atrophic condition of the posterior half of the brain include certain focal manifestations, especially those of disturbances in speech of the nature of the aphasias, the other symptoms do not differ very markedly from the symptoms accompanying more generalized or frontal atrophy, and previous to death it is not usually possible to diganose this condition. Kraepelin[2] reports

[2] Kraepelin, E., General Paresis (trans. by I. W. Moore). Nerv. and Ment. Dis. Monog. No. 14. Pp. v + 200. (See especially pp. 134-135.)

that in this Lissauer type of paresis the course of the disease is spasmodic and resembles, to some extent, cortical epilepsy, while the deterioration is more gradual than in the frontal atrophies. This type of case is estimated by Alzheimer to comprise about 15 per cent of the total cases of paresis. Similar circumscribed, or regional, atrophies are also found in cases of senile dementia, arteriosclerotic dementia, and dementia precox.

In regard to the relation of atrophies to the clinical symptoms Blackburn has written: "The conclusions reached by long experience are that in all cases of insanity of long standing in which there is a demonstrable mental deterioration we may confidently predict that some shrinkage of the brain may be found; that as a rule the degree of dementia is commensurate with the atrophy found or present; and that the localization of this shrinkage in the prefrontal region in most cases is a strong presumptive evidence of the seat of intellectual processes in that part of the brain."[3] He furthermore states that the fact that the secondary degenerative atrophy "is confined most frequently to the frontal lobes and the prefrontal region is strikingly significant in view of the supposed intellectual function of these parts." On the other hand, it should be mentioned that senile dementia may be evident without concomitant atrophic conditions in the brain. This is also true for dementia precox, and whatever relations the atrophic conditions bear to the changes in mental characters which are grouped together under the general term "mental deterioration" are at present unknown. Since deterioration may exist without obvious atrophy it is apparent that the atrophy, in itself, is not necessary for the production of the symptoms. That, however, the symptoms do, in many cases at least, depend upon the cerebral changes we may believe. The relation, direct or indirect, of the cerebral lesions with the symptoms has not yet been sufficiently shown.

After the elimination of the cases with multiple lesions a total of sixty cases was obtained with sufficiently complete clinical and pathological histories to make certain comparisons of value. Some of these were not usable in the present study on account

[3] *Op. cit.*

of the fact that they were diagnostically doubtful cases or there were too few cases of the special kind of mental disease to make valuable symptom-lesion correlations. In general it was believed that at least four or more cases of a particular psychosis were needed if the individual differences and similarities were to be dealt with properly, and on account of this twenty-two cases were omitted from the present work. The omitted cases were: manic-depressive and allied psychoses, 7; intoxication psychoses, 2; imbecility, 1; epilepsy with dementia, 1; paralysis agitans, 1; cerebral syphilis, 3; organic diseases of the brain not otherwise differentiated, 3; undiagnosed or unclassified psychoses, 4. The remaining thirty-eight cases were distributed as follows: dementia precox, 9; general paralysis of the insane, 6; arteriosclerotic dementia, 9; senile dementia, 14. Thirteen of these cases were described in the autopsy records as simple frontal atrophies; two were cases in which the brain was generally atrophied but the atrophies of the frontal regions were great; eighteen cases were described as anterior atrophies, and by this is meant that the regions anterior to the central fissure (including, therefore, the so-called motor region in addition to the frontal area) were atrophied; four cases showed atrophy over the anterior two-thirds of the cerebrum, including therefore more of the cortex than in the cases previously mentioned; one additional case, in which the atrophy covered the frontal region and the posterior portion of the parietal area, was included for comparison. The distribution of these extents of atrophies in the different diseases is given in the accompanying table and comparisons are also made in the discussions.

Mental Diseases	Characters of atrophy					
	Frontal	Frontal and general	Anterior	Anterior two-thirds	Frontal and posterior parietal	Totals
Dementia precox	3	0	5	1	0	9
General paralysis of the insane	3	0	3	0	0	6
Arteriosclerotic dementia	2	2	5	0	0	9
Senile dementia	5	0	5	3	1	14
Totals	13	2	18	4	1	38

DEMENTIA PRECOX, CLINICAL HISTORIES

Case 1, white female, was admitted to the Hospital at the age of 54 and lived for 3 years and 6 months.

Her family history was bad; her father was nervous, her maternal cousin was insane, and her mother was an invalid for a number of years before her death, which was due to ovarian tumor; the patient attended private schools until the age of seventeen; she was considered to be sickly all her life; for many years she showed marked peculiarities of conduct, was contrary, and had spells of high temper at intervals varying from a week to several months; at one time she lived in an eighteen-room house with only a dog for company for a period of fifteen years. The mental disorder which led to her commitment was probably of very long standing, but the occasion of commitment was the manifestation of delusions of persecution by "witches" and by the "Black Hand Society"; she was also extremely nervous, had insomia, refused to eat, and exhibited homicidal tendencies. She would not permit either physical or neurological examination, but exhibited no obvious physical or neurological abnormalities except a few small sores over trunk and limbs. She was restless, suspicious of almost every one about her; she refused to talk freely about herself; at times she imagined the food was poisoned and refused to take it on this account, but on being assured that there was no poison or after it had been tasted by another, she would take it; she also feared that the towels, the combs, the water, etc., contained poison; she had hallucinations of hearing (she had heard her mother's and brother's voices talking to her) and also of skin sensations (she said that she was electrical and could give out power at any time; she also reported that electric currents had been turned upon her for years by her enemies); she believed that she was especially favored by the Lord and that she received signs of this; her memory was excellent and when she was persuaded to talk, she gave detailed accounts of her past and of the conditions which led up to the persecutions to which she believed she had been subjected; her attention did not appear to be

impaired, and there was no distractability; she had no appreciation of her mental condition; she was well oriented in all spheres; there was no clouding of consciousness; she reported (incorrectly) that she did not sleep well; and she answered incoherently at most times. Later she became indifferent, but at times was noted to be emotionally labile; she was irresponsible; her answers were circumstantial, irrelevant, or incoherent; at times she was disturbed, noisy, destructive, violent, and untidy; she wandered away; talked constantly; her answers showed that her memory was poor for recent events, and there was evidence of gradual mental deterioration.

Death was due to purulent parotitis and bronchopneumonia. Besides these, the autopsy revealed: diffuse nephritis; pulmonary tubercular nodules; an insufficiency of the tricuspid valve of the heart; numerous uterine fibroids and endometritis; the brain was slightly shrunken in the frontal regions, but no other gross cerebral lesions were found. The histological examination showed a slight chromatolysis of the ganglion cells, neuronophagia, and an increase of the neuroglia.

Case 2, white male, 36 years of age at the time of admission, lived 25 years and a half in the Hospital. The duration of the mental disease at the time of admission was noted as 2 years and 3 months.

His family history was negative; the patient came to the United States when young, entered the army, and, as has been indicated above, exhibited for more than two years previous to his entrance to the Hospital mental abnormalities. Physically and neurologically no pathological conditions were detected. He was quiet, tidy, had little to say voluntarily, but would answer questions; his answers showed that he had delusions of a fantastic nature which were fleeting in character, but which did not, however, appear to cause him any discomfort; he appeared to be indifferent to his surroundings, but in general was satisfied and happy, industrious, and he willingly helped with the ward work; his memory was fair; in general he was disoriented; his delusions concerned God and religion, and combined with these, there

were auditory hallucinations that the "Almighty" talked with him and that other voices abused him, and for that reason he swore at them occasionally; he often talked to himself. Later he became almost completely disoriented; memory became very poor, for the most part he talked unintelligibly, but he gave plain evidence of the existence of delusions; he said that God Almightly persecuted him by ordering him to do things he did not like to do; he occasionally stopped eating in the midst of a meal and explained this as being due to the fact that God had told him to eat no more; he used very profane language and swore at times, and would have nothing to do with the other patients; he asked for whiskey to drink so that in this way he might punish God Almighty; he kissed the walls; he muttered unintelligibly, and he informed a physician that God's voice was inside his body, and that God talked so quickly that he could not repeat what was said; he showed no interest in his surroundings except as exhibited in his daily, almost continuous, polishing of the floor, which he said was done at the command of God; he had practically no knowledge of current events; his reasoning and judgment were very much impaired; he was illogical; his conduct was silly; and his insight was almost lacking.

At the autopsy there were found: marked generalized arteriosclerosis; calcification of the mitral valves of the heart; hypostatic congestion of the lungs; interstitial nephritis; and shrinkage of the frontal portions of the cerebrum.

Case 3, colored male, exhibited mental abnormalities for 5 or more years previous to his admission at the age of 30. Hospital residence was 11 years and 6 months.

Nothing was learned of this patient's family or previous personal history except that it was reported he had been mentally abnormal for at least five years previous to his admission, although his marked mental abnormality was evident for only a year previous to his commitment; during that time he was noted to be melancholy and restless; he showed extreme anxiety and had hallucinations; he upset everything in his room, and was untidy and filthy in habits. Physical and neurological examinations

were negative except that hearing and smell were slightly impaired; his gait was slow and his attitude, although fairly erect and steady, was slightly relaxed; his actions in general were slow, imperfect, uncertain and unreliable. He was quiet, dull, often stupid; he was also untidy; memory was markedly impaired; his ideation was slow and uncertain; in general he answered fairly well, although at times irrelevantly; his reasoning and judgment were bad; he appeared to have very little mental capacity; no hallucinations or delusions were observed and could not be detected from his actions; he was unappreciative and had no apparent interest in his surroundings; he appeared stupid; he usually sat in one place and assumed one position; he spoke only when spoken to, and then only after much persuasion; at times he was noisy, turbulent, talked incoherently, and was destructive; echopraxia, mutism, negativism and catatonia were observed, but none of these conditions was marked; orientation was lacking.

The patient died of tubercular pneumonia, and shrinkage of the frontal lobes of the cerebrum was also found at the autopsy.

Case 4, white male, entered the Hospital at the age of 54 and lived for 18 years.

He fought in the Civil War and since its ending (he was twenty-two years old at that time) was abnormal, with intervening lucid intervals; the character of his abnormality during this period of twenty-one years was not very clear, but presumably it was of a precox nature. On his entrance to the Hospital he was untidy; he answered irrelevantly; he exhibited poor memory; he said little; he went out walking daily; at times he would not keep his clothing on and was filthy in habits. Later the patient was found to have interstitial nephritis, and for about seven years before his death he was almost entirely confined to bed on account of this pathological condition and heart disease; he became much demented, took no interest in his surroundings; questions often remained unanswered, but if answers were obtained, they showed no grasp of his surroundings and were given in a slow, hesitating manner and in so low a voice as to be almost inaudible and unintelligible; he talked to himself a great deal and appeared to have

auditory hallucinations; occasionally he arose from his bed and peered about the ward; echolalia was present; he remained most of the time in bed motionless with his arms across his chest and his fingers intertwined.

Death was due to purpura hemorrhagica. The autopsy showed: some heart disease; atheromatous aorta; small cysts in the kidney; hypernephroma; chronic cytitis; the section of the brain revealed no lesions except atrophy of the anterior convolutions.

Case 5, colored male, lived for about 2 years after admission at the age of 23.

A brother and sister had spasms in early life; otherwise the family history was negative; he attended school for five years, but made little progress; he drank alcoholic liquors to excess and sometimes was drunk two or three times a week; he had gonorrhea several times and a chancre a year previous to his admission; he was arrested on account of a brawl and sent to the workhouse, where his mental condition was recognized as abnormal. From there he was sent to the Hospital, where he was excited; he said that another inmate had shot some dope or chloroform into him, that all the other prisoners were dodging about to avoid it, this was blown at him through a long stem, and he could not sleep and felt queer; he believed he would have been killed by it if he had remained, for he heard them talking about "kill that nigger," and he became frightened and excited; bells were also rung in his ears, voices asked him how he felt; he believed some one was after him trying to read his mind; he said that the poisoned stuff which was being shot at him he could feel, smell, and taste, but could not see the dust of it, and could not see the people; some nights he jumped out of bed because he thought electricity was being used upon him and for several days he had the feeling of things crawling over his body like insects. The physical and neurological examinations revealed no abnormalities except a complete positive Wassermann of the blood serum; he was uneducated, and his general information and memory were poor, but he exhibited a good memory for occurrences in his own life; at first he was quiet and orderly;

he was tidy in habits; he helped with the ward work; he appreciated his surroundings; he answered questions promptly, but talked little with the other patients; and he appeared to be somewhat depressed. Later he became sullen; he stood in various places about the ward; he was slow in movements and showed a tendency to remain in one attitude for a considerable length of time; he took no interest in what went on about him; he never spoke unless spoken to; he was disoriented for time but oriented for place and persons; he had auditory hallucinations of voices which seemed to come from his stomach, and which were interpreted as the spirit of God talking to him; the voices said different things, but he could not, or would not, recount any particular thing; insight was lacking; pulmonary tuberculosis was diagnosed three months before death.

The autopsy showed: pulmonary and intestinal tuberculosis; fibrous deposits over the small intestine, and infiltration of the mesenteric glands; slight shrinkage of the anterior portions of the cerebrum, but no other gross cerebral lesions on section.

Case 6, white male, was 25 years old at the time of admission and lived 28 years subsequently.

No family or previous personal history was obtained except that the patient exhibited mental abnormalities for a month previous to his admission; during his Hospital residence he became gradually demented and exhibited periodic variations in his behavior. At one time he would be quiet and orderly, and he would sit or stand for hours at a time in one place; for the most part he was tidy in his habits; he seldom answered and volunteered no information; he appeared to be dull and stupid and in almost a semi-conscious condition. This state would last for a week or two and be replaced by one of general activity; he sang loudly and irrationally nearly all night; he was restless, destructive, and untidy in dress and habits; he ran around the ward moving or picking up everything he could reach. At times his face was expressionless and at other times he appeared to be very much depressed; his talk was unintelligible, and he mumbled to himself continually; it was judged that he had auditory hal-

lucinations because at times he turned his head suddenly to the right or left and muttered unintelligibly or excitably as if he were talking to or scolding some one; some of his mutterings which were heard indicated that he believed some one was after him and wished to harm him; he showed no interest in his surroundings; he could not be made to work; his memory was poor. In his later years it was noted that he "exhibited no marks of intelligence"; he either did not understand questions or could not make himself understood; his clothing was disheveled; he was filthy in habits; and when he could he stole from his fellow patients; the only reaction which was often elicited when he was spoken to was the opening and closing of his eyes.

Death was due to pulmonary tuberculosis; in addition to this condition, cardiac atrophy and atrophy of the anterior portions of the cerebrum were noted at the autopsy.

Case 7, white male, 36 years of age at the time of admission; had exhibited mental abnormalities for 4 or more years previous to his admission, and lived in the Hospital for 7 years.

This patient was a wife murderer who showed the following evidence of insanity immediately after his imprisonment for life; he was melancholic; he was unconscious of his surroundings; he answered in monosyllables when at all; part of the time he would not talk and he was noted to have a treacherous disposition. Whether or not the murder of his wife, for which he was convicted, was due to paranoid ideas was not determined, but in view of his later history this seems probable, and the psychosis may have begun many years previous to the date assigned above. His expression was dull and indifferent; his attitude was stooped and careless, and he walked in an apparently reckless and slovenly manner. Physical and neurological examinations showed no abnormalities of importance. On admission he recognized what was said to him; he knew where he was; he exhibited a fair memory; he rubbed his hair and face, twisted his mouth, grinned meaninglessly and hummed to himself; he attempted to strike an attendant with a shoe; but at this time no delusions or hallucinations were detected; he was restless, continually moved about

the ward, he walked rapidly and in an excited manner; he wanted his own way, but otherwise was apparently indifferent to what went on; he rarely spoke voluntarily, but sometimes sang to himself; he was noisy at times and at other times appeared to be depressed; he was clean in habits; he butted his head against the door and walls of his room; false hearing was suspected on account of his frequent talking to himself; he used abusive terms towards parts of the room in which no one was present; he would not tell what or who was bothering him; he shouted vile names; he answered general questions, although this was done in a surly manner. Later his hallucinations and delusions became more evident; he believed that a woman was after him, that she came into his room at night to bother him; he called to her out of the window, using a number of names indicating her indecent character; he also bawled at some chickens which he believed were on the floor under his feet, and he attempted to "shoo" them away and to stop their cackling; a month later a swelling of his feet and legs was observed, and at that time he was frequently found on his hands and knees on the floor looking under the bed for the dogs which he believed were there and upon which he stepped; at this time he admitted having auditory hallucinations (of voices); and also visual hallucinations (of ghosts and people) when he closed his eyes; he assumed catatonic attitudes; he exhibited numerous mannerisms, and at times had impulsive outbreaks; at the same time he was negativistic; he was found to have pulmonary tuberculosis, and death was due to this.

In addition, the autopsy showed: intestinal tuberculosis and some shrinkage of the cerebral convolutions anteriorly.

Case 8, white male, had exhibited mental disturbance for more than 6 months previous to his admission; he was aged 30, and lived 2 years and 8 months in the Hospital.

His family history was negative; the patient had attempted a criminal assault and was convicted for this; in the last few months of his term in prison he developed a disorderly temperament; he laughed when questions were asked; he refused to wear

clothing and to obey orders, and occasionally to eat. The physical and neurological examinations revealed nothing of importance except a distended, tympanitic abdomen and stumbling over test speech phrases. On admission he conversed with a physician pleasantly, but appeared to be suspicious; he had notable mannerisms of gritting his teeth and drumming on the table with his fingers; he was neat and tidy; he believed his family had been sent to the same prison as he; at times he became irritable and was pugnacious, especially when another patient walked in front of him, and because of this he had several altercations with them; he expressed the belief that he was some kind of a Mason, although he had not been initiated into or by a regular lodge, but had been "admitted through another personality"; his replies indicated that he believed his personality changed from day to day, although he said he could not reveal the secret of this because it was Masonic and military; in general he was well oriented and showed fair memory and considerable general knowledge, but he had no insight into his condition; he refused to answer many questions on the ground that they were "too easy"; at various times he said that the Government owed him money, that he was a rich man, and that he used to travel about a great deal; he continued to be reticent about his previous life and his ideas, but was cross and disagreeable; he refused medicine and food, and many times fought with the attendants and with the other patients; hallucinations of any kind were not recorded as having been evident; he frequently complained of abdominal pain and suffered from distention of abdomen; an operation was planned, but not performed on account of the sudden death of the patient from intestinal obstruction and gangrene.

In addition to the diseased conditions which caused his death, the autopsy revealed fatty changes in the liver and slight shrinkage of the anterior portions of the cerebrum, with no other gross cerebral lesions.

Case 9, white male, admitted at the age of 34 and lived nearly 20 years in the Hospital.

The mental diagnosis which was made was "probably cerebral syphilis," but later this was changed to dementia precox, prob-

ably paranoid form. The certificate on entrance stated that the patient had visual hallucinations and delusions of persecution but no maniacal explosions, although he talked incessantly about the loss of some musical instruments; he also had hallucinations, which were nocturnal in character, of seeing women coming to the beds of patients who were in the same ward with him. He admitted having had a soft chancre at eighteen, and gonorrhea at nineteen; the physical examination was negative except for irregularities and inequality of the pupils; there was no disorder of voluntary movement, or of the reflexes or of sensation; there were hypertrophy of the heart and lesions of the valves. He smiled constantly, his expression was dreamy but fairly intelligent; no peculiar actions were noted; he reported that soon after his arrival at the Hospital he was given some black medicine which injured his health, making him nervous and giving him pains in the legs like needles, and causing him to spit, which made his tongue sore; subsequently, no delusions were elicited except a brief mention of this supposed poisoning episode. Thirteen years after his entrance, it was noted that he was not depressed; he talked and associated with the other patients; he played games of different kinds when on the ward, and also played a musical instrument; he sat quietly; he was not overly religious; he did not assume peculiar attitudes; he was tidy in habits; he did not lack in initiative; his memory for recent and old events was good; he was not agitated as a result of any of his delusions; he did not become excited, abusive, profane, destructive or untidy; he slept well; his conversation was coherent; he had parole of the grounds; he was well oriented; he appeared to be content; he never complained, and he played in the Hospital band. On several occasions later he became restless and very much confused, being unable to comprehend what was said to him and seeming to be much disturbed; one of these attacks immediately preceded his death. During the later years of his life he showed marked loss of intelligence and very little judgment; it was difficult to get his attention, and when his attention was obtained, it was almost impossible to hold it; he showed much retardation; he spoke indistinctly, and at times his teeth were kept closed so

that it was difficult to understand what he said; he also seemed unable to comprehend some of the simplest questions, and when asked to repeat one which had been asked, he was unable to do so; he remained orderly, but took no interest in his surroundings; he was neat and tidy; he was also fairly well oriented in all spheres; he had fair memory of his personal history, but of other events his memory was very poor.

Death was due to cardiac valvular disease. The autopsy showed that he had: hypertrophied heart; marked aortic atheroma; mitral aortic valves contracted; pulmonary tubercular scars and pulmonary hypostasis; nutmeg liver; some adhesions in the region of the appendix; brain shrinkage over the anterior two-thirds of the convolutions, but no other cerebral lesions; and a slight sclerosis of the large vessels at the base.

Dementia Precox, Discussion

Although these nine cases have somewhat different clinical symptoms, the symptomatology of all is sufficiently alike to warrant the clinical diagnosis of dementia precox. The form of the disease, it should be remarked, is not the same in all cases, five being judged to be catatonic (3, 4, 5, 6, and 7), and two to be paranoid (1 and 8). Cases 2 and 9 were committed to the Hospital many years ago. The case histories of these patients contained no, or very meagre, information regarding their mental conditions previous to commitment, and only outlines of their behavior during their early hospital residence. We are not entirely justified in making a definite diagnosis of the form of precox from the information obtained in their later years, but the general diagnosis of precox is, however, justified by the accounts which have been kept, and the symptoms recorded in the records during their later years might be interpreted to indicate that case 2 was a paranoid case, and case 9 an hebephrenia.

Looking at these cases from another point of view, it will be noted that the anatomical lesions do not correspond with the clinical forms. Of the three cases in which the brain was noted to have shown frontal atrophy one was diagnosed as paranoid, a second as an hebephrenic and the third was a "possible paranoid"

case. Of the five cases with anterior atrophy the mental diagnosis of catatonia was made in four, while the fifth was a paranoid case. The ninth case, with atrophy covering the anterior two-thirds of the cerebral convolutions was the case mentioned above as possibly hebephrenic. The only evidence of a possible correlation between the forms of precox and the character of the cerebral atrophy is the fact that most of the cases of lesions of the anterior convolutions are catatonic. This might be taken to indicate that motor disturbances in catatonia may be associated with pathological changes in the anterior portions of the cerebrum, but case 8, whose brain also exhibited similar lesions did not exhibit these behavior disorders. It should also be remembered that case 9, in whom the atrophy covered slightly more of the cortex than in the catatonics did not exhibit motor disturbances of the nature of catatonia. These two cases (8 and 9) are sufficiently definite to prevent a generalization regarding the relations of such anterior lesions with motor disturbances of the nature of catatonia or negativism.

During their Hospital residence all of these patients were noted to show gradual mental deterioration, although the amount of this decadence differed in the individual cases. The histories show that cases 2, 3, 4, 6, and 9 showed towards the end less evidence of being thinking beings than the other four cases showed. Excluding case 4, whose age at the time of death was seventy-two, and whose lack of mentality might have been due to the natural decadence associated with old age, the other four cases are not chronologically aged, and, in fact, of the other cases there were two (1 and 7) whose ages were respectively greater than those of cases 3, 6, and 9, and case 3. While the degree of atrophy in these five cases is not specified, even roughly, there is nothing to indicate any definite relation between the greater mental deterioration and the degree of atrophy. It is true that the brains of cases 1, 5, and 8 are described as showing only "slight" atrophy, but case 7, in whom extreme mental changes were not found was also described as showing "some" atrophy, which term may be interpreted, as I interpret it here, to indicate only a medium degree, rather than a slight degree. No mathematical

estimation has been made in the individual cases regarding either atrophy or mental deterioration, and the data at hand do not permit the correlation of these two conditions at the present time.

It is, however, of interest and importance to note that the degree of dementia in those cases in which the frontal lobes were atrophied did not differ to any appreciable extent from those cases in which the atrophic regions were larger. Thus case 2 has been described as exhibiting no knowledge of things occurring about him, and case 3 to have "very little mental capacity," although the latter patient at the time of his death was only forty-two years old. In addition, it has been noted that case 1 had a poor memory.

Although the degree of dementia, or mental abnormality, does not appear to be directly correlated either with the extent or with the degree of the atrophy in the cases which we have studied, we may seek for correlations in the individual mental symptoms. Differing in the individual cases, and giving, as they do, special characteristics to the disease, the mental symptoms can not be dealt with in great detail. Nor can the individual elements of the mental processes be considered, for in the clinical histories the complex mental states or processes have not been analyzed into their elements. This is, however, not different from the methodological condition found in most clinical work, *e.g.,* in neurology, and the attempts at correlation of the complex processes with cerebral lesions may therefore well be attempted regardless of the lack of analysis of these complexes.

Underlying all diagnostic methods in psychiatry are the assumptions that mental states are mirrored by acts, that acts change in accordance with the mental states, and that changes in mentality, which are supposed to be produced by or correlated with functional or anatomical cerebral lesions, are evidenced by alterations in general behavior. In their general form these assumptions may be satisfactory, but when they are made more specific they become open to criticism. In the cases which have been described above this latter appears to be true. It will be noticed that four of these patients have been described as tidy in habits, while four others have been described as untidy or

filthy, while the ninth has not been specifically described but appears to have been tidy. Two of the untidy patients were those in which only the frontal regions were atrophied, and two in which the anterior lobes were shrunken. Case 9, in whom the atrophy extended farther backwards than in the other eight cases, was, however, noted to be tidy. In this respect there is correlation neither with the extent nor with the degree of the atrophy.

Although the frontal lobes are believed to have more direct relations with motor processes, the data at hand regarding the motor manifestations, other than the catatonic attitudes, etc., in these patients do not appear to be correlated with the lesions. A comparison of the movement differences in the patients under consideration shows that the variations are not variations corresponding with the regional atrophies. Certain of the patients varied from a quiet to a restless state; others were almost continually restless or noisy; and two were noted to be uniformly slow, unresponsive, and, during part of the time, motionless. Some may be inclined to interpret the general motor manifestations to be evidence of a supposed inhibition function of the frontal regions of the brain, in some of the cases there being a greater amount of inhibition, and in others a lesser amount of inhibition than in normal individuals. The fact that the variations were not always in the same direction in the different patients, would, however, be a matter needing special explanation in addition to the general hypothesis. We should, on the basis of our present knowledge of the motor functions of the cortex, be able to explain or to correlate these irregular weekly or monthly variations in activity in the same patient with exaccerbations in irritation or degeneration of the ganglion cells, but the pathological facts which would warrant such explanations or correlations are lacking. One element, which appears to the writer to be important in this connection is that the motor phenomena in the cases under consideration did not differ very greatly. If these motor disorders were due principally to the pathological conditions of the cells in the atrophic areas, we should expect to find greater motor disturbances associated with

those atrophies which were of the greatest extent, or at least we should expect that the motor activities in those patients in whom the precentral, or physiological motor, area was involved should be more greatly changed than in those in which only the frontal lobes were atrophied. Such, however, is not the case. There is, as has been written above, no apparent difference between the motor derangements in those patients with frontal lesions and those with lesions which also involved the precentral areas, nor even between the motor phenomena in the case with frontal lesions and those in the one case in which the atrophy also involved the precentral areas and parts of the parietals in addition to the frontals.

Certain clinico-neurological facts have been interpreted to mean that the activities of the frontal lobes are especially associated with emotional states or emotional expression, and were this true, different degrees of frontal lesions might be expected to result in variations in emotional tone or in the character of the affective conditions. In these nine cases, however, the emotional conditions were somewhat similar, in that it was variable in all. It varied from depression to indifference, and occasionally to a high degree of happiness. Many of the affective states in these patients depended upon, or resulted from, or, to speak accurately, accompanied, and corresponded with, delusions, and it is not possible to separate the affective elements from these other mental states. Neither the degree nor the extent of the cerebral changes appears to be correlated with the intensity, character or variability of the affective states, for the fear and suspiciousness of cases 1 and 5, in which only slight atrophies respectively of the frontal and anterior convolutions were noted, did not differ from similar states in patients 3 and 7, whose brains showed corresponding areal distributions, but with slightly increased degrees, of atrophy. An examination of the case histories also shows that the fluctuations from one affective state to another is not associated with particular degrees or extents of the lesions.

Notable variations both in the presence and in the characters of hallucinations were also recorded. Of the nine patients, four

exhibited plain evidence of auditory hallucinations (cases 1, 2, 5, and 7). Two others (cases 4 and 6) appear to have had auditory hallucinations, although this is not as certain as in the other four cases. The presence of auditory hallucinations in case 4 has been inferred from his talking to himself, and similarly in case 6 because he mumbled to himself and because he had been noted to turn his head towards a special part of the room and appeared to listen when no one was present there. Definite evidence of visual hallucinations was found in only two of the cases; viz., patients 7 and 9, and in one of these it has been noted they were more frequently present at night. Patients 1 and 7 also exhibited actions which were interpreted to mean that they had tactual hallucinations or paresthesias. Patient 1, it will be remembered, reported that she could give out electrical power, and that electric currents had been turned upon her. Patient 7 complained of chickens and dogs which he thought were in his room and which he was compelled to step upon when he got out of his bed. Whether or not the latter case is a mixed hallucination, *e.g.*, tactual and visual, was not determined. The actions of the patient indicated that he did not see the animals, for he searched for them under his bed. Case 3 was reported to have had hallucinations previous to his entrance to the hospital, but during his Hospital residence these were not discovered. In the case history of patient 8, in whose brain the atrophy extended over the anterior portions, no hallucinations were recorded at any time.

With the exception of cases 3 and 4, these patients were noted to have delusions. It may not be definitely stated that patient 3 did not have a delusion of any kind, for there is internal evidence in his case history that mental abnormalities of this kind may have been present. It is stated, for example, that in the year preceding his commitment to the Hospital he was restless and melancholy and exhibited extreme anxiety. The reasons for these affective states are not mentioned, but it appears doubtful that they were independent of ideas of impending harm, or of persecution or the like. None of his actions during his Hospital residence was indicative of the presence of a delusion, although

during those years he was observed to fluctuate between excitement and mutism. Case 4 was also judged to be free from delusions during the period of his Hospital residence, although the general facts regarding his mental condition for 21 years previous to his admission are not sufficient to warrant the statement that delusions had not been present during that period of time. The considerable degree of dementia which was present during his Hospital residence may have made the expression of delusions difficult, but his reactions to the auditory hallucinations from which he suffered would not lead to this conclusion. The characters of the delusions of the other seven cases ranged over the fields of somatopsychic, autopsychic, and allopsychic. Delusions of persecution were the more frequent, but these alternated with delusions of grandeur in some cases. None of the somatopsychic delusions was definitely associated with corresponding pathological physical conditions, with the possible exception of those of case 7. This patient complained that chickens and dogs were on the floor of his room, and that he had to step upon them when he rose from his bed. The physical condition associated with this delusion was a swelling of the feet, and as has been suggested above, the hallucinations and the delusion may have resulted from the stretching of the skin. The association of the different characters of delusions with the cerebral atrophies in these cases is neither constant nor definite, cases 3 and 4 belonging respectively to the frontal and anterior atrophy groups, so that we are forced to the conclusion that the lesions can not be constantly associated with delusion formation. These results are of interest in connection with Southard's studies of delusions and especially with his conclusion that the presence of delusions is "to be correlated more with lesions of the anterior association center."[4]

Regarding the conditions of memory in these patients there is little information. Six of them were unable to recount recent events or events in their own lives, or were unable to repeat simple questions which had previously been asked. The other

[4] Southard, E. E. The Mind Twist and Brain Spot Hypotheses in Psychopathology and Neuropathology. Psych. Bull., 1914, **11**, 117-130. See especially p. 123, and other references there given.

three cases exhibited a fair degree of memory. Whether these apparent memory defects were due to lack of attention or to inability to retain the impressions which were received can not be decided. All the patients with simple frontal lesions, irrespective of the degree of atrophy, had poor memory, whereas patients 4, 7, and 8 with anterior atrophies exhibited fair memory.

In contrast to the memory defects of these patients the degree of orientation is to be noted. Although orientation depends, at least to a certain extent, upon retention, it is not necessarily associated with general memory ability. This is shown in case 9 where memory appeared to be very defective, although he was fairly well oriented in all spheres, and in case 5 who, although disoriented for time, was oriented for place and persons. On the other hand patient 4, who exhibited a fair degree of memory, had no grasp of his surroundings. The relation of orientation ability to the lesions in the nine cases is not definite, case 1 being opposed in this particular to cases 2 and 3, and cases 5, 7, and 8, showing good orientation while the corresponding cases, 4 and 6, were in general disoriented. Case 9, in which the atrophy extended beyond the anterior region, was also noted to be fairly well oriented.

The ability of the patients to attend to stimuli is not mentioned in all of the case histories, but reading between the lines, it is evident that this was poor. It is possible that some of the apparent memory defects were due to lack of attention, and that certain of the other mental disturbances were also caused by the failure to attend to stimuli. It is also possible that the degree of dementia is correlated to a certain extent with the failure to attend.

When the facts of atrophy and the facts of mental abnormalities in these nine patients are taken together, it is seen that there are decided differences in the character of the psychic symptoms associated with similar cerebral lesions. It is also apparent that regardless, of the extent of the atrophies similar mental symptoms may be evidenced. The conclusion that follows, therefore, is that similar cerebral lesions in cases of dementia precox do not always result in similar forms of the disease, nor in similar symptoms in all individuals, nor in the same degree of dementia.

GENERAL PARALYSIS OF THE INSANE, CLINICAL HISTORIES

Case 10, colored male, was admitted to the Hospital at the age of 30, and lived over 4½ years.

There is nothing of importance in the patient's family history, and the only facts of interest in his personal history is that he admitted gonorrhea, denied having had syphilis, and admitted that he had used alcoholic liquors since he was a boy, but said he had never been drunk. The physical examination revealed nothing of interest, except that there was a complete positive Wassermann of the blood serum and a trace of the reaction in the cerebrospinal fluid. He had diminished knee jerks, sluggish reactions and inequalities of the pupils, well-marked tremor of the tongue, lips and facial muscles; speech was somewhat ataxic, and there was difficulty in repeating test phrases. The onset of the mental disturbance appeared to be a sudden one; he had been working as a waiter two days before his arrest; he said he had found a check which called for $30,000,000, on the back of which there was a notice to return it to the bank and receive $1,000,000 for it; the bank was closed but he showed it to a number of people and tried to get $300 for it; one man gave him $500 for it, but a policeman arrested the patient, took him to a hospital and later he was brought to this institution. How much of the above incident was based upon a minimum of fact was not determinable. On entrance his expression was one of exaltation; he was quiet and cheerful; his habits were tidy; he gave no trouble except slightly by constantly requesting that he be permitted to be allowed to go out so that he could get his money; he was well oriented for time, place, and persons; his attention could easily be attracted and held; he comprehended what was said to him, and answered coherently and relevantly, except when his delusional ideas were touched upon, whereupon he became rambling and disconnected in conversation; his mem-

ory for recent and remote events was good for one of his grade of intelligence; his emotional tone was one of exaltation, he was as "happy as a lark"; he was sociable with the other patients and worked on the ward; no hallucinations could be elicited. Later, he had a period of confusion for a few hours, in which he took the dishes from the table and placed them outside of the window (reporting that he thought thereby he would get some tobacco), and attacked one of the nurses and demanded his keys; his delusions of wealth had not changed materially; subsequently he had convulsions, was then confined to bed, and developed contractures. At that time he spoke rarely and then only a few phrases, he took no cognizance of what went on and led a nearly vegetable existence till his death from exhaustion of paresis. The autopsy showed that the cerebral convolutions over the frontal regions were shrunken.

Case 11, colored male, had been known to have mental abnormalities for at least 7 months prior to his admission at the age of 37, and he lived for nearly 2 years in the Hospital.

His family and personal history were not obtained in any detail, for he could not give much information and what he gave appeared to be rather unreliable. He denied a syphilitic history, but was found to have a scar on his penis due to an old sore; the Wassermann reaction with the blood serum was complete positive, with the cerebrospinal fluid a trace, the number of cells in the cerebrospinal fluid was 170 per cu. mm. The neurological examination showed marked tremors of the tongue and fingers, and somewhat generally throughout the body; station and gait were tremulous and impaired, he was unable to stand on one leg; coördination was impaired; there was a marked speech defect; some of the reflexes were diminished, others were absent; the pupils were unequal and reacted only slightly to stimuli. He appeared to be contented and did not seem to worry; he sat in a listless, though cheerful, mood, and paid little attention to his surroundings; he did not appear to be oriented; he obeyed simple

commands, but when questioned he did not answer at times; he was tidy in his dress and in his habits and did not conflict with his surroundings; he believed he owned a race horse for which he had paid $3,000. He had a brief attack of unconsciousness followed by a period of confusion in which he talked to himself and made signs with his hands. Physically and mentally he declined, until he was unable to do anything for himself; he replied to no questions, and was apparently oblivious of his surroundings. Death was due to exhaustion of paresis. The autopsy also revealed pulmonary tuberculosis, pericarditis, atrophy of the heart valves, fatty degeneration of the liver, chronic cystitis, and general shrinkage of the frontal lobes. The microscopical examination showed that the frontal and central convolutions exhibited the characteristic pictures of paresis, but that the parietal lobes did not show any marked changes.

Case 12, white male, had been suffering from mental disease for at least a year previous to his admission at the age of 51; he lived 2 years and 8 months after his admission.

The only fact of interest in the family history was that his mother had died of pulmonary tuberculosis when the patient was eight months old. He received a high school education, and after serving for eight years in the army, was a clerk. He had contracted syphilis thirty years previous to his admission and had gonorrhea at a later period, but subsequently married and begot three healthy children; he used tobacco to excess. About a year previous to his admission he became mentally fatigued very easily, his memory was impaired; he could not comprehend as well as he formerly could; his speech became indistinct; his writing was careless, showing many omissions and mistakes in spelling; his gait was ataxic. At the same time he became morose, sullen and irritable; he worried over the state of his health; he made remarks about killing the members of his family and himself; he also bought immense quantities of perfumed soap and bathed constantly. The neurological examination showed coarse tremors of the facial muscles and twitchings of the thigh muscles; Romberg sign was present; gait was unsteady; the

knee jerks were not elicited; the Wassermann reaction with the cerebrospinal fluid was complete positive; the number of cells per cu. mm. was 20. On entrance to the Hospital he appeared to be cheerful, contented and appreciative; but was inclined to be fault-finding with his surroundings and fretful that he was not permitted to have all his clothes and his special toilet articles in his room; he kept busy washing his hands and face and combing his hair; he appeared to be bewildered at times, and expressed the belief that he had offended some one and he worried about this; in general, he showed no interest in what went on about him; his memory for recent and remote events was poor; no evidence of the existence of hallucinations or delusions was discovered; his habits were tidy; he was usually quiet, but at times was nervous. Later, fantastic and ridiculous delusions of a grandiose type were evidenced, *e.g.*, he was to take a marvelous train ride through the country, he had invented things, etc. At times he became worried, he wanted to shoot a fellow patient, whom he believed to be an enemy; he imagined people were going to do something mean to him, that they came to take away his trunk in which he had his money, he also spoke of being tired and explained that this was due to his having had to fight negroes during the night; he became untidy in habits. The depressive delusions apparently disappeared, leaving only those of a grandiose type, that he owned the Hospital, had immense amount of money, etc. He became much demented, he was bedridden, contractures of the left arm and leg developed, there were no convulsions; death was due to exhaustion of paresis. The brain showed great atrophy in the frontal lobes.

Case 13, colored male, admitted to the Hospital at the age of 41, lived for 3 years and 2 months subsequently. The duration of mental disease at the time of admission was about 2 years.

The family history was negative. The medical certificate stated that the patient had had syphilis; mentally he had a violent temper and was very irritable; he had been melancholy, and had exhibited delusions and homicidal tendencies. Physical ex-

amination showed only a slight heart involvement, Wassermann reactions with the blood serum and the cerebrospinal fluid were positive, there were 65 cells per cu. mm. in the cerebrospinal fluid. The neurological examination showed irregularities in outline of the pupils; tremors of tongue, lips, eyelids, and extended fingers; patellar reflexes were very much diminished, and there was a Babinski phenomenon on the right; his station was poor; there was hyperextension of the legs at the knee; the gait was slightly ataxic; coördination was poor; and there was a marked speech defect. His facial expression was placid; he was orderly and quiet, he had little or nothing to say voluntarily; he was indifferent and inclined to be stupid; his attention was easily obtained and held; he comprehended questions and answered coherently and correctly, but slowly; he was not oriented for place, time, or people; his memory was very defective; his judgment was poor; he lacked insight; emotionally he was neither exalted nor depressed, but rather indifferent and apparently satisfied; he did not associate with the other patients and manifested no interest in his surroundings; no delusions or hallucinations could be elicited, nor were they judged to be present because of his conduct. Later he was restless, disturbed and at times noisy; he talked to imaginary people, but recognized no one who saw him; dementia became profound; he comprehended little; his conversation was rambling and incoherent; occasionally he expressed some words indicating that he had grandiose ideas, that he possessed houses and diamonds; at times he became disturbed and noisy; and often was restless, destructive and filthy; when he walked, his gait was very ataxic. The autopsy examination revealed shrinkage of the cerebral convolutions, especially in the anterior parts.

Case 14, white male, was admitted at the age of 33 years, and lived 8 months; his mental disease was evident for more than 2 months previous to his admission.

The medical certificate stated that the patient's father died of tuberculosis, but this was the only interesting point in the family history. A comrade reported that the patient had acted

peculiarly for several months. The patient denied that he had used alcoholic liquors. He showed tremors of the lips, tongue and hand, difficulty in speaking, some impairment of intellect, muscular weakness, diminished knee jerks, and Romberg sign. The Wassermann reaction with the blood serum was completely positive, the cerebrospinal fluid contained 145 cells per cu. mm. On admission the patient would not talk, and his lack of co-operation prevented a careful examination of his mental condition. He had a very stupid, blank expression, stood or sat in a stiff, unnatural position until told to do somethig; several times he rose from his chair and started towards the window as if governed by some idea, but at command he readily resumed his seat; jerkings of different muscles were observed; if undisturbed, he closed his eyes as if going to sleep; he did not apparently know how to hold a pencil and his first efforts at writing were scribbles; his movements at unbuttoning his coat were incoordinate; there was no evidence of apparent purposefulness in any of his movements; his attention was obtained and held with difficulty; he appeared to know the name of the Hospital; on account of his non-coöperation it was impossible to determine anything about the character of his memory, or the presence of hallucinations or delusions. Later it was noted that he was tidy, disoriented for time, place and persons, his memory was very poor; he could not find his bed, etc.; he did not answer questions readily and seldom talked. He was confined to bed and died of exhaustion. The autopsy revealed shrinkage of the anterior cerebral convolutions, hypostatic pneumonia, interstitial nephritis and purulent cystitis.

Case 15, white male, was noted for one month previous to his admission to exhibit signs of mental abnormality; his age was 38, and he lived in the Hospital for 1 year and 6 months.

The family history obtained from the patient contained nothing of importance. The medical certificate accompanying him stated that he had syphilis six years previously, but this was denied by the patient; the Wassermann reaction with the blood serum was complete positive, also with the cerebrospinal fluid;

the number of cells in the cerebrospinal fluid was 16.5 per cu. mm. The patient had tuberculosis during his residence in the Hospital. Previous to his admission his ward mates in another institution had complained of his irrational conduct and conversation. He had a feeling of well being and of importance, with delusions of grandeur, but no delusions of persecution or hallucinations; in addition to the tuberculosis it was found that the patient's pupils were unequal, the left reacted neither directly nor consensually to light stimuli; the patellar reflexes could not be elicited; coördination was good, there was a slight Romberg sign and wavering gait. He was oriented for place and persons, and mostly for time; his general memory was poor for both recent and remote events; he could not tell the times and places of his occupations; he showed no insight into his condition and said he thought his admission into the Hospital was a "frame-up"; an occasional slight buzzing in his left ear was the nearest to an hallucination that was detected; and no delusions other than that recorded above; his general intelligence was poor; he was irritable, easily angered when questioned and swore fluently; in general, he appeared to be happy; he emitted loud screams occasionally, but no reason for these could be obtained; his writing was ataxic, his speech was tremulous; he became untidy in habits; did not talk voluntarily; he became much demented and enfeebled. Death was due to pulmonary tuberculosis. The examination of the brain showed that the convolutions were shrunken over the anterior half.

General Paralysis of the Insane, Discussion

Of these six cases, three had atrophies in the frontal region and three were of the anterior portions of the cerebrum. Only one of these has been described as showing a great degree of atrophy, viz., case 12. All of these patients showed a very great degree of dementia previous to death. The one who seemed least demented was case 13, although the degree of dementia can not be determined with accuracy. It is of interest to note that the total duration of the disease in this patient was longer than in the other five patients, and the dementia

appeared to be more gradual in its appearance. With this case there should be compared case 14, who lived less than a year after the first signs of mental abnormality. Most of these patients towards the end lived practically a vegetable existence; they were oblivious of their surroundings; they reacted little, if at all, to ordinary stimuli and were apparently unable to comprehend anything. These general mental conditions which are found in all cases of paresis are not, however, correlated with the degree or with the extent of the atrophy of the brain, for the patient (case 15) whose brain showed the greatest amount of atrophy was no more demented than the other patients at the time of death, nor was the patient (case 12) whose brain showed the greatest degree of atrophy any more demented than the other patients. Both of these cases showed an extreme degree of dementia, and in this respect they differed not at all from the other cases (with the possible exception of case 13, which is mentioned above).

It is to be noted that all of the patients exhibited motor derangements. With the exception of case 15, tremors, especially of the lips, tongue and hand, were found. Case 15 did not show tremors of these parts, although his writing was tremulous and associated with this there was a certain degree of ataxia. It does not appear, however, that the ataxic gait and the inability to walk steadily and to perform other necessary movements were any greater in those patients who exhibited lesions extending beyond the frontal lobes, and in this respect we find no definite correlation between the atrophies which included the electrically excitable (*i.e.* motor) portions of the cerebrum and those which did not extend as far backwards. Only one of the six patients had had convulsions, case 10, and this patient it will be remembered was a case in which the frontal regions were atrophied. On the other hand, two of the patients (cases 10 and 12) developed contractures, and it is of interest to note that both of these were cases of frontal atrophy. Periods of confusion or of bewilderment, which are probably similar in nature to the convulsive seizures, were noted in cases 10, 11 and 12, and in one of these (case 11) such a condition was at

one time preceded by a period of unconsciousness. These three cases were those in which only frontal lesions were discovered.

The affective states in these patients were not similar. In general, although they appeared contented, some had feelings of exaltation, and at times some were depressed. Cases 10 and 11 appeared to be almost continually contented and cheerful. Case 15 appeared to have feelings of contentment, of well-being, and of self-importance at practically all times, and, although he complained of having been sent to an institution and called it a "frame-up," his remarks about this matter appeared to have little affective accompaniment. On the other hand, patient 14 appeared to be indifferent, and the only evidence of worry or depression on his part was his disinclination to talk and his lack of coöperation. The reasons for the impulsive tendencies which were noted in his case were not learned, but these were not accompanied by noticeable emotional reactions. Patients 12 and 13 showed variations in affectivity, for they ranged from sullenness, moroseness and homicidal tendencies to those of cheerfulness and exaltation. It will be observed that these variations are not associated with particular lesions, and that similar variations in emotional or affective states are found associated with the more extensive as well as with the frontal atrophies.

In none of these patients were hallucinations noted at any time, with the possible exception of case 15, who had complained of a buzzing in his ear. Whether this was due to a peripheral or a central irritation could not be determined; it did not apparently lead to any interpretative elaboration, and because of this it may be disregarded.

Case 14 showed no evidence of the presence of a delusion at any time. The other five patients were noted to have delusions of grandeur or of persecution, although these were most frequently mild in character and those of some of the patients were not much beyond the scope of the individual's life. In a few instances the delusions were of a very fantastic and absurd character, notably those of patient 10. It appears remarkable, however, that with the exception of the temporary and unsystematized

delusions regarding the race horse (case 11), the possession of houses and diamonds (case 13), and some of grandeur, of which the nature was not specified (case 15) and which were noted only previous to his entrance to the Hospital, these evidences of mental abnormality were not prominent in these three cases. Moreover, it may be mentioned that some of the delusions of patient 12, *e.g.*, those which were evidenced by his complaints that various people were trying to get his money away from him, were not too far out of bounds, and might not have been delusions in the strict sense of that term. In this connection it must also be remembered that with the possible exception of the delusion regarding his retention in the Hospital, which he described as a "frame-up," patient 15 did not show any evidence of delusions during his Hospital residence of about eighteen months. We are led to conclude from the facts which have been recorded that these mental symptoms do not appear to be concomitants of special extent, or of special degree, of atrophy of the anterior regions of the brain, and that delusions, in cases of paresis at least, may not be due to the cerebral changes in the frontal lobes.

It is of interest to note that in these cases the memory differed very greatly. Although the memory of all was very poor during the later weeks or months of their Hospital life, in some cases, even at times when the other evidences of abnormality were plain, *e.g.*, delusions, it was noted that the memory for remote and recent events was fair. Thus, case 10 appeared to have a remarkably good memory for the events of his past life and even for other events which did not so immediately concern him, although his delusions regarding his wealth were very absurd and in this respect his judgment was very defective. Regarding case 14, no information could be obtained on account of his lack of coöperation. The memory in the other four cases may be said to correspond in general with the degree of dementia, although not with the extent or the degree of the atrophy.

In most cases the degree of orientation corresponded also with the degree of dementia, and also with the degree of memory. Patient 10, who recalled quite well both recent and remote events,

was fully oriented for time, place and persons, and in general the other patients who exhibited memory defects were not oriented. One exception to this general statement is patient 15, who, although he could not recall much of his own personal history, was well oriented for place and for persons and also exhibited fair orientation for time. It may also be noted that patient 14, whose lack of coöperation has been mentioned, appeared to know where he was.

At the time of their admission to the Hospital the attention of these patients could be readily obtained, and, in two cases, 10 and 13, it was noted that they could attend to things well. The latter patients understood what was said to them and could carry on a conversation coherently and relevantly, and appeared to be able to attend to such impressions as they received. Cases 11 and 15 also exhibited a fair degree of attention ability, although at the same time it was noted that their memory was defective. On the other hand, case 12 was apparently unable to attend to things well, for he is noted to have been unable to attend to what was said to him or to comprehend readily, and case 14 also exhibited a similar difficulty of attention. These variations, like those in the dementia precox group, are not associated with the special lesions.

These six cases of paresis do not differ extensively from one another in symptomatology, although they may be differentiated as belonging to the simple dementing form (*e.g.*, case 14) or to the expansive form (*e.g.*, case 10) of the disease. Although the symptoms in these cases are more nearly equal than in the cases of dementia precox, the differences are also sufficiently evident to make possible a comparison with the difference in the extent of the lesions. It appears, however, that the symptomatological differences are not to be correlated with the anatomical differences in the extent or the severity of the anterior atrophies. Those patients who exhibited only frontal atrophies were, apparently, as markedly demented, they showed about the same degree of emotional or affective change, and they exhibited lack of memory, of orientation, of attention, and of comprehension to about the

same degree as those cases in which the atrophy extended beyond the limits of the frontal lobes. On the other hand, it appears equally probable that with frontal or with anterior atrophies some paretic parents will exhibit a fair degree of memory and others an almost complete loss of memory, that some will have fantastic or persecutory or grandiose delusions and others will have none of these. It is apparent, therefore, that with comparable lesions the symptoms may differ, and that with lesions which do not even approximately correspond the symptoms may be similar..

ARTERIOSCLEROTIC DEMENTIA, CLINICAL HISTORIES

Case 16, white male, was admitted at the age of 63, and died 7 years and 4 months later.

The diagnosis on admission was acute confusional insanity, intoxication psychosis; the duration was given as three months plus; he was noted as having used alcohol only moderately; the medical certificate stated that he burned papers on the floor of his room; frequently wandered around aimlessly at night; showed loss of memory, with all the symptoms of senility; had fixed transitory delusions, one of his fixed delusions being that he was "still in active service in the army, but at that time on furlough"; he was disoriented for time; he made meaningless remarks. His family history was negative. On admission he was disoriented for time; appeared perfectly satisfied with his surroundings; showed only a slight amount of insight; he was up and about the ward; his expression was placid; he was poorly nourished but there were no physical or neurological abnormalities. His intellect and memory were defective; his attention could be obtained and held without difficulty; he was quiet and orderly; he appeared to be much demented, and seldom spoke unless addressed; he remained seated in one place in the ward the greater part of the day; he comprehended readily, and his replies were given promptly and were relevant and coherent; no delusions or hallucinations were elicited. Later he claimed that some one put laudanum in his beer, and that this had doped him and caused him to be sent here; when asked if any one had put poison in his food since he was in the Hospital, he said it was not for him to say, he became indignant, his face flushed, and he said he had a right to his beliefs; a speech defect was observed. For over a year previous to his death he was confined to bed; he became disturbed and excited if he did not get the things he wanted; he thought some one had

stolen his money, hidden his clothes, and imposed upon him in various other ways; his memory grew more defective, and he was unable to give the name of the institution; he thought some one was sending electric currents through him, and that these caused contracture of his fingers; his feet and legs became contracted about six months before his death.

The autopsy showed atrophy of the frontal convolutions; there was left bronchopneumonia, and the kidneys showed a slight degree of swelling and some inflammation.

Case 17, white male, was admitted at the age of 65 and subsequently lived for a little over a year.

His family and personal history was negative; the medical certificate stated that the patient had been nervous and talked at random about large amounts of money he thought he was going to get from people in England; he made all kinds of absurd statements; he asked to have his feet and toes amputated; he could not carry on a connected conversation and he attempted violence upon other inmates in the Soldiers' Home in which he was. On admission to the Hospital he was restless most of the time; he would not sit for even a few minutes in one place; he appeared to be profoundly demented; he was disoriented; his memory was markedly defective, and his talk was disconnected and incoherent; coarse tremors of the tongue were noted; the pupils reacted slowly in accommodation, and the superficial reflexes could not be elicited; his coördination was fair; physically he showed signs of cardiovascular renal disease and pulmonary tuberculosis.

In addition to these the autopsy showed marked shrinkage of the brain, especially in the frontal regions.

Case 18, colored male, 73 years old at the time of admission, lived for about 1 year subsequently.

The certificate accompanying the patient stated that he had impaired cerebration, and for the preceding six years there had been a tendency on his part to wander away. On his admission

to the Hospital he was found to be enfeebled; he was restless; the only thing that could be elicited from him by questioning was his name; he was disoriented; he talked very indistinctly; he seemed to be very much demented; he was tidy in habits; spasmodic laughing and crying and negativistic tendencies were noted; he showed perseveration; his voluntary acts were apparently purposeless, and his movements were inaccurate; neurologically, there were no atrophies found; a slight arcus senilis was present; there were marked tremors; his gait was slow and unsteady, and his walk was shuffling; he was noted to have some ataxia; although a right homonymous hemiamopia was noted in the history, this was not detectable at a later date and may have been surmised because of special acts due to his negativism and his general mental inertia; sensory and motor aphasia were also noted; smell was diminished; there was a diminished sense of temperature and a hypoalgesia; he was untidy in habits and he could not find his bed; he took no interest in his surroundings, and at the time of his death he was in a condition of extreme dementia.

The autopsy revealed shrinkage of the cerebral convolutions, especially in the frontal lobes, pachymeningitis, slight arteriosclerosis of the basal vessels, valvular heart disease, atheromatous aorta, congestion of the kidneys.

Case 19, white male, was admitted at the age of 62 and lived 16 years. At the time of admission no information was received regarding him except that the diagnosis of "acute mania" had been made.

In the Hospital he was orderly and quiet and assisted with the ward work; he was fond of reading; he spoke very little voluntarily, but answered questions readily; he was untidy in appearance, and he collected and filled his bed with trash; he was very childish; at times he talked almost incessantly. Later he was noisy and restless, somewhat destructive and untidy, and he became hypochondriacal, and sometimes had to be restrained but at other times he associated with the other patients and played games with them; he comprehended what was said to

him; he was coherent and relevant in his conversation, but his reasoning and judgment were limited; his memory was poor for recent events, but he appeared to take considerable interest in his surroundings, and was oriented in all spheres; his station was good but his gait was rather unsteady; there was noted a slight double cataract and double arcus senilis.

The autopsy revealed internal hemorrhagic pachymeningitis, shrinkage of the anterior convolutions but no other gross cerebral lesions, sclerosis of the aorta and of the cerebral basal vessels, pulmonary tuberculosis and pneumonia, and intestinal tuberculosis.

Case 20, white male, age 72 on admission and lived for 1 year and ½ month. He had been gradually losing his mental faculties for a year, and while in another institution he had been unable to find his bed and to take care of himself; he was disoriented and confused, and had no insight.

There was fine tremor of the tongue; pupils were slightly irregular in outline; the heart was somewhat enlarged; there was a coarse tremor of the right arm; the tendon reflexes could not be elicited; station and gait were greatly impaired. He was not oriented for time, place, or person; his memory for recent and remote events was very poor; emotionally he was apparently indifferent; there was no insight; no hallucinations or delusions were detected; the patient was quiet, feeble, and was agreeable and rather childish in his reaction; three or four days before his death he could not move his left arm and leg; the tongue was protuded slightly to the left; there was Babinski phenonema on the left; whether or not this attack was accompanied by a convulsive seizure is unknown.

The autopsy showed shrinkage of the frontal lobes; hemorrhage was found in the Rolandic region; in the left occipital lobe there was an old softening affecting this part; the heart valves were insufficient, and the heart enlarged; and parenchymatous nephritis.

Case 21, colored male, 65 years old at the time of admission and lived 3½ years subsequently.

The medical certificate stated that the patient had been normal until a few years previous to his commitment; he had bad memory and did not seem to remember anything; he was disoriented for time and place; he was restless, he talked senselessly; his reasoning was bad; and he appeared to be excited. The physical examination showed bronchitis, sclerotic superficial vessels, feeble heart sounds, no tremors, coördination was good; he had a poor grip; there was a slight arcus senilis with some visual impairment; no speech defect was observed. On admission he appeared to be senile; he was quiet and tractable; he showed some confusion and marked clouding of consciousness; he was disoriented; his attention could not be held; his memory was poor; his conversation was rambling and incoherent, and he usually answered incorrectly; no definite evidence of hallucinations or delusions was obtained, but he appeared to be suspicious that he was to be harmed in some manner; at one time, however, he said that colored people had been after him and almost scared him to death, but that white people came to his rescue; and later he also spoke of his farm and sheep having been stolen, etc.; at times he was restless and wandered around aimlessly, talking in a rambling manner; he became untidy in habits; he was very restless, and asked that he be permitted to go to his work.

The autopsy revealed atrophy of the anterior convolutions, sclerosis of the basal arteries, dilated heart, and chronic cystitis.

Case 22, white male, was 70 years of age on admission and lived for only 1 month subsequently.

His mother had been insane and confined in a hospital; otherwise, his family history was negative. The patient always had been a heavy drinker and occasionally he had a prolonged period of intoxication; he had been treated for dipsomania a number of times and six months prior to his entrance to the Hospital, following a lengthened drinking spree, he became quarrelsome and abusive; he thought other men were putting lice into his

bed and trying to injure his reputation in other ways; he threatened them; he believed he was in command and ordered those about him to do things for him; he heard voices of women and of his superior officers talking to him and he replied in a loud boisterous voice. Physically his muscles were of poor tone; his coördination was fair; his station and gait were unsteady, and his apparent delusion regarding lice may be explained by the fact that these vermin were actually found upon his body; he was neat and tidy in appearance; he was disoriented; he had no insight; his general memory was fair; there were auditory hallucinations of voices, but he would give little information about the voices, people, or what was said to him; he became irascible; swore frequently and fluently; he thought everything in the ward belonged to him; he gave orders to others to attend to the horses, etc.; and he conversed with imaginary people out of the window.

The autopsy showed that the convolutions were atrophied anteriorly; there were also atheroma of the aorta, cystic kidneys, interstitial nephritis, and cystitis.

Case 23, white male, was admitted at the age of 47 and lived 1 year and 7 months subsequently.

At the time of his admission no medical certificate was received and no previous family history was obtained; at first he was diagnosed as an unclassified psychosis, but on account of the pathological findings this was changed to arteriosclerotic dementia. On admission he appeared to have no use of his legs from his knees downward; he said he knew he was going to be killed and burning was the way to do it; he imagined that people were talking about him, and he heard them talking about it at night; he imagined he had plenty of money; he was noisy, untidy, occasionally talkative; he continually complained about everything, and he was very irritable; he was oriented; his memory was only fair; at times he was stupid; at one time he had a convulsion affecting the right side, after which he could not talk. Later he had a convulsion principally on the left which also affected the right.

At the autopsy it was found that he had bronchopneumonia, atheroma of the coronary artery and of the aorta, nephritis, and the convolutions of the anterior half of the brain were considerably shrunken.

Case 24, white male, admitted to the Hospital at the age of 55, and lived nearly 18 years subsequently. He had been admitted to a Soldiers' Home because of a paralysis and epileptic seizures. There he attempted suicide and was violent at times.

On entrance to the Hospital he was found to be deaf; he was depressed and had many morbid fancies. Later he was noted to be feeble, quiet, orderly; he did not answer intelligently; his mind wandered; he was indifferent to his surroundings; he was completely disoriented and showed no insight into his condition; at times he became very talkative and destructive, although most frequently he was quiet and comfortable; delusions of a pleasurable nature were evident at times, and later these gave way to delusions of persecution when he talked about the property and money which had been stolen from him; there was left hemiplegia with contractures; his gait was firm and rugged for one of his physical condition, but he dragged his left leg; the knee jerks were absent.

The autopsy showed slight enlargement of the heart, hypostatic congestion of the lungs, peritonitis, ulcerative cholecystitis, granular kidneys, marked shrinkage of the brain, but no areas of softening or of hemorrhage could be found to account for the hemiplegia.

Arteriosclerotic Dementia, Discussion

Only two of these cases (16 and 20) are strictly frontal cases. Two others (17 and 18) were cases in which there was a certain degree of atrophy of the cerebrum as a whole in addition to the marked frontal atrophy. The remaining five cases were those in which the atrophy extended over the whole anterior portions of the cerebrum. Case 22 was noted to be an alcoholic case, but the relation of alcoholism to the mental disorder is not clear, and the facts which have been recorded in the history

do not give any indication that alcohol played any great part in the production of the symptoms during his Hospital residence. We may believe, however, that it was a contributing factor. Case 24 appears at first sight from the history to be a case complicated with epilepsy, but no epileptiform convulsions occurred during the period of his Hospital residence, and it seems more likely that the convulsions were of a character which later resulted in the left hemiplegia, in other words, that they were seizures similar to an apoplexy. Before death all of these patients exhibited plain evidence of dementia. They were enfeebled, childish, indifferent, confused, were not affected by their surroundings to any extnet, and most often exhibited no insight into their mental condition, etc. The two cases which showed most evidence of mental enfeeblement (cases 17 and 18) were those in which some general atrophy was found to accompany the intensive frontal atrophies, and it is possible that the great degree of dementia in these cases is to be correlated with the extension of the atrophy to the posterior regions of the cerebrum, although the atrophy in the latter areas was not of great degree. The other seven cases did not differ to a great extent in the apparent degree of dementia which was present immediately preceding death, and in this respect there can be no great degree of correlation between the extent of the atrophy and the degree of the dementia.

The physical enfeeblement probably kept most of these patients less active than would have been normal for them, and the two patients who exhibited effects of paralysis, cases 16 and 24, were especially orderly and quiet most of the time. The physical enfeeblement did not, however, prevent these patients from becoming disturbed, noisy, restless and at times excited, and these states alternated with states of quiescence and even confusion, the only exception being that case 20 (with frontal atrophy) was uniformly apparently indifferent, inactive and agreeable. Lesions to account for the paralytic phenomena were not discovered, and it may be that part of the contractures in these patients were due to disuse and not to special paralysis. In other respects every one of these patients showed variations

from the normal motor ability, both in the presence of tremors and in their inaccurate, slow, and feeble voluntary movements. Patient 18, whose brain showed some general atrophy in addition to the marked atrophy in the frontal regions, also exhibited negativistic tendencies, and at other times he appeared to be purposelessly active. This patient, it will be noted, also showed other symptoms like those of the dementia precox group in that he was noted to laugh and to cry spasmodically and without apparent reason and to show perseveration. Both the similarities and the variations in these motor symptoms in these patients do not appear to be directly correlated with the distribution of the atrophies, for the unsteadiness and the tremors and the restlessness were found equally in those with frontal and in those with the more extensive atrophies.

The speech disturbances were not as pronounced as in the cases of general paralysis of the insane. At least four of these cases could talk readily, and also coherently and relevantly, and there was no difficulty in carrying on a conversation with them, if one did not approach their delusions or in the conversation make too much of a demand to strain their memory. There was in general none of the speech defects which are so commonly found in paretics, and when the patients would and could talk, their words were usually well-pronounced. Defective speech was, however, noted in some of them; patient 16 was observed to have a slight speech defect; patient 18 was also recorded at one time to have both sensory and motor aphasia, but the diagnosis of this condition is a very doubtful one, and should be accepted, if at all, with caution, for at that time the patient was in a very negativistic mood; patient 23 also showed a motor aphasia after a convulsive attack. Assuming the accuracy of the facts just mentioned, we may believe that these conditions were due to local cerebral injuries that were, however, not discovered at autopsy, and which may have been temporary or functional. Considering only the speech ability anterior to these accidents, we find that, with the exception of case 23, the speech of all the patients was similar; at times it was almost incessant, at other times they conversed voluntarily very little

but would answer questions, and at other times it was difficult to get any information from them. In other respects also their talk was similar; two patients with frontal and two patients with anterior atrophies talked at random, or incoherently, two other patients with frontal and two patients with anterior atrophies talked relevantly and could carry on conversations on minor matters. In these respects, therefore, we find with similar atrophies quite dissimilar characters of symptoms, and with dissimilar atrophies quite similar symptoms.

The affective conditions in these patients differed widely. Of the patients with frontal lesions three varied from an indifference to a general satisfied condition, but the fourth patient exhibited from time to time spasmodic laughing and crying, but whether this alternation was accompanied by the appropriate emotional states is not sure. This reaction has previously been compared with those of dementia precox patients, and in addition it may be said that it also resembles to a certain degree the similar symptom associated with lesions of the optic thalamus, especially in view of the association of hypoesthesia for temperature and pain. One of these patients (case 16), in speaking of his delusions of persecution, did not appear to react with appropriate emotional tone to them. The other five patients, those with anterior lesions, were depressed, suspicious, irascible, and quarrelsome, with more normal or more contented, or indifferent, intervening periods. Four of the latter group (patients 21, 22, 23, and 24) had corresponding delusions, and their affective states were associated with and corresponded with these other mental derangements. Patient 19, on the other hand, appeared hypochondriacal without apparent reason, for if he had delusions, they were not made evident (see below), and no hallucinations were discovered. Whether or not the greater frequency of particular types of emotional reactions and of special feelings is to be definitely correlated with the more extensive lesions can not be determined. That the general atrophy in cases 17 and 18, which it will be remembered was associated with a more marked degree of frontal atrophy, did not produce similar affective states is an indication that the special emotional con-

ditions, which superficially appear to be definitely associated with the anterior lesions, are better interpreted as chance occurrences, and that in a more extensive series they would probably not be found in as great proportion. This conclusion also appears more likely in view of the results which have been found in the other diseases which have been studied.

Only one-third of these cases gave evidence of hallucinations. These were cases 16, 22 and 23. Apparently case 16 had paresthesias in the fingers, for he complained that electric currents were sent through him so that they caused contractures of these parts. Regarding the other delusions of which he complained, viz., that he had been doped and that laudanum had been put into his beer, it is more difficult to judge whether these were purely ideational delusions or delusions due to paresthesias. The auditory hallucinations of patients 22 and 23 were very evident, but when patient 22 conversed with imaginary people outside of his window, it was not certain that the hallucinations were entirely auditory. The peculiar requests of patient 17 that his feet be amputated might be due to hallucinations, but this was not determined. Those patients who had sensory defects (patient 24 with deafness, patient 21 with visual defect, and patient 18 with hypoesthesia for smell, temperature and pain) did not apparently have hallucinations either in these fields or in others, nor did patient 20 in whose brain a small softening was discovered in the left occipital lobe. These facts do not indicate any definite relation between the mental conditions and the extent or degree of the cerebral atrophy.

There appears to be no more direct connection between the presence or the character of delusions and the atrophies of the anterior portions of the cerebrum. Patients 18 and 20 did not have delusions which were detected, and one of these (case 18) will be recalled as having had general as well as the well-marked frontal atrophy, the other being a simple frontal case. The other two patients with frontal atrophies did have delusions, some of the delusions in both being allied to hallucinatory phenomena, although a conclusion regarding this relation can not be stated with definiteness. The delusion of patient 16 that

he was still in active army service was probably a filling-out due to memory defects, but those regarding the loss of money, the action of electric currents and the presence of poison in his food are probably not due to this failure of memory, nor do the delusions of patient 17 regarding the money which he expected from England appear to be restrospective interpretations. It can not be said with certainty that patient 19 did or did not have delusions; the fact that he collected and attempted to fill his bed with trash indicates that he believed this to have some value or to have some relation to himself, but information on this point is totally lacking. The other four patients, all with anterior lesions, had delusions of persecution which with the exception of those of patient 21 alternated with mild delusions of grandeur.

All of these patients showed defective memory, and although it is almost impossible to determine the degree of the defect in the individual cases, the general reactions of patients 16, 17, 20 and 21 would lead to the conclusion that they were more abnormal in this respect than the other four cases. Four of these patients, it will be noted, are cases of frontal lesions, and the memory defects seem to be correlated with the degree of dementia, since it has already been mentioned that two of these (cases 17 and 18) were profoundly demented. The other two frontal cases, patients 16 and 20, were confused and bewildered and in their cases the memory defects may be either evidence of the confusion or the result or the concomitant of these conditions.

In marked contrast to the character of the memory is the orientation of the individual cases. Patients 17, 18, 20, 22, and 24 were completely disoriented; patient 16 was disoriented for time; and patient 21 was disoriented for time and places. The partial orientation of patients 16 and 21 is the more remarkable in view of their poor memory, and the good orientation of patients 19 and 23 is also to be contrasted with the degree of memory loss. The latter two cases, it will be recalled, are cases of anterior lesions, and this fact indicates that even with such extensive changes orientation for time and space may be retained.

Not much more can be said regarding the other mental pro-

cesses directly, although indirect information is obtainable in the case histories regarding the patients' ability to attend to impressions. In general, in these cases of arteriosclerotic dementia there remains considerable ability to attend to impressions, as has also been shown experimentally, and this ability appears to be independent of the memory disorder. Even though the patient was apparently very much demented or even confused, his attention could usually be obtained without difficulty, and this was noted especially for cases 16, 19, 20, 22, and 24. At times patient 23 appeared stupid, i.e., his attention could not be obtained, and although the attention of patient 21 could be obtained it could not be held. Whether or not we shall interpret the perseveration of patient 18 as "good" or "poor" attention can not be definitely settled; there is sufficient ground for either conclusion. The fact that with either frontal or anterior atrophies there may be good ability to attend is an argument against the supposition of an "attention function" for the frontal lobes, and the fact that the ease or difficulty of attracting the attention did not differ in accordance with the extent of the lesions which are here considered is evidence that direct correlation does not exist.

The variations in the mental processes which have here been considered permit the conclusion that neither the extent nor the severity of the atrophy of the anterior regions of the brain in arteriosclerotic dementia is directly correlated with the mental symptoms, and they also show that with similar atrophies dissimilar symptoms may be frequently encountered in different patients.

SENILE DEMENTIA, CLINICAL HISTORIES

Case 25, white male, aged 63 on admission, had been admitted in an obviously insane condition to a Soldiers' Home 4½ months previously, and lived 13 months subsequent to his admission to the Hospital. In the Soldiers' Home he was very restless, constantly wandered about, exhibited a defective memory, was careless of his personal appearance, and imagined that strangers were relatives who had been dead for years. Physically there were incontinence of urine, chronic cystitis, and marked tachycardia. No family or previous personal history could be obtained. Neurologically, there was tremor of the extended hands and protruded tongue, most of the tendon reflexes were exaggerated, coördination and station were good, the larger voluntary movements were fairly accurate and exact, but his handwriting was very shaky. He smiled and laughed spasmodically and without apparent reason, and without any apparent emotional accompaniment; he responded very poorly to the routine mental examination, forgot the questions which were asked, and showed little memory for his past life and what information he gave was apparently incomplete and inaccurate; he could not find his bed; he appeared to have no intelligent understanding; he had no insight into his condition; no hallucinations or delusions could be elicited; he was disoriented in all fields, and addressed patients and others by names not theirs, apparently thinking them friends or relations; he was so untidy that he had to be cared for in bed. Death was due to hypostatic pneumonia. In addition, the autopsy showed; chronic cystitis, nephritis, hemorrhagic enteritis, heart valves atheromatous, and circumscribed atrophy of the frontal lobes, but no other cerebral lesions. The clinical diagnosis was arteriosclerotic dementia, but the miscroscopical examination of the brain showed senile changes and did not confirm the clinical diagnosis, and the case is, therefore, included in this section.

Case 26, white male, had been noted as insane for 10 months previous to his admission at the age of 67; Hospital residence was 8 months. The signs of insanity noted on the medical certificate were: the patient wandered away from the ward, tore his clothing, he showed mental confusion, impairment of memory, occasional maniacal manifestations, incoherent talk, and was sleepless. The account he gave of his family and past life was incomplete but negative. Physically he had hypertrophied heart, superficial arteriosclerosis, slight arcus senilis, his hearing was impaired, the tendon reflexes were mostly exaggerated, and there was a tremor of extended fingers. He was kept in bed as much as possible, and at first was quiet and orderly, coöperating well. The mental examination showed a total lack of orientation, no insight except that at one time the patient said that if the questions had been asked a month previous he would have been able to answer them; his memory was very poor for recent and remote events; the only evidence of a delusion was his statement that he had been robbed of thousands of dollars; his talk was disconnected, but his speech was good. Later he became restless, fumbled with the bed clothing, was noisy, sang loudly, laughed and talked to himself, usually calling to horses, as if he were taking care of or driving them, and advising those around him to get out of the way or the horses would run over them; he pulled the bed clothing and his remarks were apparently due to ideas that he was driving; he took off his clothes and went about his room naked; apparently did not know how to put them on, for he was found putting his shirt over his legs. The autopsy showed shrinkage of the convolutions of the frontal lobes, but no other gross cerebral lesions; heart valves atheromatous, hypostatic congestion of the lungs, congestion of the stomach, intestines, liver, spleen and bladder, and slight fibrosis of the kidneys.

Case 27, white male, as an inmate of a Soldiers' Home was considered to be senile for nearly two years previous to his entrance to this Hospital at the age of 87, where he lived 2 years and 5 months.

The medical certificate stated that he was careless of his personal appearance, was childish, and, unless confined, wandered away and became lost. Physically he was very active for one of his age, and was in good general health. He showed, however, a beginning cataract in both eyes and was very deaf; there was sclerosis of the superficial arteries, the muscles were small (atrophied) and their force was slight, but movements were accurate and quick; there was a fine tremor of the extended hands; gait was normal and coördination was good. He was quite cheerful; he wandered about the wards in an aimless manner; he slept wherever he happened to sit down; he was untidy in habits; he lost his way on the ward; he was completely disoriented; he seldom spoke voluntarily, but answered cheerfully; he was inclined to be argumentative, especially regarding religious topics; he showed marked humor; occasionally he was excited and disagreeable and fought with other patients; he persisted in keeping his clothes on night and day; his memory was impaired, but he talked intelligently about historical events of which he had read; he spoke of $1,000 which he believed he had and which he wished to get so that he could go to his friends; this was the only near-delusion which was elicited. Death was due to cardiovascular and renal diseases; the autopsy also showed atrophy of the frontal convolutions, arteries sclerosed, emphysematous lungs and consolidation of the right lung, nutmeg liver.

Case 28, white male, was noted to have mental enfeeblement 4½ months previous to his admission at the age of 71; he lived 10½ months.

Neither family nor previous personal histories could be obtained on account of the patient's condition. There were no previous attacks known, and the first signs of mental enfeeblement became evident only a few months before his entrance to the Hospital. Alcoholism was given on the medical certificate as a probable cause of his condition, which was noted to be a "confusion." He believed himself to be on board a ship, persecuted, without his rights and often asked when he was to

be murdered; he also had hallucinations and threatened to commit suicide; he was quiet and unassuming. Neurologically, hearing was much impaired, a slight degree of arcus senilis was present, and the right pupil was smaller than the left; there were slight tremors of the fingers; skin sensations were somewhat impaired; all tendon reflexes were very much diminished with the exception of the biceps. He was disoriented for time, place, and persons; his memory for even the general events of his life was very uncertain; his remarks were almost unintelligible; but he appeared to have some insight, *i.e.,* he said he thought his mind was affected in some way; he took no account of the time or condition of things, he complained of the weather being snowy and cold when it was bright and warm, and he inquired why he was without shoes and clothes with the snow up to his knees; he denied having hallucinations; he also said he did not mind the snakes, but he was afraid of the big alligators lying flat with their eyes down; looking up at the ceiling he talked at imaginary people, and his remarks could not be understood, except that he swore and became very excited and sang and shouted. At one time he was found to have a twitching of the eyelids, and later the left and then the right arm were noted to be twitching (convulsion?); after this the Babinski phenomenon was present on the left, and he moved the left hand more than the right. The autopsy showed that the right hemisphere was shorter than the left, and there was slight shrinkage in the left frontal region; no other gross cerebral lesions were observed; the heart was dilated, with few atheromatous patches on the valve leaflets and on the aorta; pulmonary tuberculosis and hypostatic congestion; nephritis. The micoscopical examination revealed senile changes, although the primary clinical diagnosis had been arteriosclerotic dementia, and the case is therefore classed with the senile.

Case 29, colored male, his age on admission was 69, the duration of the mental disease was not given, but the patient had been in this Hospital for more than four years with a mental disturbance, the nature of which is not clear on account of lack

of clinical data, 13 years previously. He lived only 2 months subsequent to his second admission.

No family or personal history of value could be obtained, although his previous residence in the Hospital is known. The medical certificate stated that he exhibited delusions of wealth, was slovenly in his appearance, sang and danced for hours, but at times was irritable and quarrelled with others, and was unable to repeat test phrases. Syphilis was given as a probable cause of his condition, but a subsequent Wassermann test was negative. When received he complied with all requests willingly; he was extremely talkative, spoke well and intelligently; told how extensively he had traveled and recalled every place and event of importance, and his memory seemed to be accurate and exact; he spoke a few foreign phrases and thought he could talk several languages; he was bright and alert, was ready to talk when spoken to and ceased when requested and this without apparent offense; he was restless and wished to be doing something all the time; he denied having hallucinations, and his ideas of wealth were not out of proportion to his station, although previous to his admission he had peculiar ideas regarding some financial dealings with others; he jumped from one topic to another in his conversation; he was well oriented for place and persons, but not well for time; he appeared to have some insight into his condition for he said he was a "bit excited" on his admission and that his memory was not good. He said he had fallen from the seventh-story window thirty-four years previous to his admission and suffered from "concussion," and had been bothered with this more or less ever since. His feet were swollen and the skin over them was glazed, there was marked dyspnoea, radical arteriosclerosis, double arcus senilis, great emaciation, pulmonary tuberculosis . The autopsy showed slight frontal shrinkage, but no other cerebral lesions, valvular heart disease, atheromatous aorta, tubercular lungs, hypostatic pneumonia, nephritis. The miscroscopical examination showed marked senile changes in the cerebrum, especially in the frontal lobes although the clinical diagnosis was arteriosclerotic dementia (maniacal excitement).

Case 30, white male, was 65 at the time of admission and had exhibited mental disturbances for a year previous; he lived 13 years and 2½ months.

The medical certificate stated that he was admitted to a Soldiers' Home for various disabilities, including nervous prostration, at the age of 54, and he was placed in the insane part of the Home a few months previous to his admission to the Hospital, on account of "delusional insanity." It was noted that he was quiet and depressed; his memory was imperfect and his perceptions were impaired. On admission he appeared deeply depressed, he was quiet, and apparently he took no interest in his surroundings; evidences of delusions or of hallucinations were not found, but he constantly asked questions about words which he found in the books and papers he read, and figured a great deal on paper about them. At times he was cross and disagreeable to other patients and fought them, and was very noisy in the halls and had to be secluded. He appeared to have peculiar ideas about politics, taxation, the coinage of money and the money question, but it was difficult to understand what he meant; he drew maps of model towns and sent them to different people to have them adopted; he talked freely; he was tidy and cleanly. Later he took no interest in his surroundings and the peculiar ideas noted above became exaggerated and further elaborated; he also thought that the patients carried electricity around with them and shot it into him so that he was prevented from urinating, or that they hypnotized him and played witchcraft upon him; he was described at different times as being "completely disoriented" and "completely oriented," and as having a "good memory" and a "poor memory"; he stated that at night when he was alone and in bed he used to hear the voices of his enemies speaking on political matters; he wrote incoherently and almost incessantly. His gait was slow, there were no paralyses, the radial arteries were sclerosed, general tremors were present. Death was due to chronic bronchitis. The autopsy also showed: atrophy of the anterior cerebral lobes; atheromatous aortic valves, consolidation of the right lower lung; chronic cholecystitis; chronic inflammation of the liver, spleen, kidneys

and bladder. Three clinical diagnoses were made at different times: (1) undifferentiated psychosis (dementia); (2) paranoid state associated with arteriosclerosis; and (3) senile depression.

Case 31, white female; 77 years old at the time of admission; she lived 8 years and 3 months subsequently; the duration of the mental disease at the time of admission was not learned.

No family or previous personal history, and no physical, including neurological, examination accompany the records, although on admission it was noted that her health and condition were good for one of her age. She was much confused and wandered around the ward in an aimless manner; she was free from delusions and hallucinations; she was forgetful and easily irritated, and childish and dependent in manner; she was tidy in habits. A year after her admission she had an epileptiform convulsion, which left her very much confused and reduced mentally but did not result in any paralysis. Epileptiform convulsions were present at irregular intervals, and previous and subsequent to these she became confused. Three years after her admission to the Hospital she was noted to have many delusions, especially those of great wealth, that the attending physician was her son, that she was going to will him a great deal of property; she often said she had just been visited by her relatives; she thought at times she was Queen Victoria, and at other times that the Queen was her best friend. She was noted to be picking imaginary objects from the floor and said she was gathering money there. She became hypochondriacal; her memory was defective; she lacked insight; there was poverty of ideas; she was disoriented; and her reasoning and judgment were impaired. For fifteen months before death she remained in bed helpless, totally indifferent to her surroundings; she never initiated conversation, and answered only in monosyllables. The autopsy showed that the convolutions of the anterior lobes were markedly shrunken; in addition there were sclerosis of the aorta, mitral and aortic valvular lesions, purulent bronchitis, interstitial nephritis and chronic cystitis.

Case 32, white male, admitted at the age of 74. The duration of his mental disturbance previous to entrance to the Hospital was not recorded. He died in 6 months.

This patient was admitted to a Soldiers' Home where he was found to have emphysema, spinal curvature and an old fracture of the ribs on the left side. While in that institution he had a slight fever and delirium which were thought to be due to gastritis, and following this he was noted to show evidence of dementia. He talked incoherently; he wandered around the ward and tried to get out; he was unable to find his bed, and constantly disturbed other patients by getting into their beds; he had "no conception of anything." Physically, he was poorly nourished, the mitral and aortic valves of the heart were slightly involved, there was sclerosis of the superficial vessels, there was bilateral arcus senilis; the pupils were unequal and irregular, the right gave the Argyll-Robertson reaction; there was tremor of the fingers; the tendon reflexes were not elicited; the Wassermann reaction with the blood serum was negative. He appeared to have no insight into his condition, but at one time he remarked there were things in his mind he knew were "not right"; emotionally he was indifferent; he was disoriented for time, place and persons; his memory was greatly impaired; he was unable to find his seat in the dining room or his bed at night; he was up and dressed and was fairly tidy; as a rule he was quiet and orderly, but later became very much confused, restless and untidy in habits. A right lobar pneumonia developed, from which the patient died; at the autopsy there were also found: cerebral convolutions atrophied anteriorly; calcification of the aortic and mitral valves; atheromatous arch of the aorta; tubercular scars in the left lung; liver and spleen somewhat cirrhotic; cortices of kidneys markedly thinned.

Case 33, white male, admitted at the age of 79, had been observed for over a year to show signs of mental impairment, and lived for 7½ years after admission.

The medical certificate stated that he had an uncontrollable temper, had hysterical attacks, delusions of persecution and loss

of memory. Physically there were: slight peripheral arteriosclerosis; hearing was very much diminished; the voluntary movements were normal in accuracy and rapidity, but they lacked force; the knee jerks were absent. The family and previous personal history was poor because the patient's memory for recent and remote events was defective and what was obtained showed nothing of interest or importance. The patient's expression was stupid, he was rather untidy, he appeared to be simple-minded and rather childish; usually he was good natured, happy and contented, but at times he was irritable and abusive; he was very industrious making baskets which he tried to sell; he talked and associated with the other patients in a normal manner; his memory for recent and remote events was not good, but, on the other hand, was not entirely absent; he conversed coherently, relevantly and freely; he was oriented, showed fairly good judgment, but exhibited no insight. Fluid accumulated in the abdomen and for this he was tapped twice, but died. At the autopsy the chief findings were: fifteen liters of fluid in the abdominal cavity; marked sclerosis of the abdominal aorta; peritonitis; sclerosis of the liver and kidney; and marked shrinkage of the anterior cerebral convolutions.

Case 34, white male, exhibited mental changes for nearly 3 years previous to his admission to the Hospital at the age of 80; and lived 1 year 2½ months subsequently.

The patient's family history and the account of his previous life were not well obtained, but what was learned was unimportant. The medical certificate reported him to be childish, restless, inclined to wander away and become lost. His general attitude was one of weakness, or weariness and fatigue; his gait was shuffling, and slow; he had impaired vision (beginning cataract); and defective speech. Neurologically he showed: arcus senilis; unequal pupils, the left failed to react to light; the knee jerks were diminished; there was a slight ankle clonus; there were tremors of the tongue, lips and face; a slight Romberg was present. He was noted to be harmless, agreeable, and coöperative;

he was absolutely disoriented; his memory was very poor both for recent and remote events; he was somewhat confused and was easily upset; emotionally he was unstable, and occasionally irritable, and possibly on the borderline of depression; he had nothing to say voluntarily; he preferred to be let alone and he sat in one corner and did not associate with the other patients; he appeared to have fair insight into his condition; his general comprehension, reasoning and judgment did not seem impaired when his mind was occupied with simple things; his mental associations were not very active; his ideation was limited in amount; he paid little or no attention to his environment. He became untidy, refused to answer questions and used profane, vulgar and abusive language to his questioners. The autopsy showed: slight atrophy of the anterior cerebral convolutions, but no other gross cerebral lesions; aorta and aortic valves atheromatous; bronchitis; pulmonary tubercular nobules; pulmonary emphysema; cirrhosis of the liver; fibrous spleen and kidney; the right adrenal contained an overgrowth and an hemorrhagic area.

Case 35, white male, has been mentally changed for a year previous to admission, at the age of 61. Hospital residence was 11 years and 2 months.

This patient was sent to the Hospital on account of delusions of "strange and impossible happenings" and hallucinations of hearing (fictitious voices) and of vision (mysterious objects). Physically he showed a dilated heart, bleeding hemorrhoids, and a right inguinal hernia. Neurologically his movements were deliberate, slow and rather weak; his coördination seemed somewhat impaired, although his gait was firm and steady; a slight fibrillary tremor of the tongue was observed; hearing was defective. He appeared to comprehend what was said to him, but was deliberate in answering; his memory was good, somewhat better for remote than for recent events; his reasoning and judgment appeared to be below par; he heard voices outside his door at night; he was mildly depressed but claimed to be fairly well satisfied with his surroundings (ex-

cept for his delusions); he also showed some irritability. Later he became more irritable, and at times he was ugly and insulting; he refused to answer questions; he was distrustful and suspicious, and exhibited delusions of persecution (he claimed that the physicians had him "wired," that they conspired to keep him in the Hospital, and hold him for robbery and mistreatment; and he refused to converse with them); he claimed that the patients ought to be sent to school and educated; he was oriented; he was tidy; he was usually quiet and orderly, but occasionally he became indignant, irritable and wrought up over his detention. Delusions of grandeur were added to those of persecution (he thought himself to be a very rich man and that the Government was robbing him of thousands of dollars daily); his memory became poor; he was disoriented for time; when talking with the physicians, regarding whom he had delusions, he became so emotional that his voice trembled; he refused to answer questions regarding his condition; he was usually quiet, orderly and well-behaved except when approached by one regarding whom he had delusions; later he believed the attendants were putting poison into his food and drinks, trying to shave him against his will and injure him in other ways; insight into his condition was lacking. Death was due to cardiovascular and renal diseases; the autopsy also showed shrinkage of the cerebral convolutions over the anterior two-thirds and atheromatous cerebral vessels.

Case 36, colored female; the duration of the mental disease at the time of admission was not stated in the medical certificate; she lived in the Hospital 7 years and 5 months.

The age of this patient was unknown, but she was undoubtedly old at the time she was admitted from the Alms House; there she had been observed to be "maniacal," *i.e.,* very much excited; she could not answer questions intelligently and at times showed that she had delusions that people were after her; she was noisy, especially at night. Her facial expression was one of apathy; her gait was slow and feeble; the physical examination showed nothing abnormal; neurologically she showed fine tremors of

the extremities, sight and hearing were defective. She was somewhat disoriented and there was some clouding of consciousness; she did not appear to appreciate her surroundings; her memory for remote events was fair, but poor for recent events; in talking she lapsed into incoherency, goal ideas were lost; her reasoning and judgment were impaired; she thought she could talk with the Lord, and she became religiously excited at times, but as a rule she sat quietly in the ward, taking no interest; she was tidy in habits. She exhibited the signs of gradual mental enfeeblement; memory became practically a blank, and she became untidy in habits; she did not want to be interfered with by the nurses, and occasionally she showed a rather cross and irritable disposition; she sat in one chair with an apron over her head for hours; she never spoke unless spoken to and then always complained of being burned up by fire; the reason for covering her head could not be learned. Death was due to pulmonary hypostasis and hemorrhagic cystitic; the autopsy showed in addition generalized arteriosclerosis, cardiac atrophy, chronic diffuse nephritis and atrophy of the anterior two-thirds of the cerebral convolutions.

Case 37, white male, had been mentally deranged for 2 years previous to his admission at the age of 74; he lived in the Hospital 3 years and 2 months.

The family history was negative. At the age of 43, as a veteran of the Civil War, he was admitted to a Soldiers' Home, for "physical disability and mental incapacity." The physical disability was a contusion of the right shoulder; the character of the mental incapacity was not noted, but could not have been a marked mental change since the patient was able to take care of himself and was permitted to go at will. Twenty-four years later, at the age of 67, he was noted to have "impaired cerebration," but this term is not defined; six years subsequently he was noted to be senile; to have impaired cerebration and delusions of persecution (he thought he was to be hanged for misdemeanors of which he was not guilty); he was inclined to be talkative, but his conversation was disconnected; there was inability to concen-

trate his thoughts; he showed impaired judgment and reasoning. On one occasion a rope, carefully and securely fixed, was found in his locker, although it is not known that he had attempted or planned suicide. Physically he was quite active for his age, and his physical condition good with the exception of difficulty of hearing and right inguinal hernia. On admission he was restless and confused; he showed no interest in his surroundings; he was untidy in appearance, but tidy in habits; it was difficult to make him understand, and he failed to answer questions; no delusions could be elicited, although he appeared to be apprehensive and afraid that any one who approached him would do him harm; his consciousness was clouded; he was disoriented for time and place; his memory and intellect were very much impaired; his emotional tone was one of indifference. Soon he became untidy in habits, and there remained to him only a remnant of his former knowledge; he was kept in bed; he took no interest in his surroundings; when approached and questioned he cried and whined pitifully, he volunteered no information and he answered few questions; he was entirely disoriented; he seemed to remember the events of his childhood but none of recent date; no delusions or hallucinations could be elicited. He was restless and pulled and rearranged his bed clothing frequently and resisted attempts to help him. Death was due to bronchopneumonia. The autopsy showed marked shrinkage of the frontoparietal convolutions.

Case 38, white male, was admitted to the Hospital at the age of 72; his mental disturbance began 2 months previous to, and he lived only 1 month after his admission.

For two months previous to admission the patient was childish, forgetful, disoriental, and had a depression. His family history, as far as it could be ascertained, was negative. Physically he showed slightly enlarged heart, double arcus senilis, and defective hearing; Wassermann reaction with the blood serum was negative; albumin and casts were found in the urine. Neurologically he showed: sluggish accommodation reactions, and irregular pupils; deep reflexes diminished; slight Romberg sign; gait was very feeble; muscles wasted and atrophic; voluntary move-

ments feeble; irregular tremors of the fingers. Mentally he said he was sad, but usually he appeared to be indifferent; he had a poor memory; he was not oriented for persons, and only partially for time and place; insight was lacking; no hallucinations or delusions were elicited; his speech was good. The patient developed diarrhoea and died from exhaustion; the autopsy revealed no arteriosclerosis; the cerebral convolutions were shrunken over the frontal lobes and the posterior portions of the parietal lobes, but section of the brain showed no other changes; aortic atheroma; pulmonary tuberculosis; and parenchymatous nephritis.

Senile Dementia, Discussion

These fourteen cases are not entirely alike as far as lesions are concerned, and, it will be noted, some diagnostic questions have been raised regarding some of them. Case 28 has been noted as being a possible alcoholic psychosis, and some of the hallucinations which this patient had are suggestive of the alcoholic delirium. Patients 29, 30, and 37 were also considered at one time to be rather doubtful. Patient 29 was admitted to the Hospital for the first time at the age of 56, was subsequently discharged, but readmitted at the age of 69. Patient 30, on the other hand, had been noted to have had "nervous prostration" eleven years previous to his admission to the Hospital, but the symptoms which he exhibited at that time were not recorded, and it is impossible to determine the nature of the condition. Since the term "nervous prostration" is so inaccurately used by general practitioners, it is difficult to be certain that the patient exhibited anything more than a disinclination for mental and physical work. Patient 27 also had been noted as exhibiting "mental incapacity" thirty-one years previous to his admission to the Hospital, but, as has been noted in the case history, this was probably a very general term, and it may have been only a means of having him enrolled as an inmate of the Soldiers' Home in which he spent these years. Patient 31 had epileptiform convulsions, but no previous history of disturbances of this nature was obtained, and it is likely that these convulsive seizures were due to the degenerative cerebral conditions which mentally resulted in the dementia.

Regarding the cerebral conditions, similar variations are noted. Patient 28 exhibited what appeared to be an unilateral atrophy on the left side of the cerebrum. The description of the atrophy in case 37 is probably to be taken to be the equivalent of that which has been noted in cases 35 and 36, namely, that it covered the frontal, central and parietal regions of the brain, in this way taking in approximately two-thirds of the convexity. The brain of patient 38, like that of patient 28, also showed rather circumscribed atrophies, and it has been noted that these were in the posterior parietal lobes as well as in the frontal lobes. This case is added for the purpose of comparison with those cases which are strictly frontal atrophies, and for the purpose of comparison with the extensive lesions which were found in cases 35, 36, and 37. The degree of atrophy in these cases was varied, cases 28, 29, and 34 exhibiting only a slight amount of atrophy while cases 31 and 33 showed a marked degree of shrinkage.

In general the mentality of these patients did not greatly differ. All showed a considerable degree of dementia. They had little intelligence or understanding of what went on about them; they were at times unable to answer questions; they had become childish, slovenly in appearance, and they wandered around the wards aimlessly. At the same time, they were mostly harmless and usually quiet, agreeable, and sometimes apparently stupid, but at times they became restless and irritated. Patient 34, who exhibited only a slight degree of atrophy of the frontal regions, was apparently as demented as any of the other cases, and patients 28 and 29, whose brains were also noted to exhibited only slight atrophies, were at the same time considerably demented. On the other hand, the marked degree of cerebral atrophy which was found in the brains of patients 31 and 33 did not appear to bring about any greater degree of dementia or loss of mentality than in the other cases. These two patients were confused or wandered away, or were stupid, simple-minded or childish, but in these respects they were not any less mentally active or mentally endowed than patient 25, who was noted to exhibit "no intelligent understanding," or than patient 26, who was quiet, confused, or than patient 27, who was childish and wandered

away. The relation of the general mental condition of dementia to the frontal, or to the distributed anterior, or to the even more extensive frontal-parietal atrophies is not a definite one, and it is apparent that in these cases, as well as in those which have previously been considered, the relation of the degree of atrophy to the degree of dementia is not simple.

Most of these patients exhibited rather marked degrees of motor disorder. Tremors of the hands, tongue, face, or fingers were found in nine of these patients, and it is of interest to note that with the exception of patient 29 the frontal cases showed these disturbances as much as those cases in which the atrophies extended beyond the limits of the frontal lobes. In fact, those patients whose brains were found to have the more extensive atrophies (patients 31, 33 and 37) did not show motor disturbances of this character. Patients 27, 29, 33, and 37 were active for individuals of their age, and although in connection with general muscular atrophy they usually showed a slight amount of force in their movements, their movements were accurate and quick. It will be seen that some of these patients were those in which the precentral region was also included in the atrophic zone. In these cases, aside from the tremors, the five patients with frontal atrophies (including case 38) were apparently motorially more capable than those patients with the more extensive atrophies. This, however, is only true in a general way. The cases showed such extensive divergences in this particaular that they can not be considered to be correlated with any special degree or with any special extent of the pathological conditions of cerebral atrophy.

The conversation of most of these patients was disconnected and frequently incoherent. Their remarks were often almost unintelligible. They answered questions in an irrelevant manner, sometimes slowly or, as it has been described, deliberately, and at times they refused to answer or failed to answer at all. These variations from the normal activity were found in practically all these fourteen cases, although there is one exception, viz., patient 38, who not only answered properly and intelligently, but his speech, *i.e.*, his enunciation was good. In the case of speech as

distinguished from conversation, it was found that many of these cases exhibited no specific alterations, although patient 29 has been described as having been unable to repeat test phrases, and patient 34 was noted to exhibit defective speech.

The emotional tone of patients 27 and 28 is not specifically mentioned, and conclusions regarding their conditions in this respect must be drawn from the other facts in the case histories. We may conclude from the general accounts that patient 27 was usually cheerful, but at times, on account of his delusions, apparently depressed, and, as has been noted in the account given above, he was occasionally excited, disagreeable and pugnacious. The hallucinations which were evident in patient 28 and the delusions which he gave voice to did not appear to bring about very marked emotional reactions, although he was excited at times. As a rule, the other patients were usually indifferent; they were quiet; some of them were stupid, childish, and as may be concluded from their general mental symptoms, they ranged in their affective states from indifference to excitability, or to feelings of well-being, or to a depression or sadness. Patient 25 was perhaps the only one who exhibited no evident emotional reaction, although it should be remarked that he laughed and smiled spasmodically. Externally he appeared to be emotionally labile, but in reality he had no apparent affective concomitant with these reactions. The relation of these emotional conditions to the extents and degrees of atrophy is not apparent. Those patients with frontal lesions appeared to be as much affected as those with the more extensive lesions, and the condition of marked atrophy in patients 31 and 33, it will be noted, did not give rise to any special degree or character of affective phenomena.

Eight of these patients showed at no time any evidence of hallucinations. The other six patients did have hallucinations, with a possible exception of patient 26. The latter patient, as the case history shows, laughed and talked to himself and had delusions of driving horses or of calling to them, and, like patient 22, he was found calling to horses as if he were taking care of or driving them. Whether these symptoms should be interpreted to be entirely delusionary or to be partially hallucinatory, as if he

had the particular sensations in the hands and arms of driving or of rubbing down the horses, or of the visual experiences of seeing the horses, cannot be determined. It appears probable, however, that the delusion of his taking care of and driving these animals was due to the presence of hallucinations as much as to anything else. The hallucinations of patient 28 are much like those of the alcoholic delirium, as has been noted above. The hallucinations of alligators and snakes were especially like those which a patient with delirium tremens experiences, and the evident disorientation regarding the seasons when he complained of the cold weather, with snow on the ground, when in reality it was bright and warm, and when he complained of his being without shoes and clothing with the snow up to his knees, appeared to be much more like the paresthesias which an alcoholic might have. This apparent delusion, or disorientation for time, appeared, therefore, to be much more like a tactual paresthesia, or to be dependent upon such a condition, although it is not certain that we can exclude the visual element. In the expression of her delusions patient 36 also gave evidence that she had paresthesias, for it will be remembered that she complained of being burned up by fire. It is also possible that her delusion regarding her ability to talk with the Lord may have had as a basis the presence of auditory hallucinations of voices. Patients 30 and 31 at the time of their entrance to the Hospital were noted to be free from hallucinations, but at a later date both of these patients gave evidence of the presence of these abnormalities. Patient 30 complained that he heard voices at night. At the same time it should be remembered that he also complained that electricity had been used upon him, which had prevented his urination. Patient 31 was found trying to pick imaginary objects from the floor. Whether or not this reaction was due to a visual hallucination or to a combination of visual and tactile hallucinations was not determined. The delusion of patient 30 regarding the action of electricity was undoubtedly of an hallucinatory nature, as has been mentioned, the particular hallucination being of the organic type. It is of interest in this connection to note that these patients who exhibited hallucinations showed these abnormalities more frequently in the field of the skin sensations than

in other fields. From what we know regarding the functions of the postcentral areas of the brain it might be expected that this kind of hallucination would be more common in those patients who exhibited atrophy in the parietal region, viz., patients 35, 36, and 37, but of these three patients only one had hallucinations of this character. This woman complained of being burned up by fire. Patients 26 and 28, whose brains were only atrophied in the frontal lobes, also had the same kind of delusions, apparently based upon tactile or organic hallucinations. From these facts it appears that the hallucinations in these cases are not directly connected with the degree or the extent of the atrophies which have been recorded.

Three of the patients were entirely free from delusions of any kind. Two others, patients 25 and 37, were somewhat doubtful, although it appears that patient 25 in mistaking individuals and calling them by names not their own was suffering from a defect of memory or of orientation for persons, and did not have, primarily, a delusion. It is impossible in the case of patient 37 to determine whether the ideas of persecution which he spoke of were or were not delusions. At any rate, they were not particularly evident, although it should be remembered that he frequently appeared to be apprehensive, as if some harm would happen to him or as if he were being persecuted. Delusions of persecution were also found in patients 26, 28, 30, 33, 35, and 36. These gave way to delusions of grandeur or of exaltation in the case of patient 35, and perhaps also in the case of patient 36. Delusions of grandeur were also given expression by patients 27, 29, and 31. Although patients 25, 30, and 31 did not show any evidence of the presence of delusions at the time of their admission to the institution, at later dates delusions, of which mention has been made in the individual case histories, were in evidence. The association of delusions with lesions of the frontal region, in view of the lack of these abnormalities in cases 32, 34, and 38, and possibly also 37 and 25, can not be said to be demonstrated by these series of cases. If we believe that the *"Personenverkennung"* of patient 25 to be a real delusion, we can conclude that all of the simple frontal cases exhibited delusions. Opposed to this,

however, is the fact that the extension of the atrophies beyond the frontal region in the other nine cases did not always result in delusions. Case 38 is particularly interesting in this connection because the frontal region was undoubtedly atrophied, and added to this atrophy there was an atrophy of the posterior portion of the parietal region. If frontal lesions in themselves were especially allied to the delusion formation, it is to be expected that the more extensive atrophy would have been accompanied by this mental condition. Such, however, was not found. In these cases, therefore, delusions appear not to be directly associated with a particular location or a particular degree of atrophy.

Patient 29, who showed only a slight frontal atrophy, exhibited an accurate and exact memory. Patient 35, especially during his early Hospital residence, was also found to have a good memory, and although patient 30 was noted as having an imperfect memory at the time of his admission, it will be noted that according to the case history his memory varied from "good" to "poor" during his later Hospital residence. At times he appeared to have a very good grasp upon his surroundings, to know the events of his past life as well as other events, and at other times he did not appear to remember these things. In the other cases memory was poor. In the cases of patients 36 and 37 memory for remote events, especially those of their childhood, was fair, but for more recent occurrences memory was bad. When we consider these phenomena in connection with the extent and degree of the atrophies which the brains of these patients exhibited, there appears to be no correlation whatsoever.

Case 33 was the only patient who was completely oriented, and this is particularly noticeable in view of the extent and degree of atrophy in his brain. Nine of the other cases were completely disoriented for time, for place, and for persons. Patient 29, with a slight frontal atrophy, was disoriented for time, and similarly patient 35, while patient 38 was disoriented for persons and only partially disoriented for time and for place. Patient 30 exhibited the same kind of fluctuation regarding this mental function as he did for memory, in that at times he appeared to

be completely disoriented, to know nothing of time or of place or of persons, and again to have an excellent grasp upon these things. In this way there appeared to be fluctuations in his mental condition, and these have, as far as can be determined, no direct correspondence with the cerebral lesions in his case. The abnormalities in this field do not apparently depend upon the character or degree of the atrophies, the opposing evidence shown in case 33 alone being such as would prevent any definite statement regarding a relation.

Nine of these patients lacked insight. One, patient 34, had fair insight into his condition, whereas the other four cases had what might be termed partial insight in that, in answers to questions, they gave evidence that they recognized that something was wrong with them. They were incapable of making any kind of analysis, and in at least some of the cases it is not certain that their remarks should be interpreted as evidence of insight. Thus, patient 26 appeared to have no insight into his condition except that he remarked at one time that if the questions had been asked him a month previously, he would have been able to answer them. Patients 28 and 32 were more evidently in a condition in which they appreciated that something was wrong with their minds, for both admitted that there were "things in their minds which were not right," and that their minds were affected in some manner. There appears to be some relation between the degree of brain shrinkage and general insight in that in every case in which there was a slight degree of atrophy insight was present, partially at least. Insight, however, as related to the extent of atrophy, does not appear to have much correlation, although of the five frontal cases three did exhibit some insight into their condition, while of the anterior atrophies only two exhibited insight, and of the four remaining cases none exhibited insight in any degree.

Some of the other abnormalities which have been recorded in the case histories may have relations to the sensory defects which were present in these patients, although this is not apparent. Apprehensiveness, or delusions, or feelings of depression or apathy may be due to the presence of defects of hearing,

which abnormality was found in eight of these cases, and which in otherwise normal individuals appears at times to be associated with suspiciousness and allied affective states. It will be remembered that patient 28 had some impairment of the skin sensations, and it is possible that his hallucinations and his delusions of disorientation, snow on the ground, etc., which have been described in a previous paragraph, may have been due to the hypoesthesia for skin sensations. At the same time it should be recalled that patient 27 and patient 34 exhibited signs of beginning cataract, but these visual defects did not bring about any types of visual hallucinations or delusions. It is unfortunate that the "impairment of perception" noted in patient 30 is not more fully described, for it is possible that there were, in his case, sensory abnormalities which may have had certain relations with the delusions and hallucinations of which this patient gave evidence. The impairment of skin sensations in patient 28 is not correlated with atrophy of the postcentral region, since it will be remembered that this patient exhibited only a slight atrophy in one hemisphere.

When we deal with these patients as a group, we find, as in the other psychoses, extensive atrophies associated with some mental conditions quite similar to those found in the patients with the less extensive atrophies. In general it may be said that the exaggerated atrophies have given rise to no more prominent symptoms than the milder or slight degrees of atrophy which were recorded as being present in the brains of three of these patients.

SUMMARY

Although all the cases which have been studied exhibited atrophies which always included the frontal cerebral convolutions, and some also included atrophies of the neighboring central and parietal portions of the cerebrum, no one symptom was found to be constant, with the possible exception of that complex condition which is called dementia. It is also to be noted that although the degree of atrophy varied from "slight" to "marked" no one symptom or degree of symptom was found to correspond with these cerebral changes. In general, therefore, we may say that there is no apparent correlation between the extent or the degree of atrophy and the general mental condition. Those individuals who exhibited only frontal atrophies at times showed as much dementia as those in which the atrophy was more extensive, and many of the cases in which the atrophy was of a slight nature were also as demented as those in which the atrophy was noted to be great.

Nor does there appear to be any correlation between the form of the disease in the individual groups and the extent or the degree of the cerebral atrophy. It is true that more of the dementia precox group with anterior atrophies were catatonic in nature and that more of the frontal cases appeared to be rather paranoid. On the other hand, both with frontal and anterior atrophies, sufficient cases with other forms of the disease were observed, and it seems certain that the extent of the atrophy is not the determining element in the production of the collection of symptoms which give warrant for the diagnosis of the "form" of the disease. For the arteriosclerotic, senile and paretic groups of cases a similar statement may be made. In none of these collections of cases did there appear to be any definite correlation between the degree of the atrophy and the special form of the disease, and in the special discussions of the individual groups of cases it has been stated that no

correlation between the degree of dementia (paretic, arteriosclerotic, senile, or precox) and the extent or the degree of atrophy was present.

A similar statement holds true for the probability of correlation between degrees of atrophy and the general behavior of the cases which have been considered. Such behavior as the care of the person and the relations of the individual to his environment and to the other patients did not vary in accordance with the location or the amount of the cerebral changes.

On the motor side, similarly, we find no definite correlation existing. In the dementia precox group those with atrophies extending beyond the frontal regions differed in no respect from those in which the atrophy was confined to the less extensive area. The paretics with simple frontal lesions were perhaps more active than those with the lesions extending over the central convolutions and into the parietal lobe, but the cases of senile dementia and those with arteriosclerosis cerebralis were about equal in this respect. The motor phenomena which are found associated in these cases with atrophies do not appear to be correlated with the degree of the atrophy. In none of these collections of cases was it found that the motor phenomena differed to any extent when the degree of atrophy was great from those in which the atrophy was slight.

The emotional or affective states of these patients varied considerably. No one fact stands out particularly to indicate any possible relation between the affective states of these patients and the extent or the degree of the cerebral atrophy, and in fact in this case the conclusion can also be drawn that there is no correlation of this character.

The variety of the hallucinations which have been recorded and the fact that these symptoms were not uniformly present in those with similar atrophies does not indicate any definite relation between the appearance of hallucinations and the atrophies with which we dealt. It would appear that in the dementia precox group the more extensive atrophies were more frequently associated with the presence of hallucinations,

but such a conclusion can not be made regarding the groups of paretic, senile and arteriosclerotic dements.

Nor do the delusions appear to be correlated with the extent or degree of atrophies. Delusions appear to be as relatively frequent in case of frontal atrophy as in those cases in which the atrophy is more extensive, and in this connection it is of interest to note that with the marked changes in the frontal lobes which have been noted in connection with a number of the cases delusions were not always found. From the data which were available to him, Southard has concluded that frontal lesions are more frequently accompanied by delusions, but in the present series sufficient cases in which no delusions were present have been observed, in which frontal atrophies were present, either simple, or combined with those of the central convolutions and at times with those of the parietal region. It is worthy of note that of the dementia precox group there were three; of the paretics, one; of the arteriosclerotics, three; and of the senile, five; a total of twelve cases, in which no evidences of delusions was discovered, although in all of these cases an atrophy of the frontal lobes was discovered at the time of the autopsy. As a possible definite relation with the cerebral lesions it may be said that most of the patients exhibited poor memory and poor orientation. On the other hand, the accuracy of memory of some of the patients was remarkable in view of the degree of dementia which was noted to be present, and in some of the cases the orientation ability was also remarkable in view of the extensive cerebral changes which were found.

Summing up this portion we may definitely say that there has been discovered in the present collection of 38 cases no definite relation between (A) the degree of mentality, or lack of mentality, the character of the disease, the motor and affective states, the presence of delusions or hallucinations, memory or orientation ability, and (B) the degree and extent of the cerebral atrophies.

GENERAL DISCUSSION

On the assumption that similar portions of the brain in different individuals have like functions, we should expect that corresponding lesions would give rise to similar symptoms. That, however, the symptoms differ even though the lesions be similar is shown by the study of the case histories which have been summarized in previous sections. In addition, it requires no extensive acquaintance with the clinical contributions of neurologists to recognize that cerebral lesions other than atrophies do not always result in similar mental abnormalities, or symptoms. Nor does it require any great amount of critical ability to reach the conclusion that numerous facts which have been recorded in clinical neurological literature do not always warrant simple explanations of the relation of cerebral activities and and mental phenomena. It is apparent that the variations in the symptoms which accompany similar cerebral lesions in different individuals have often been minimized and sometimes disregarded, perhaps for the sake of simplicity of explanation.

In some few cases, on the other hand, the variations in the results of physiological investigations of stimulation and extirpation and the differences in the clinical symptoms accompanying similar cerebral lesions have also led to numerous polemics. Dissimilar symptoms have been shamefully taken from their settings, estimated too highly and extravagantly emphasized by those who controverted the quasi-phrenological views of cerebral function.

There is, however, no good reason either for disregarding the dissimilarities of symptoms accompanying cerebral lesions or for concluding that these dissimilarities demonstrate that all parts of the brain act in the same manner and that there are no cerebral "centers." The fact of dissimilarity must be accepted and brought into relation with the other facts which are known regarding cerebral function and control.

It has already been pointed out that in physical diseases the symptoms of individuals may differ to a considerable extent, and also that lesions in widely separated portions of the brain

may give rise to different symptoms in different individuals. Many neurologists now recognize the latter fact, and von Monakow in particular has been insisting that this fact is of primary importance for deducing the functions and functional connections of the cerebrum. The similarity of symptoms accompanying different lesions is readily understood if we conceive of the nervous system, and especially the cerebrum, as a collection of cells with connections, the function of which is fixed largely because of the intercommunicating connections. The individual cell has its own function, but in the production or control of any of the cerebrally produced or controlled processes in other parts of the body, or of mental states, it is the serial or grouped activities of nerve cells which must be dealt with. When this view is taken it becomes clear why dissimilar lesions may produce similar symptoms. A break at any part of the chain will prevent the normal function, which is serial.

It is now recognized that widely separated areas are always involved even when only a very small portion of the cerebral cortex is injured or destroyed. The destruction of some portions may immediately produce perfectly obvious defects or exaggerations of normal behavior, while the destruction of other portions may give rise to effects which are not immediate or obvious. The effects of the latter lesions are sometimes to be discovered only indirectly and at other times they are, as von Monakow points out, of a "latent nature and only become manifest when there is added to the primary operation (*i.e.,* a lesion) a second operation upon, or a pathological process in, another region of the cortex."[5]

The present series of facts are, however, different from those with which von Monakow and others have dealt. They are the reverse conditions, and they are not readily understandable on the hypothesis which von Monakow has set forth to explain the similarity of symptoms with dissimilar lesions. In connection with these studies of frontal and anterior atrophies it should be pointed out that dissimilarities of symptoms from

[5] Monakow, C. von. Theoretische Betrachtungen über die Lokalisation im Zentralnervensystem, insbesonder im Grosshirn. *Ergebnisse der Physiol.,* 1913, 13, 206-278.

frontal lesions have not infrequently been the cause of much discussion and recrimination. Thus, the clinical findings which have been recorded at different times by different investigators whose material (patients) was not exactly the same have given rise to the hypothesis that the frontal lobes are (1) intellectual centers, (2) centers for emotional states, (3) centers for inhibition, and (4) motor centers. Without attempting at the present time to advance a more general hypothesis than those already suggested, it may be said that the clinical facts are not mutually exclusive and that all can be brought together under one heading which gives a suggestion for the explanation of the functions of the frontal lobes.

Facts of an experimental nature are also at hand to show that the definiteness of control by the motor (precentral) cortex is not as great as that which is usually assumed to be the case. These will be dealt with in the second part of this monograph. All of the facts indicate that we must conclude that the action of the cerebrum is a diffuse activity, and an activity which varies from individual to individual, and in the same individual from time to time. A full discussion of this hypothesis will appear in connection with the study of the variability of control from the motor cortex. At the present time it may be mentioned that it seems most satisfactory to consider the cerebrum as a labile organ or, in other words, as a series of cells with numerous possibilities of connections. The number of connections makes possible a variety of activities, since at one time a cell may act through its main axonal connection upon a second cell, and at another time through its collateral connections it may act upon a third or fourth cell. Probably the cerebral cells do not always discharge, or influence other cells, in the same manner. We should, therefore, not hold to a belief in a definiteness and simplicity of physiological connections, but rather to a manifoldness of connections, any one or more of which may be used or not used at one time. The use, non-use, or disuse of any one of the possible paths at different times will produce differences in behavior, and similar lesions of cells may, therefore produce different symptoms in accordance with the normal (to the individual) connections which have thus been interfered with.

II

VARIATIONS IN DISTRIBUTION OF THE MOTOR CENTERS

INTRODUCTION

The earliest positive results of the electrical stimulation of the cortex were obtained by Fritsch and Hitzig, and at that time and for a number of years the movements obtained on stimulation of the cerebral cortex were described in terms such as to suggest that the resulting movements were definite movements of individual muscles. Subsequently attempts were made to determine the cortical localization or representation of individual muscles or muscle groups, but it was amply demonstrated by more recent experiments (especially those of Sherrington and Grünbaum (**6**) that all the movements which result from cortical stimulation are complex movements. These are "movements" in a particular sense of the word and not simply contractions of muscles. They are movements which are best described as behavior phenomena, not only movements of flexion but movements of grasping, not simply extension movements but movements of repulsion or thrusting away. In many cases the complex activities of the associated muscular contractions can best, and at times can only, be described in terms of such behavior activities.

From time to time in attempting to demonstrate the motor control by the cortex by stimulating the so-called motor centers difficulty was experienced by me with some animals in obtaining special reactions of parts which appeared to be readily obtainable in other animals.[1] These variations in the stimulability or in the control from the cortex were at first, on account of the

[1] Compare also Sherrington's remark: "In the cat it is in my experience quite infrequent to obtain primary extension of the crossed elbow from the cortex. Flexion is readily and regularly obtained." *Integrative Action of the Nervous System*, 1906, page 293.

definiteness with which most previous results have usually been described, believed by me to be due to defects in technic or to variations in the excitability of different cortical regions in different animals under anæsthesia. A careful examination of the literature devoted to the experimental investigation of the motor cortex in animals indicated, however, that notwithstanding the supposed definiteness there was considerable variation in the location of special areas in different animals. This variation appeared to depend, to some extent at least, upon the varying configurations of the fissures and consequently the varying positions of the collections of cells governing particular movements. On the other hand, it also appeared possible that some of these variations might be variations of a primary nature, *i.e.,* not due to the adventitious condition of anæsthesia or other similar circumstances. In fact, the careful examination of published work on the motor cortex, especially that of the Vogts (**11**), shows that the location of the individual cerebral areas controlling certain of the small bodily segments is not as anatomically (spatially) definite as has been supposed. Such as least was the suggestion that was received when the results of previous investigations were compared. Accurate determinations of the variations of previous investigations were not found to be practical, both on account of the differences in method that individual investigations had employed and their methods of recording results and also on account of the different species of animals on which the tests were made.

Because of these considerations, it was thought advisable to attempt comparisons of the results of the stimulation of the brains of a number of animals of the same species in order to determine how much, if any, variation there is in the relation of parts of the precentral cortex to the control of different bodily segments. It appeared possible that in this area of the brain there are variations of an individual nature, not explainable on the ground of variations in fissural configurations. The animals chosen for the present investigation were monkeys, *macacus rhesus,* five of which gave results of value.

METHODS

An animal was driven from its cage into a large burlap sack and completely anæsthetized. It was then transferred to the operating board and kept under the anæsthetic during the whole period of the experiment. The A.C.E. mixture was used in all of the experiments. At the time the movements of the animal were to be determined all the limbs were untied, but the head was kept steadied in a head-holder so that head movements might not take place or be minimized. The present series of tests were intended to deal largely with the relation of the cerebrum to the leg and arm movements, and the head movements were disregarded except when the latter were associated with movements of the other segments. Since, however, the head was kept fairly rigid, most of the head movements were prevented and with the exception of a few have not been recorded. This procedure of steadying the head were also used for another reason, viz., to prevent possible injuries to the brain when the head moved at the time the stimulating electrodes were applied. Except by having the electrodes attached firmly to the skull so that they move with it, it is not always possible to avoid accidental injuries of this nature, but in the present series such avoidable injuries to the brain were prevented by keeping the head steadied.

A one-half inch trephine was used to cut through the skull to such a point that the button of bone could be readily removed. The trephine was not permitted to cut entirely through the inner table of the skull on account of the possibility that the trephine teeth might also cut through the dura mater and thus injure the brain. In this way also injury to the cerebral cortex was prevented as much as possible, and in no case, as far as could be determined by an inspection of the brain through a magnifying glass was any gross injury produced. After the skull openings had been made in this manner they were enlarged in different

directions by bone forceps in order to uncover a large portion of the frontal area, all of the so-called precentral region and a considerable part of the postcentral cortex. Bleeding from the diploë was checked by the application of bone wax. When the large openings on both sides of the skull had been made the bridge of bone which covered the longitudinal fissure was cut through after ligatures had been placed at both extremities of the bridge in order to prevent bleeding from the longitudinal sinus. In previous tests bleeding from this source was found to be very great and in one of the animals used in the present series even the precautions of ligating the longitudinal sinus which were taken did not prevent death from hemorrhage. The dura was next cut and this was partly reflected and partly cut away so as to leave the portion of the cortex which was to be stimulated bare.

The part of the brain which was not at the time being subjected to stimulation exploration was covered with thin rubber tissue which had been wet with warm normal salt solution and all was covered with a large sponge of cotton which had also been wet and warmed in the same solution. Sufficient time elapsed between the individual stimuli to permit the recording of results and this also rested the brain tissue. After a series of half a dozen or more stimulations the part of the brain which was being used was covered by the rubber tissue and the sponge, and the brain was permitted to rest for a longer period, five to ten minutes. In this way the brain was protected at times when the tests were not being made. In this way also drying could not take place, and little, if any, of the anæsthetic gases escaping into the room could act directly upon the cerebral cells. At the same time the use of the rubber tissue prevented too much moistening of the brain substance, for it should be recognized that there is a possibility that the use of too much of the normal salt solution may, by osmosis, sufficiently change the chemical character of the cortical cells to produce alterations in their irritability. The duration of the tests on one side of the brain was usually about three hours. In certain cases where the number of stimulable points was small this time was short-

ened and on one animal in which the number of points was large, this time was much increased. In addition to the careful administration of the anæsthetic, the precautions to avoid "fatigue" and those to prevent osmotic changes from the application of the moistening solutions tended to keep the cortical irritability at approximately constant level, and any experiment, if it had appeared necessary or advisable, might have been carried on for a greater length of time.

It was not found difficult to keep the animal sufficiently under the effect of the anæsthetic during the whole period of time, for care was taken that the quantity should be sufficient to prevent any voluntary movements which might mask or interfere with the movements which were produced by the electrical stimulations, but at the same time the anæsthetic was not pushed to such a degree as would be necessary in experiments in which complete relaxation of the involuntary muscles is desired. In no case was the anæsthetic deep enough to produce a relaxation of the sphincters, but by continuous careful application all of the voluntary movements were prevented, even at the times when cutting and trephining were performed.

The cortex was stimulated by the bipolar method, the induction coil being a standard Helmholtz apparatus. The platinum points were separated by approximately one-quarter of a millimeter and each of the points was approximately of the same size. The distance, therefore, between the centers of the points was approximately one-half of a millimeter. The electrode points were applied to a special portion of the cortex and after the stimulation and the resulting reaction (when any occurred) they were removed. The secondary coil of the inductorium was arranged at the beginning of a series of tests on an animal at such a point as to give a supra-minimal stimulation. It was kept at this point throughout the series of tests on that animal, with the exception that when with this strength of current an apparently non-stimulable area was found, the strength of the stimulus was increased to determine whether the failure of reaction was due to a normal non-stimulable character of the special area or to a decrease of irritability. It was found

that the increased stimulus seldom gave rise to movements, and when failures with the increased stimulus were encountered it was concluded that these areas were normally non-stimulable. It is likely that further increases in the strength of the stimuli might have resulted in reactions, but with greater strengths of stimuli the possibility of "spreading" is greater and the results would have been open to serious objection on this score.

The stimulations were usually first begun at the upper portion of the precentral area where the motor cortex dip downwards into the longitudinal fissure. Eight or ten stimuli were given in a regular order as close as possible to the central fissure, and extending serially towards the fissure of Sylvius, the stimulated points being approximately one millimeter apart. Another series was begun at the extreme upper limit of the precentral area and the stimuli were carried downwards in a line which was approximately one millimeter in front of the line along which the previous series of stimuli had been given. Third, fourth, etc., series were made in the same manner, each extending one millimeter anteriorly to the previous one. In this way the experiment was carried on until in passing forwards a line or series of stimuli had been given which produced no observable reactions. In certain animals, on account of the presence of blood vessels and extra fissures, lines in which no stimuli were given were present. In most cases, however, the blood vessels which were encountered were not much greater than one millimeter in diameter and thus the general experimental relationships were not markedly disturbed. After such an area, about ten millimeters in length and in width to correspond to the stimulable zone, had been carefully examined, similar series were made in the area immediately below (towards the fissure of Sylvius). In this manner the whole of the superficial precentral cortex extending from the longitudinal fissure downwards as far as the head area was carefully mapped out.

After every second stimulation a small portion of a mixture which was composed of vaseline and analine-black was applied to the point which had been previously stimulated. This mixture was viscid, and sufficient could be taken upon the point of

a sharp probe which, when lightly touched to the brain, left a speck of this "paint" upon the brain surface. In some cases the individual points did not stand out by this method as clearly as was desired, but in many of the experiments the points of application of the analine-black mixture could be correctly determined and the relative locations of the individual points of stimulation were therefore accurately given on the cortex. The application of the wet rubber tissue and sponge after a series of tests tended to obliterate the marks which were made, but the pia mater (and the brain?) was sufficiently stained in many cases so that the individual points were to be seen when the brain was examined with a magnifier. The stained points were later compared with the photographs and with the diagrams which were used.

At the time of the performance of the experiment a rough sketch (with a magnification of about ten diameters) of the general appearance of the precentral and postcentral regions of the hemispheres was made. On this sketch the longitudinal fissures, the central fissures, subsidiary fissures, and the blood vessels were noted. Following each test the location of the stimulated point was marked on the sketch so that this could be compared with the location of the stain which had been applied to the brain. The serial numbers of the tests were noted on the sketch in approximately correct relations. These sketches were subsequently used for the identification of the stimulated points. After the removal of the brain and its hardening in formalin (10 per cent) the area which was found to be stimulable was again sketched by placing over the cortex a piece of transparent paper which was pressed down tightly and which was marked to show all of the points of interest (fissures, blood vessels, extent of the stained zone, etc.) in that particular area. These diagrams were then placed in the Leitz projection apparatus and drawings were made of the results with a magnification of ten diameters. On the drawings which accompany the present work corrections have been made in the diagrams by comparisons with actual brain pictures (photographs), so that the diagrams which are here represented are combinations of the sketches taken at

the time of the performance of the experiments with the actual pictures of the brains. At the time the brain was photographed a two millimeter scale was placed along the central fissure and photographed with the brain. The photographs were later magnified uniformly at 10 diameters, each millimeter on the photographed scale corresponding to 10 on the diagram, and drawings made of all the important landmarks.[2]

On these drawings the points of stimulation were noted and the numbers corresponding to the serial tests were recorded. Since the diagrams were drawn to scale, the results which are recorded in them may be considered to represent fairly accurately the extents of the stimulable motor areas in the individual hemispheres of the five monkeys which were used. It will be noted that these areas differ considerably in absolute sizes, monkey 2 having a more extensive responsive area than any of the other animals, monkey 4 having the least extensive stimulable motor area.

At the time the experiments were performed there were usually four observers. The chief duty of one was the manipulation of the electrodes. This observer also directed the experiment, noting on the rough sketch the points which had been stimulated and

[2] Since there is a considerable curvature of the brain from the longitudinal fissure towards the temporal areas (of special interest in this connection being the curvature in the region of the central fissure) the photographs showed considerable spatial distortions of the sides of the brain. In the projection of the photographs only the two millimeter divisions on the relatively flat superior surface of the brain could be made to correspond with the twenty millimeter divisions of the projection screen. The landmarks (fissures, blood vessels, etc.) and the scale divisions were recorded as they were magnified. These drawings were then dealt with as if the curved surface was simple, *i.e.*, like that of a cylinder, and the proper geometrical projections were made to bring about the uniform distribution of the area. It is realized that for the most accurate representation we should deal not only with the superior-inferior curvature but with the fronto-posterior curvature as well. The latter curvature in the region of the central fissure is however slight as compared with the superior-inferior curvature and has been disregarded. The error of recording due to this method is, I am advised, probably not as large as 5 per cent. Since also these drawings were later compared with the brains, with the enlarged diagrams on transparent paper, and with the original sketches, the error is doubtless much less than this amount. It is presumed, however, that the error is about equal for all brains and the results are, therefore, comparable.

applying to the cortex the analine-black mixture. A second observer took charge of the anæsthetic, his attention being directed principally to the matter of keeping the animal under good anæsthetic control, but he assisted at times in the observation of the activities of the animal which accompanied the stimulations. A third observer recorded the results of the individual stimuli on sheets of paper, noting at the same time the serial numbers and the times of the stimulations. This observer also coöperated with the fourth one in noting the character of the movements. The fourth observer had as his sole duty the observation of the movements which resulted from the stimuli and the description of the movement so that they might be recorded. As has already been said, the anæsthetist also occasionally helped to observe the movements. Only when the two or three special observers of the reactions (movements) were satisfied regarding the characters of the reactions were they recorded. If there was a doubt of a more or less serious nature regarding the combination of movements which was produced the particular point was subjected to a second stimulation at a later time.

Following the determination of all the available points in the leg and arm areas the animal was killed by an overdose of chloroform. The brains were hardened in formalin and preserved for future study. The extent of the stimulable areas was determined in the manner described above after the brain had been thoroughly hardened. The location of the points for the individual segments or parts of segments was also made in the manner similar to that described above, and are here reproduced in the diagrams.

The serial numbers of the original individual tests have not been included in the present accounts, for to bring about an areal correspondence of the allied areas in all animals the serial numbers in the individual experiments were not available. This was due to the fact that variations in the conduct of the experiments, *i.e.*, the varying location of the different fissures and different blood vessels, etc., were present to alter the constant serial character of the experiments in the different hemispheres.[3] Furthermore, in

[3] That is, test 10, or test 36, or test 72, did not always bear the same relation to the well known anatomical landmarks in all hemispheres.

the illustrations which are given later the areas have been, for the purpose of comparison, divided into special zones, although it should be understood that these zones by the methods used, are only approximately determinable for any one hemisphere.[4] At the same time, since the individual areas differ widely in extent, it should be noted that spatial comparisons of two or more hemispheres can be only approximate.

In the present work as has been noted above, attention was directed to those areas which are concerned with the movements of the leg (including the thigh, lower leg, foot and toes) and with the arm (including the shoulder, forearm, hand and fingers). The associated movements of the head which were occasionally met with in the stimulation of the arm area will not be detailed in the present paper. The present paper, therefore, deals primarily with the areas concerned with the anterior and posterior limbs and occasionally with the associated movements of the tail. The results of the experiments are given in four divisions as follows: (1) the total extents of the stimulable areas for the arm and leg; (2) a comparison of the distribution for the leg and for the arm; (3) a comparison of the distributions of the areas for the smaller segments (fingers, hand, lower arm, upper arm, toes, foot, lower leg and thigh); and (4) the anomalous distribution of the stimulable areas, namely (*a*) those areas which gave leg movements when the surrounding areas gave arm movements, (*b*) those areas which gave arm movements when the surrounding areas gave leg movements, and (*c*) the nonstimulable (or relatively non-stimulable) areas which were surrounded by readily stimulable areas.

Several possible objections may be urged against considering the diagrams to include all of the motor responsive areas for the arm

[4] In other words, in the diagrams each point of experimental stimulation is represented by an area. Since the stimulated points were one millimeter apart, the square millimeter surrounding a point was considered to correspond with the point. A micrometric method of moving the stimulating electrodes or the use of one pole, by the unipolar and monopolar methods, would have permitted the stimulation of more points, and the diagrammatic representations would have been nearer the actual conditions. Since, however, we deal with comparative results with the same method on all animals the slight variations due to method can be largely disregarded.

and leg. One possible objection is that the stimuli may not have been sufficiently strong to bring about responses in the outlying portions of the areas, and that in any one of the monkeys the total area which was found stimulable may be only the combination of more readily stimulated points. Such an objection would be valid were it not that in those cases in which the extent of the area seemed to be slight, additional slightly stronger stimuli were given in order that there should be a reasonable certainty regarding the outer limits. When these increased stimuli failed to produce a response it was deemed that the limits of the normally excitable area had been reached. The use of much stronger stimuli may be objected to in this connection, since the stronger stimuli tend to spread to a great degree and, therefore, to have a more widespread physiological effect than the weaker stimuli. Since the precautions were taken however, as a check and negative results were obtained, the negative results may be considered to be confirmations of the limitation of what we may call the "immediately" excitable zone.

Another objection which may be urged against considering these results of absolute (rather than relative) value is that no account has been taken of the stimulable portions of the cortex which are included within the central and within the subsidiary fissures. This objection is in most respects weighty for it is realized that there may be a possible inverse relation between the amount of the stimulable cortex on the convexity or surface of the brain and that to be found lying within the fissures. It may be admitted at the outset that in the present work no measurements (stimulation or otherwise) have been made of the quantity or extent of the motor cortex which dips down into the central fissures. It may also be admitted that some of the variations which have been discovered by the present methods may be variations of an anatomical nature as described above (inverse relation of surface and fissure extents). It is not true, however, that all the variations can be explained in this manner. Some variations that will be noted later, especially those of the distribution of the areas for the individual segments cannot be explained in this manner. On account of the possible objection to certain of

the results it may be mentioned that the correlation of the extent of the motor cortex anterior to and that within the fissure of Rolando is a problem which I hope to be able to deal with in a subsequent publication.

A third objection is that the motor areas dipping downward into the longitudinal sulcus have not been considered. In most of the hemispheres this objection does not hold since the areas within the longitudinal sulcus were investigated and the results recorded. In the case of the left hemisphere of monkey 3, however, not even all the convexity surface was investigated, as will be noted below.

EXPERIMENTAL RESULTS

Before proceeding to the accounts of the results of the experiments it appears desirable to present a series of figures which describe numerically the brains of the animals on which the experiments were performed. These figures are given for the reason that the areal variations of the stimulable zones might have correlations with the brain sizes or brain weights. Because of this there are given various linear measurements and diameters since the selection and use of one measure for possible correlation might be considered to be too arbitrary. The measurements were made approximately one year subsequent to the performance of the tests, after the brains had been continuously in formalin (10 per cent). All measures were taken in the nearest half millimeter or nearest half gram.

The diameter measurements which are recorded were made with slide calipers. The total length was taken as the longest diameter between the frontal and occipital poles. The total width is the greatest side to side diameter. This is sometimes found caudad to the position of a plane from the upper portion of the central fissure perpendicular to the longitudinal sulcus. Since the measurements just noted can give only a general view of the brain as a whole it was also thought best to take data referring to the frontal (anterior to the central fissure) portions of the brain. The frontal width was taken on each side from the longitudinal sulcus to the side of the bzrain, on a plane passing through the central fissure approximately one-half of the distance from the longitudinal sulcus to the end of the central fissure near the fissure of Sylvius. The frontal length is also given for the two sides separately. It is the distance between the anterior tip of the brain and a plane passing through the brain and beginning at the origin of the central fissure near the longitudinal sulcus and perpendicular to the latter. The length of the central fissure could not be measured as accurately as the

lengths already mentioned. A narrow pliable but non-stretchable tape was laid along the fissure beginning at either its superior or inferior end and passing over its various curves as well as possible. The weights of the brain were determined to the nearest half gram, the weights being of the cerebrum alone. The medulla, cerebellum and spinal cords had not been preserved. Three measurements of each kind were made; the results were averaged and in the table the averages are noted to the nearest half millimeter or half gram.

The brain of monkey 4 was slightly flattened on the left side in its superior-inferior diameter. This was probably due to the usual cause, lack of sufficient protection from the bottom of the containing vessel. At the same time this flattening may have been accompanied by an elongation or a broadening of that side. Since, however, the two sides gave approximately (within 0.5 mm.) the same fronto-occipital measurements it does not appear likely that there has been much variation in this particular. On the other hand, the variations in width are found to differ for the two hemispheres of other animals and it is impossible to say with surety that the superior-inferior flattening was the cause of greater width of the left hemisphere of this animal. When the brain of monkey 5 was removed from the skull both occipital lobes were accidentally cut and in the process of hardening some

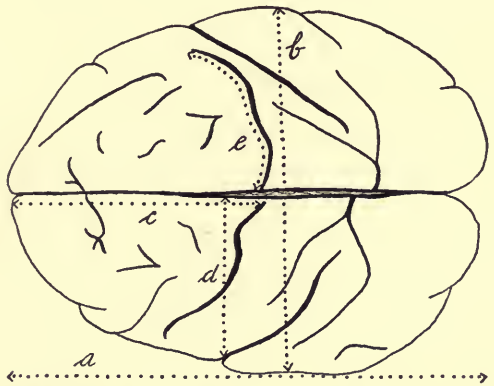

FIGURE 1. Representing the methods of making the linear measurements which are given in the text and in Table I: *a*, total length; *b*, total width; *c*, frontal length; *d*, frontal width; *e*, length of central fissure.

separation of these parts from the remainder of the brain occurred. When the brains were measured these parts were approximated to the remainder of the brain and the measures made. If there is an inaccuracy in the measurements of this brain because of this such inaccuracy relates probably solely to the total length. The measurements which have just been described are given in Table I and the methods of taking the linear measures are illustrated in Figure 1.

TABLE I. Measurements of Monkey Brains. All linear measurements are given in millimeters; those of mass in grams. The brains of monkeys 4 and 5 were somewhat distorted when measured, and the linear measurements may differ slightly from those given here (see text, page 93, for explanation).

Monkeys	Total Lengths	Total Widths	Frontal Widths		Frontal Lengths		Lengths of Central Fissure		Weights
			R	L	R	L	R	L	
1	70.0	52.0	21.5	24.0	34.0	36.0	32.0	33.0	69.0
2	67.5	48.5	23.5	24.0	32.5	37.0	33.0	33.0	65.0
3	74.0	54.5	24.5	26.0	41.0	39.5	36.0	37.0	81.5
4	67.5	50.0	21.0	23.0	35.0	36.5	33.0	28.0	59.5
5	66.0	51.0	24.0	22.0	36.5	35.0	29.0	30.5	60.5

The measurements show that monkey 3 had the longest, the widest, and the heaviest brain and, whether measured by the *product of frontal width x frontal length,* or by *frontal length x length of the central fissure,* which products may reasonably be supposed to give an indication of the extents of the frontal areas, also the largest frontal area. This, as will be pointed out in a subsequent section of this report, is of special interest in connection with the extent of the stimulable areas. In respect to the similar measures of the brain of monkey 1 it will be noted that the right hemisphere of this animal was found to be among the smallest, although the brain weight and total length are greater than those of monkeys 2, 4 and 5. At the same time it will be noted that the brain weight of monkey 2 is the median, that the total width is the least, and that the products of *frontal width x frontal length* and *frontal length x length of central fissure* are not much greater than those of the brain of monkey 1.

I. EXTENTS OF CEREBRAL MOTOR AREAS FOR THE ARM AND LEG SEGMENTS

Monkey 4 died shortly after the stimulation experiment had been begun on the left hemisphere. Death appeared to be due to an excessive hemorrhage from the longitudinal sinus which had not been suitably ligated. The results of the experiments on this animal can, therefore, be given for only one hemisphere and in this case the comparison of the two hemispheres is impossible. A general view of the results on all animals is given in Figure 2. As has already been mentioned, the points of stimulation have been dealt with as if they were areas corresponding with the spaces surrounding the stimulation points. The results of the experiments on each hemisphere are shown separately, the digits referring to the monkeys, the upper diagrams showing the results of the experiments on the right hemispheres, and the lower diagrams showing those on the left hemispheres of these five animals. The areas for the leg segment movements are represented by horizontal lines and those for the arm segment movements by vertical lines. The heavy horizontal lines represent the respective longitudinal sulci, other heavy lines represent the principal fissures (that of Rolando, or the central fissure, being very plain) and the three parallel lines indicate the locations of the principal blood vessels.

It will be first noted that the shapes of the areas differ considerably. In some cases the areas appear to run practically parallel to the central fissures (1R, 1L, 3R, 3L).[5] In other cases the form of the areas is irregular, broader at the top, or near the longitudinal sulcus, *i.e.*, near the upper portion of the Rolandic fissure, and narrower below. It is also to be noted that in some cases, and in all hemispheres in certain locations, the areas are solid, while in others there are zones in which no leg or arm reactions were obtained. In some of these cases the points were

[5] These figures and subsequent ones mean monkey 1 right hemisphere, monkey 1 left hemisphere, etc.

apparently "silent" since no movement of the arm, trunk, tail or head segments followed stimulation, but in a few cases on the other hand the stimulation of these areas gave movements of the head or of a segment other than those which are dealt with here (*i.e.,* arm and leg). These anomalous results will be discussed in a later section of this article (see p. 134 ff.).

A third difference which is obvious is that the overlapping of arm and leg areas is irregular. In the brain of monkey 1 none of this overlapping was discovered, very little was found in the brains of monkeys 3 and 4 and more was found in the brain of monkey 5, and a considerable degree of overlapping was discovered in the brain of monkey 2. These overlappings will also be dealt with in a subsequent section (see p. 128 ff.).

A further difference, which may however be only casual, is that the dividing line between the leg and arm areas is at times well marked by fissures or by blood vessels and in the brains of other animals these anatomical landmarks do not appear to have physiological differentiating characters. Those hemispheres in which fissures and blood vessels mark off the two areas under consideration are 1R, 1L, 2L, 3L, and 5L. I do not think that the greater frequency of this in the left hemispheres, or in fact any of the differences in this particular can, with our present knowledge, be considered to be of physiological significance.

A closer examination of the figures also reveals well marked differences in the totals of the stimulable areas. It is obvious from inspection that the stimulable areas of 2L is greater than that of all other hemispheres which have been examined. It is also apparent that in this respect there are great variations, hemisphere 4R shows the smallest area and the remaining seven hemispheres are intermediate between 4R and 2L. As has already been indicated (p. 91) there was an experimental error in connection with hemisphere 3L inasmuch as there was a possible line bordering upon the longitudinal sulcus which was not subjected to stimulation. In this one case had the stimuli been given to points in this area it is possible that the leg area would have been found to extend correspondingly in the wedge shape upwards to the longitudinal sulcus.

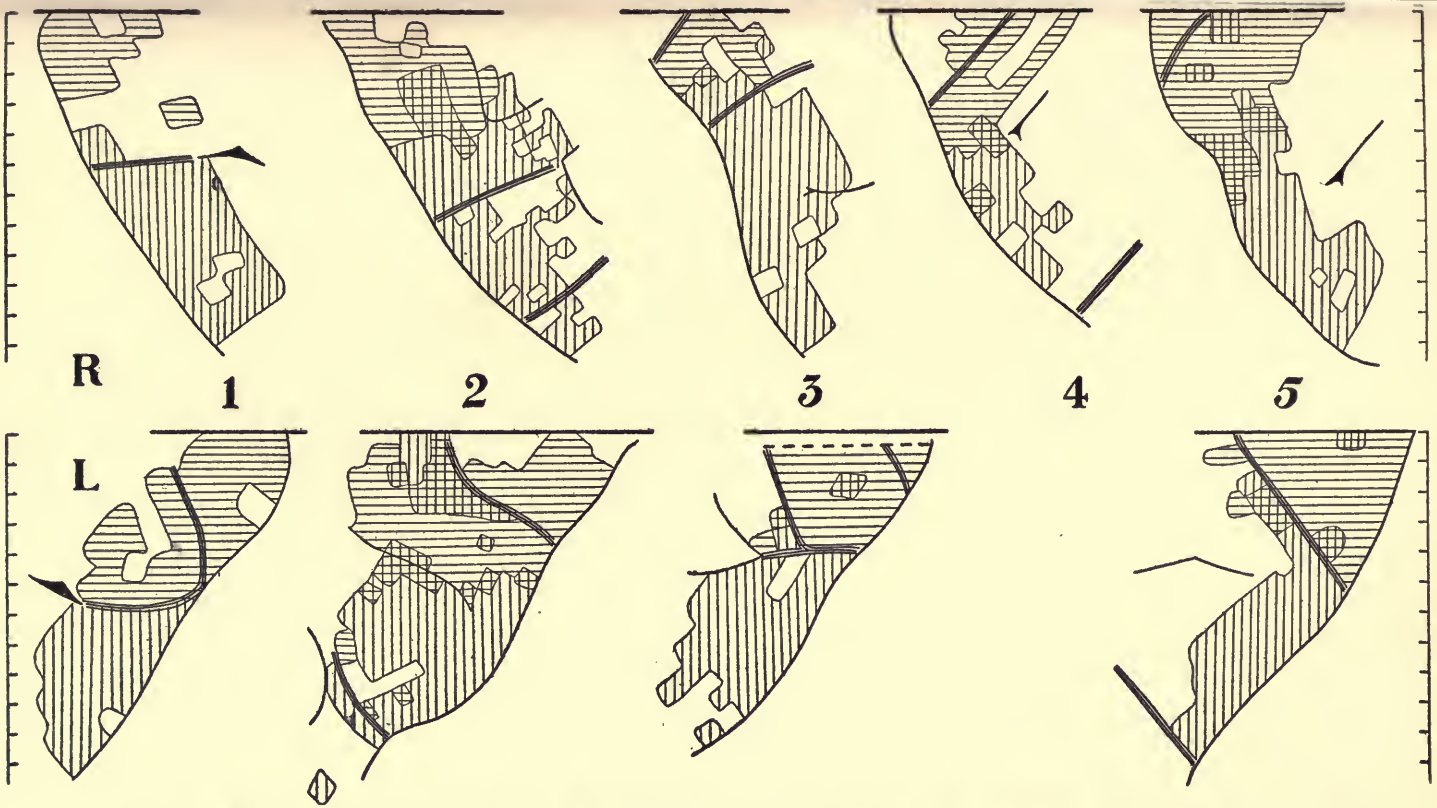

FIGURE 2. The total extents of the cerebral stimulable areas for the leg and arm segments. Horizontal lines = leg areas; vertical lines = arm areas; combined (cross-hatched) lines = arm and leg areas (*i.e.*, combined movements). Blank spaces are inexcitable, or have relation to movements of parts other than those discussed here. Fissures are shown by heavy lines, the principal blood vessels by three parallel lines. The upper series of diagrams represent the right hemispheres, the lower series, the left hemispheres. Scale marks indicate 2 mm. divisions.

More careful measurements of these areas reveal the differences which are observable on inspection. The figures representing these measurements are given in Table II. The measurements were made from the magnified (10 diameters) charts

TABLE II. Measurements of Areas of Stimulation of Monkey Brains. Figures marked with an asterisk are probably too low. For explanation of this see the text, page 91.

Monkeys	Hemispheres	Areas in square millimeters					Per cent Leg / Arm
		Leg	Arm	Totals	Overlappings	Net	
1	R	33	82	115	0	115	40
	L	86	71	157	0	157	121
2	R	61	106	167	15	152	58
	L	124	125	249	34	215	99
3	R	25	103	128	4	124	24
	L	57*	80	137*	5	132*	71*
4	R	51	34	85	7	78	150
5	R	79	83	162	23	139	96
	L	78	77	155	11	144	101

which have been described, by the aid of a transparent die divided to show actual square millimeters (in the magnified form square centimeters, of course) which was placed over the areas. Each full square covering the stimulable zone was counted as one and each part square as one-half, the latter on the supposition that the areas larger than one-half would counterbalance those smaller than one-half. The results of this comparatively rough method were compared in one case with the similar finer method of using a die with spaces representing half-millimeter squares, and since the variations did not greatly exceed one per cent the original measurements were considered to be sufficiently accurate. The method of measurement is also obviously exact enough in view of the methods which were employed for the limitation of the areas involved, and especially in view of the magnified representations of the areas which were measured. It should be remarked, however, that a turning of the die through an angle of 30 degrees varied the measures by as much as 6 per cent but even with this variation the figures appear to be sufficiently exact as they stand.

In connection with the table mention may be made again of the fact that in hemisphere 3L an area lying next to the longitudinal sulcus was not stimulated. The figures in columns 3, 5, 7 and 8 referring to this hemisphere are, possibly, too low.

At the present moment attention should be directed solely to column 7 of this table in which are given the net totals of the areas which were found to be stimulable. These figures show that the stimulable area of 4R is the smallest, that of 2L the greatest. In terms of percentage, using the lowest figure as 100, we find that the other hemispheres take the following order and show the following percents: 1R (149); 3R (159); 3L (169); 5R (178); 2R (195); 1L (201); 2L (276). It will thus be seen that the greatest area (2L) is almost three times as large as that of 4R, and that the other seven hemispheres vary from 50 per cent to 100 per cent greater than the smallest.

These data show that not only are there marked variations in different animals, but also that the variations of the two hemispheres of the same animal are sometimes great with respect to the stimulable (motor) areas. These differences of the two hemispheres of the same animal are worthy of some notice. In all four monkeys of which both hemispheres were investigated and measured it will be noted that the stimulable areas on the left surpass those on the right. In the case of monkey 5 this left-sided preponderance is not great, only 3.6 per cent and therefore within the error of measurement, and similarly in the case of monkey 3, only 6.5 per cent, close to the error of measurement. In the latter case, however, there should be recalled the suggestion (see p. 96) of the possibility that the leg area should be considered to be larger than it is sketched. With respect to monkeys 1 and 2 the preponderance of the left side is great, 36 and 41 per cent respectively. In the next section a further analysis of these figures will be made to determine the relative areas for the arm and leg movements separately.

To what factors these differences correspond is at present unknown. Certain of the general objections to considering them typical of the motor cortex have already been discussed

(p. 89 ff.) and the general relation of the differences to our conception of cerebral activities will be considered in the section devoted to the theoretical discussion (p. 140 ff.). At this point, however, it may be well to show the general lack of correspondence or correlation with the measurements of the brain which have been recorded in Table I (p. 94). Monkey 3, with the greatest brain weight, greatest length of hemisphere, and greatest width of the cerebrum did not have the most extensive motor area as determined by the methods which were used in the present work, while monkey 2, with one of the smallest brains in the series showed the most extensive excitable areas. If the measures which have been used (*frontal length x frontal width,* and *frontal length x length of central fissure*) are at all typical of the amount of the cortex of the frontal areas, it is plain that there is no direct relation between the extent of the motor or stimulable cortex and the total amount of the cortex anterior to the central fissure. Such a conclusion becomes more evident if we deal with the data regarding the other hemispheres. The only apparent fact which indicates a possible relation between brain size (or amount of frontal cortex) and the extents of the motor area is that there is a closer correspondence between the relative sizes of the motor areas and the total areas of the frontal lobes in the two hemispheres of the same animal. Thus, it might be concluded that the preponderance of the motor area of the left hemisphere is an indication of and bears a possible correlation with the (in general) larger hemispherc measurements on that side. Monkey 1 whose brain showed greater width, greater frontal length, and greater length of the central fissure on the left showed also a considerable superiority in the extent of the motor area on that side. The brain of monkey 2, in which a similar superiority in size was apparent, except for fissure length, also showed a larger area on the left side. The brain of monkey 3, in which there was a greater width and a greater fissure length on the left while the left frontal length was smaller than that on the right showed little difference in the relative sizes of the two motor areas. In a similar manner the brain of monkey 5 showed variations

in measurements, some of the right hemisphere being greater than those of the left and others of the left being greater than the corresponding measures of the right hemisphere. The cerebral measures which may be concluded to be approximately balancing for the two sides correspond therefore with the almost equal distribution of the motor areas. A disturbing element to such a conclusion is due to the unfortunate failure to complete the series of experiments on the left hemisphere of monkey 3. While there is an equal reason for believing that if the stimuli had been given in this area there would and there would not have been any great change in the sum totals of the areas, at least the case must tentatively be thrown out of consideration. Another fact which is opposed to the conclusion of such a definite relation is found in the lack of correspondence between the relations of the hemisphere measurements and the relations of the extents of the excitable zones. Those measurements which have been taken to represent the areas of the frontal lobes (*frontal length x length of the central fissure,* and *frontal length x frontal width*) do not have the same or nearly the same proportions that the total motor areas of the two hemispheres of the same animal bear. Thus our relative measures for the brains R/L are as follows: *frontal length x frontal width,* 1 = 0.85, 2 = 0.86; 3 = 1.01; 5 = 0.99. To compare with these figures we have the similarly calculated relations of the two motor areas of the same brains as follows: 1 = 0.73; 2 = 0.71; 3 = 0.94; 5 = 0.97. The absolute figures do not show a close correspondence but it must be admitted that the measures are grossly inaccurate as representing the area of the anterior parts of the cortex of the cerebrum. If we consider the relative figures there appears to be a closer correlation inasmuch as the relatively smaller motor areas on the right (monkeys 1 and 2) may be compared (not directly, however) with the smaller cortical zones on that side. At the same time the nearly equal motor areas (monkeys 3 and 5) are to be compared with the nearly equal cortical zones (or with the preponderating right hemisphere of monkey 5 as indicated by *frontal length x frontal*

width). We can conclude with certainty that if a relation in this respect exists it is neither simple nor direct.

Summary: The motor areas for the leg and arm segments differ in size in the brains of different animals, and in the two hemispheres of the same animal. These differences are not accounted for by the size variations of the hemisphere of the the different animals although there is some indication of a possibility of correlation of the sizes of the frontal lobes and the extents of the motor areas of the two hemispheres of the same animal.

II. RELATIVE DISTRIBUTIONS OF AREAS FOR LEG AND ARM MOVEMENTS

Figure 2 and Table II also contain data regarding the absolute and relative extents of the respective areas for the movements of the posterior and the anterior limbs. Examination of the parts of the figure and of columns 3, 4, 7, and 8 of the table reveal extensive differences. These differences are (1) varying amounts of cerebral areas in different animals for the leg and for the arm movements, (2) varying amounts of cerebral areas in the two hemispheres of the same animal for the leg and for the arm movements, (3) variations in the overlapping or mixing of the leg and arm areas, which matter will be reserved for discussion in a subsequent section, and (4) variations in the spatial proportions of these two areas in the same hemisphere.

The individual variations in extents of these areas should first be noted. The smallest leg area was found in 3R, the largest in 2L. The smallest arm area was found in 4R, the largest in 2L. The largest leg and arm areas were found in the hemisphere with the largest total area, which as noted above was by no means the largest brain. The smallest leg area was not found in the hemisphere with the smallest total stimulable zone, but the smallest arm area was found in the hemisphere with the smallest net total stimulable area. The intermediate sized total areas more closely correspond with the order of magnitude of the leg areas than with those of the arm areas. Thus we find the order of magnitude of the net totals of the stimulable zones (combined arm and leg areas) are 4R, 1R, 3R, 3L, 5R, 5L, 2R, 1L, and 2L; the order for the leg areas is 3R, 1R, 4R, 3L, 2R, 5L, 5R, 1L, and 2L; and the order for the arm areas is 4R, 1L, 5L, 3L, 1R, 5R, 3R, 2R, and 2L. The serial orders indicate a rough correlation between the individual arm and leg and the net total areas, with a greater correspondence of net total with leg areas. When, however, the percentage relations of the individual areas are considered it is to be noted that the only close correspondence is in the hemispheres in which the leg and arm areas are nearly equal in size. Thus we find in

general a fairly close correspondence in the cases of 2L, 5R and 5L, but in these cases with the leg and the arm areas each about one-half of the total, a direct and proportional correspondence is obviously the only possible relation that can exist.

When we examine the table we find that in only monkey 5 are the totals of the areas for the leg and for the arm closely similar for the two hemispheres. The almost exact correspondence of areal distribution for the leg movements is noteworthy and the differences in the sizes of arm areas in this animal are not great, perhaps not much greater than the errors of recording and of calculation. The only other close correspondence is for the arm areas of monkey 1, but in this case the variation is approximately fifteen per cent. In the other five cases (hemispheres) the differences are greater, the variations ranging from 18 to over 100 per cent. In the left hemispheres of monkeys 1, 2 and 3, the leg areas are larger than those of the right. In the left hemisphere of monkey 2 the arm area is the larger, while the arm area is larger in the right hemisphere of monkey 3. It will be noticed, therefore, that the left motor areas for the leg are in general considerably larger than those on the right, while a reverse condition holds for the arms areas of the two hemispheres with the exception of monkey 2 and also with the exception that the differences are not as great.

If other data were not at hand such variations might reasonably be thought to bear a possible relation to the sizes of the hemispheres, but an examination of the figures in Table I and comparisons with those of Table II show that no such relation exists.

Coupled with the individual and the hemisphere variations of these areas we may also consider the relations to each other of the leg and arm areas of the same hemisphere. In this comparison we note even greater deviations than have already been discussed. The quotients of leg area divided by arm area for the individual hemispheres are shown in column 8 of Table II. The smallest is that of 3R, the largest is that of 4R. In three hemispheres (2L, 5R, and 5L) the quotients show the two areas to be about equal, in four hemispheres the quotients show considerable spatial superiority of the arm area (1R, 2R,

3R, and 3L), and in two hemispheres a corresponding superiority of the leg area (1L and 4R). Although the importance of the observation is not apparent it is interesting to find that in the four cases in which figures for both hemispheres are available the relative superiority of the arm area is more noticeable on the right. It will be noted also that in three of these cases (monkeys 1, 2, and 3) this relative superiority is large and, in the other case, although small, it is indicated by a difference of at least 5 per cent.

An explanation of these differences cannot be given at the present time. I greatly regret that extended observations of the behavior of the animals were not made previous to the experiments, for, merely to speculate, the suggestion occurs that these cortical variations may have some relation to the normal activities of the individual animals. A few observations regarding the use of the right and left hands of some of the animals were made but the data are so few that they give no clue to a possible relation between the extensive or limited arm areas in one hemisphere and the use of the right or left hand or arm. It is for our present purposes unfortunate that even these inadequate tests were not continued a sufficient length of time with one animal to make certain any preference in the employment of the hands. The suggestion of a possible correlation of the areal differences and the differences in behavior is directly in line with previous conceptions of cerebral function, especially those regarding the relations of the associational areas to occupations and habits of thought. An extended series of observations of habits, general activity, etc., of many animals is needed along with corresponding observations of the stimulable areas before the truth of such a supposition can be determined.

Summary: The areas for the arm and for the leg differ to a considerable extent in different animals, and to an equal degree in the two hemispheres of the same animal. The leg areas are sometimes larger than, more frequently smaller than, and at times approximately equal to the corresponding arm areas. In the two hemispheres of the same animal the quotients of leg area divided by arm area are not even approximately equal, the proportions varying by as much as one to three.

III DISTRIBUTIONS OF THE AREAS FOR THE INDIVIDUAL SEGMENTS

Up to this point we have dealt with the areas for the arm and leg as if these were the main anatomical (and physiological) elements which were to be considered. It is obvious, however, that the individual segments of these larger anatomical units are worthy of more and closer study. We shall also find that the variations which have already been shown to exist are not only paralleled, but in a number of cases they are exceeded in amount, by the variations in relative sizes of the areas for the smaller segments. At the present time the analysis and comparison of the types of the movements have not been attempted, nor will the separate finger or toe movements be dealt with individually. For the present study I have made eight groups of movements as follows: *thigh,* which includes all mass movements of the leg on the trunk, such movements being of the upper part of the leg; *leg,* those movements at the knee; *foot,* those movements at the ankle; *toes,* movements of these elements taken collectively and not at the present time differentiating the movements of individual toes; *shoulder,* those movements of the upper arm in relation to the remainder of the body; *forearm,* movements of the elbow; *hand,* movements of this organ at the wrist; and *fingers,* movements of these parts, also collectively without differentiating the movements of the individual fingers or the thumb. At the same time I have for the present disregarded the characters of the movements, (1) whether they be flexions, or extensions, or rotations, or (2) dealing with the movements as they appear in their complexity as behavior phenomena, whether they be of a thrusting, or of a grasping, or of a propulsive, or a reaching, or of any other complex nature. In this section, therefore, I deal with the movements of anatomical segments and not with the movement characters.

Thigh.—The distributions of the areas the stimulation of which resulted in movements of the thigh are shown in the diagrams of Figure 3. The relative areal variations are here

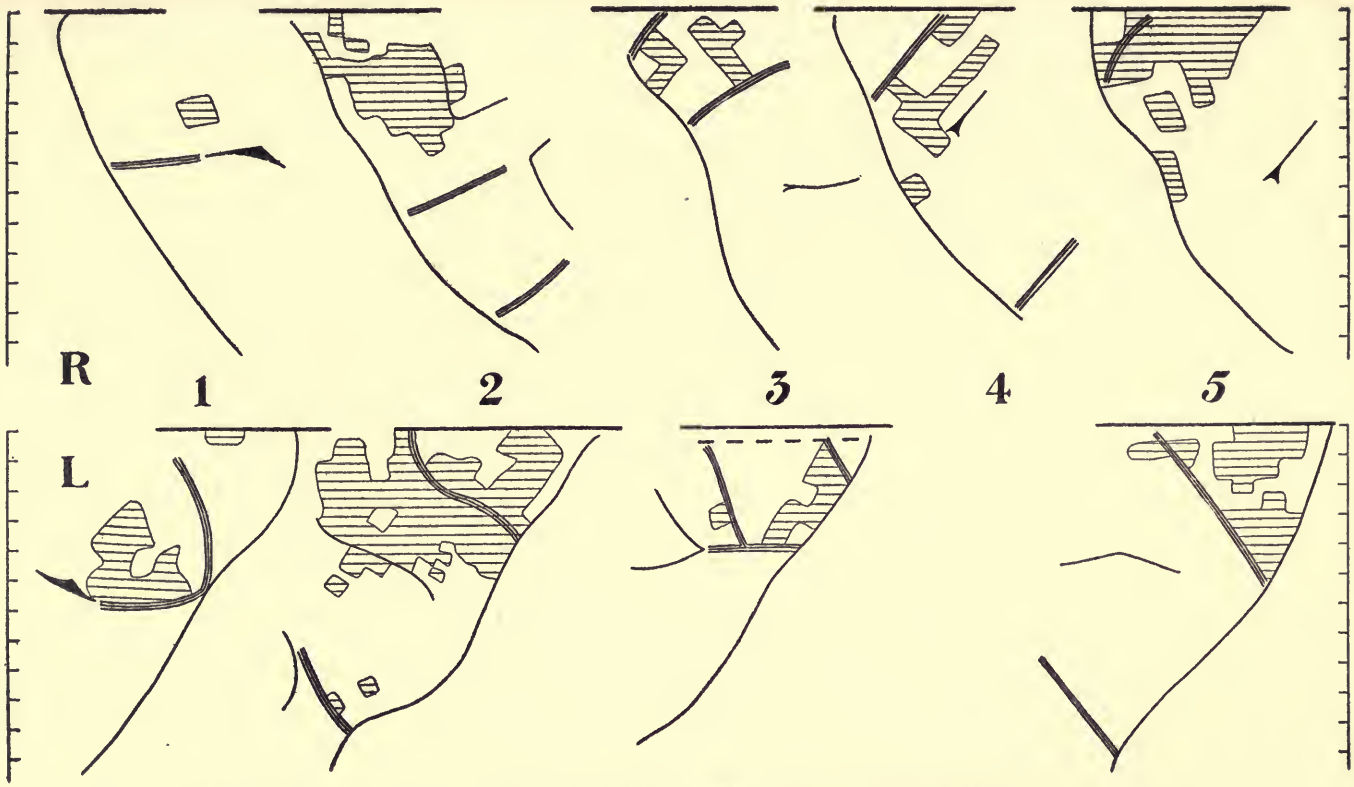

FIGURE 3. The extents of the cerebral stimulable areas for the thigh. Designations the same as in Figure 2.

observed to be much greater than those for the combined leg segments as shown in Figure 2, or than those for the arm segment as shown in the same figure. In two hemispheres, 1R and 3R, these areas do not touch the longitudinal sulcus, while in all other cases (omitting 3L which as has already been mentioned was not sufficiently investigated in this respect) the thigh areas border upon this great fissure. It is also to be noted that with the exception of the two hemispheres of monkey 1, and it may be said that the left hemisphere of this animal is a rather doubtful case in this particular, all of the thigh areas border upon the central fissure. In some of the cases the locations are suggestive of outcroppings from the central fissure, and of extensions of similarly functioning cortical zones lying within that fissure. In the same way we may consider the areas bordering upon the longitudinal sulcus although this appears a less probable explanation, except in the case of monkey 5. In all other animals there is a constriction of the area towards the longitudinal sulcus, the greater extents being on the convexity away from that zone.

The extensive variations of the area are shown in the accompanying Table III which gives numerical expression to the diagrams. Reference to this Table will be sufficient without

TABLE III. Measurements of the extents of the thigh areas. The figure marked with an asterisk is probably too low (see page 91) and the corresponding percentage R/L too high.

Monkeys	1		2		3		4	5	
Hemispheres	R	L	R	L	R	L	R	R	L
Areas in square mm.	4.5	30.0	47.5	107.0	17.5	*16.0	25.0	53.0	46.0
Percentages R/L	15		44		109		—	115	
Percentage relations of averages, Monkey 2 = 100.	22		100		22		32	65	

any textural discussion, since the data are self-explanatory. The attention of the reader is particularly directed to the two final lines in which are noted (1) the proportions of the areas in the two hemispheres of the same animals, and also (2) the percentage relations of the average extents of these areas in the five animals, using the largest average as unity.

In addition to the variations in the absolute and relative sizes of these areas the distribution of the stimulable zones is worthy of remark. With the exception of 1R, in which there appears only a small superficial area, all brains show a wide-spread distribution. In no case (except 1R) is the area solid, but the points are frequently separated by the cerebral zones for other movements or by the so-called silent or non-stimulable areas. In some cases this separation, which will also be found illustrated in some of the later diagrams, is noteworthy since the separated areas are within the zones governing the movements of the arm segments and also because they are at such relatively great distances from the main masses of the cortex which may appropriately be called the primary areas. In 1L and in 2L these separations are especially great.

Leg.—Similar variations in the extents and in the distribution of the areas governing the movements of the lower part of the leg are to be noted by inspection of the diagrams of Figure 4 and the data in Table IV. As compared with the areas for the thigh movements some hemispheres show a greater leg area (hemispheres 1R, 2R, 3R, 3L and 5R) while others (1L, 2L and 4R) show a lesser leg area. The general distribution of the areas does not differ markedly for these two segments, although the forms of the areas are not nearly the same. Both thigh areas and leg areas are located at the upper portion of the fissure of Rolando with perhaps a little more extensive advance towards the lower portion on the part of the leg area. Most of the points in both areas, as can be seen by placing the two figures together, are duplicates, indicating that the movements are combined movements of thigh and leg. In a few cases, especially in hemispheres 1R and 3L, the leg movements were not combined with movements at the thigh.

The percentage relations of the two hemispheres of the same animal and those of the average areas in the five animals are very great. It will be noticed that the relation R/L varies from

TABLE IV. Measurements of the extents of leg areas. The figure marked with an asterisk is probably too low (see page 91) and the corresponding percentage R/L too high.

Monkeys	1		2		3		4	5	
Hemispheres	R	L	R	L	R	L	R	R	L
Areas in square mm.	25.5	16.5	56.5	89.0	20.5	*30.5	16.0	60.0	46.5
Percentages R/L	155		63		67		—	129	
Percentage relations of averages, Monkey 2 = 100.	29		100		35		22	74	

63 to 155 per cent. The percentage relations of the average extents of the areas with the extents of the areas in monkey 2 as unity are also greatly different, ranging from 22 to 74. In no case do these proportions correspond with the proportions for the thigh areas, the nearest approach to correspondence being in the case of monkey 5. It can be concluded, therefore, that neither the absolute nor the relative extents of the areas for the thigh and leg movements closely correspond.

Foot.—Variations, both for absolute and relative amounts of the areas, similar to those which have already been described for the thigh and leg are also noticed for the foot areas. These are shown in the diagrams of Figure 5 and in Table V. These variations exist not only for the different animals but also for the two hemispheres of the same animal. In the latter cases, however, the correspondence is closer than in the former. If we take the net totals as standards, that is, if we take the combined stimulable zones for the arm and leg segments as standards for each hemisphere, we find that the percentages of the areas

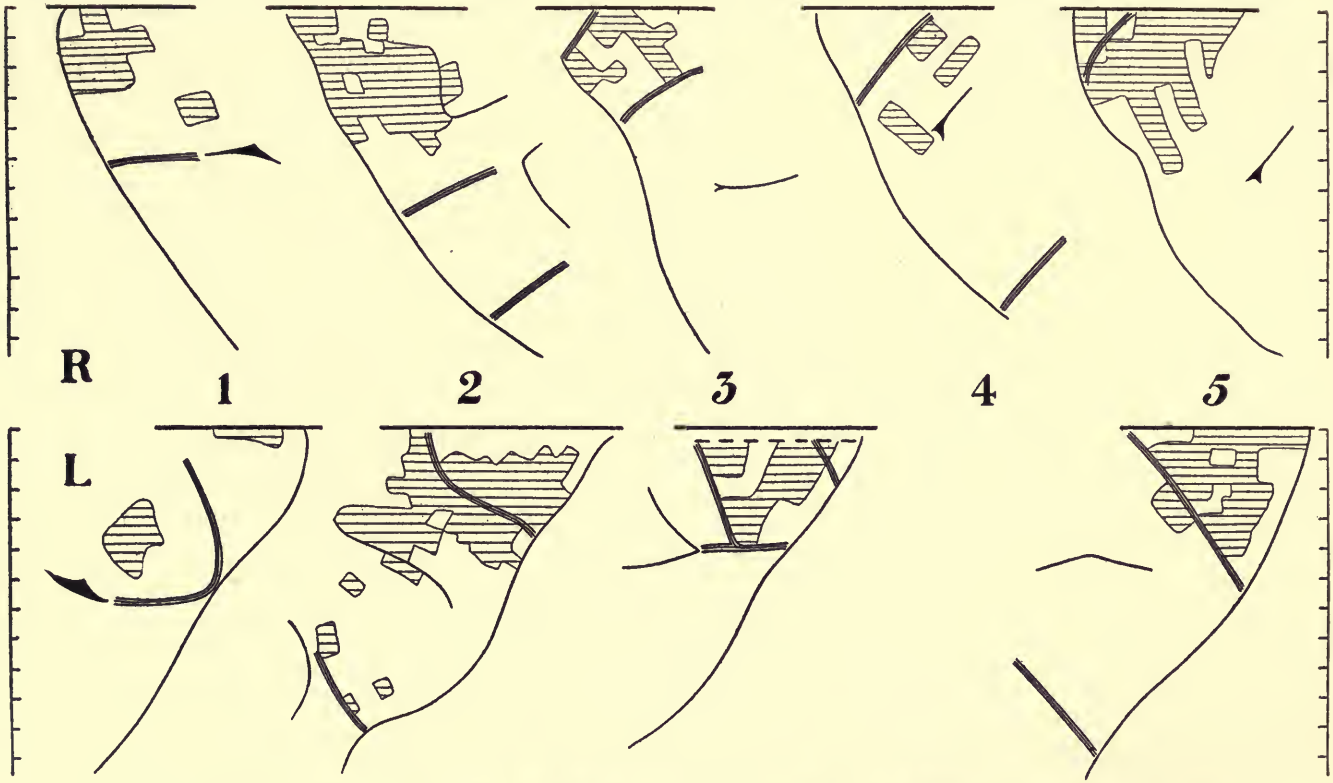

FIGURE 4. The extents of the cerebral stimulable areas for the leg. Designations the same as in Figure 2.

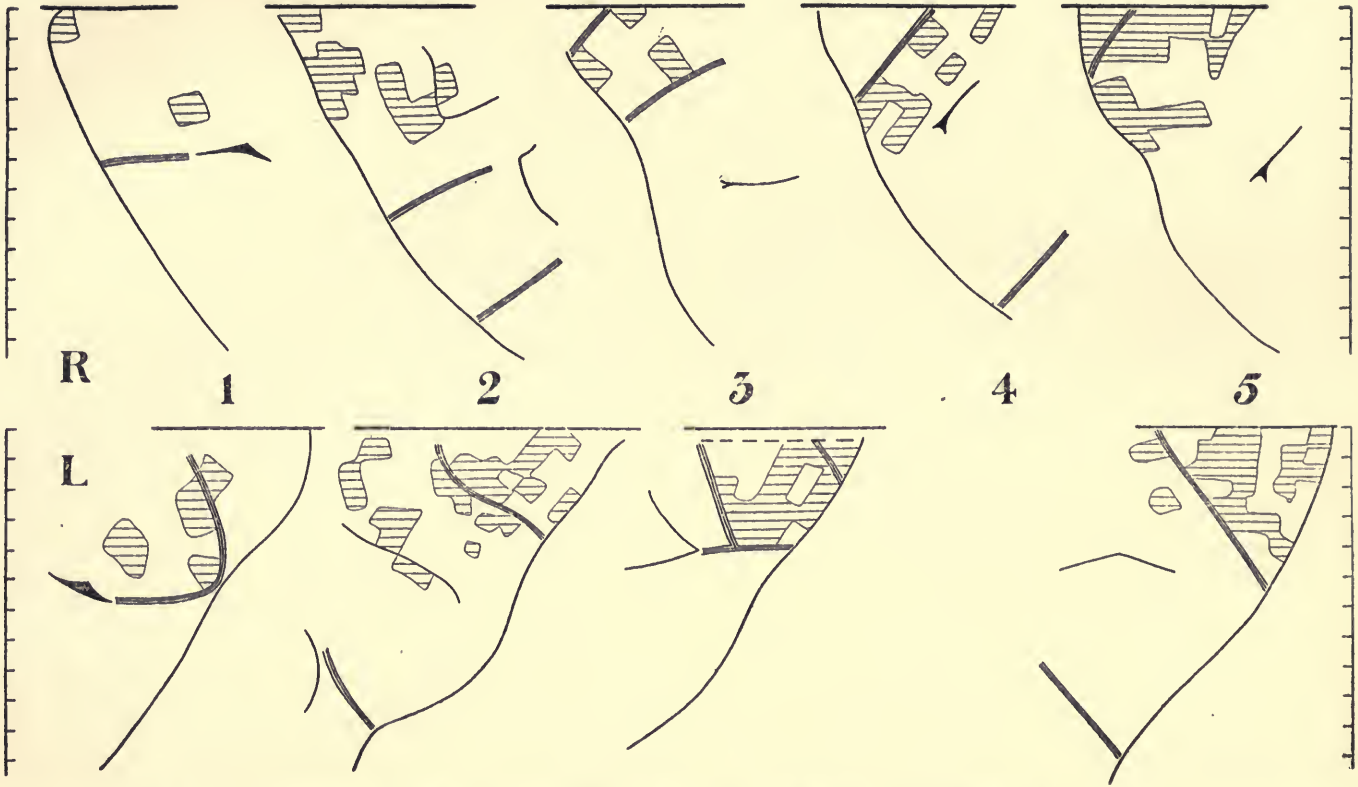

FIGURE 5. The extents of the stimulable areas for the foot. Designations the same as in Figure 2.

TABLE V. Measurements of the extents of foot areas.

Monkeys	1		2		3		4	5	
Hemispheres	R	L	R	L	R	L	R	R	L
Areas in square mm.	9.0	23.0	34.5	52.5	13.5	35.0	24.0	50.5	42.0
Percentages R/L	39		66		39		—	120	
Percentage relations of averages, Monkey 2 = 100.	37		100		56		55	163	

for the foot movements for the two hemispheres of one animal vary in two cases (monkeys 1 and 3) and do not vary greatly in the other two cases (monkeys 2 and 5). In relation to the standards which have just been mentioned we find the foot areas with the following per cents: 1R = 8; 1L = 15; 2R = 23; 2L = 25; 3R = 11; 3L = 27; 4R = 31; 5R = 36; 5L = 29. In other words the total extents of the areas governing the movements of the foot vary from 9 per cent. (1R) to 36 per cent. (5R) of the total areas for arm and leg. These percentage data do not correspond closely with the actual extents of the areas, which vary from 9 sq. mm. (1R) to 52.5 sq. mm. (2L). Nor do the relations R/L of actual measurements have the same proportions and the same serial order as the relations R/L of the percentages of the totals. This failure of correspondence is due, of course, to the varying degree of overlapping areas in the different hemispheres. The overlapping of areas does not entirely change the relative positions of the different hemispheres, however, for hemisphere 1R still remains the lowest, followed by 3R. The position of 4R is, however, considerably changed in that by this comparison it shows a relatively large area for foot movements whereas in absolute amounts it is the fourth lowest.

Comparisons of the areal amounts for the foot with those for

the thigh and the leg show many interesting relations. In the brains of monkeys 2 and 5 the foot areas are less than either the thigh or leg areas, although in both hemispheres of monkey 5 the superiority of the thigh over the foot is small and, perhaps, within the error of calculation. In 3R a similar relation holds, although on the left the reverse condition is found. In monkey 4 and in monkey 1 the relation is not constant, the thigh area being larger than the foot area in 1L and less in 1R and in 4R.

The figure illustrating the distribution of the foot areas in the different hemispheres shows other interesting variations. In a number of cases we find that, unlike the corresponding areas for the thigh and for the leg, there has been a sort of diffusion or scattering of the foot areas. The diagrammatic representation of the points of stimulation shows less of a coalesced mass and more individual patches. Whether or not this has any anatomical or physiological significance cannot be determined. A similar condition will later be noted for some of the areas for the arm segments.

Another matter which may be called to the attention of the reader is the occurrence of points or areas for "pure" movements of the foot. A careful comparison of figures 3, 4, and 5 shows that there are certain points in the foot area which have no overlapping of thigh and leg areas, and a further comparison with figure 6 shows a similar state of affairs as related to toe movements. Thus we find in 1R a small area, at the upper portion of the fissure of Rolando which borders upon the longitudinal sulcus, which is not duplicated in any of the other three diagrams for the leg movements in this hemisphere. Also in 1L there is a similar zone at the angle of the large blood vessel, and a second zone at the extreme upper portion of the area. Similar zones are found in four other hemispheres; in 4R at the extreme right upper portion, in 5R a small area in the lower part of the solid, in 5L another zone bordering upon and equidistant from the indicated extremities of the blood vessel and towards the fissure of Rolando, and in 3L a zone of this character at the left end of the solid area. It will thus

be seen that scattered throughout the solid area for the leg there is found an occasional zone for movements of one portion of the anatomical segment uncomplicated with movements of other segments.

Toes.—The relative positions of the toe areas is noteworthy. A comparison of the diagrams in Figure 3, 4, 5, and 6 shows the toe areas in 1R to be higher[6] than the thigh area and in general higher than the foot area but closely approximating the leg area. In 1L the area is massive and lies nearer the longitudinal sulcus, the thigh area, with the exception of a few points, lying lower in the field. For 2R and for 2L similar statements cannot be made, for in general the toe areas of these animals lie lower down than the areas for thigh and foot, although they approach in location the area for the leg movements. It should, however, be noted that in these hemispheres points lying much lower down than that corresponding to the toe area were found for the thigh and leg movements. In 3R the total extensity of the toe area is much less than that for any of the other leg elements but the area is apparently just as widely spread over the cerebral convexity. In 3L the area is greater than those for the other segments and to a slight degree it is more widely spread. In 4R the area is much greater and extends higher and farther backwards than the other areas. In 5R the area is the least extensive of the four leg segments and it is, unlike that for the foot and that for the thigh, compact. 5L is also an area without divisions and is more compact but only slightly smaller than the other three areas for the leg.

It is to be noted, therefore, that differences exist not only with respect to the absolute and the relative sizes of this area in the different hemispheres but also with respect to the diffusion or compactness of the area.

At the same time mention may be made of the variations which are similar to those which have already been described for the other leg segments. We find the absolute amounts of

[6] "Higher" and "lower" here refer to the diagrams, and these terms correspond to the anatomical, but more cumbersome, "nearer the longitudinal sulcus" and "farther from the longitudinal sulcus" respectively.

the areas differing in the different animals, and at the same time differing in the two hemispheres of the same animal. Moreover we find the relative amounts of the areas widely different for the different animals and for the two hemispheres of the same animal. In this respect there is an agreement with the other areas which have previously been described. In 1L, 3L, and 4R the toe areas exeed those for the thigh, for the leg, and for the foot; in 2R, 2L, 5R, and 5L the toe areas are exceeded by those for the other hind limb segments, although the excess in the case of 5L is slight and well within the observational error. The variations in totals are not as great as those which have been noted for the other leg segments, nor do the percentages in relation to the total stimulable areas vary as much. The hemisphere to hemisphere variations, with the exception of those of the brain of monkey 5, are considerable and differ in some cases by as much as 1 to 2.5. The results, diagrammatic and numerically, are given in Figure 6 and in Table VI.

Shoulder.—The totals of the shoulder areas range from 11.5 sq. mm. (4R) to 80.5 sq. mm. (2R), with percentages in relation to the net totals (leg and arm segments together) ranging from 15 (4R) to 54 (3R). The differences in amount of the

TABLE VI. Measurements of the extents of toe areas.

Monkeys	1		2		3		4	5	
Hemispheres	R	L	R	L	R	L	R	R	L
Areas in square mm.	24.0	51.0	20.5	52.5	16.5	45.0	33.5	37.0	41.0
Percentages R/L	47		39		37		—	90	
Percentage relations of averages, Monkey 2 = 100.	103		100		84		92	168	

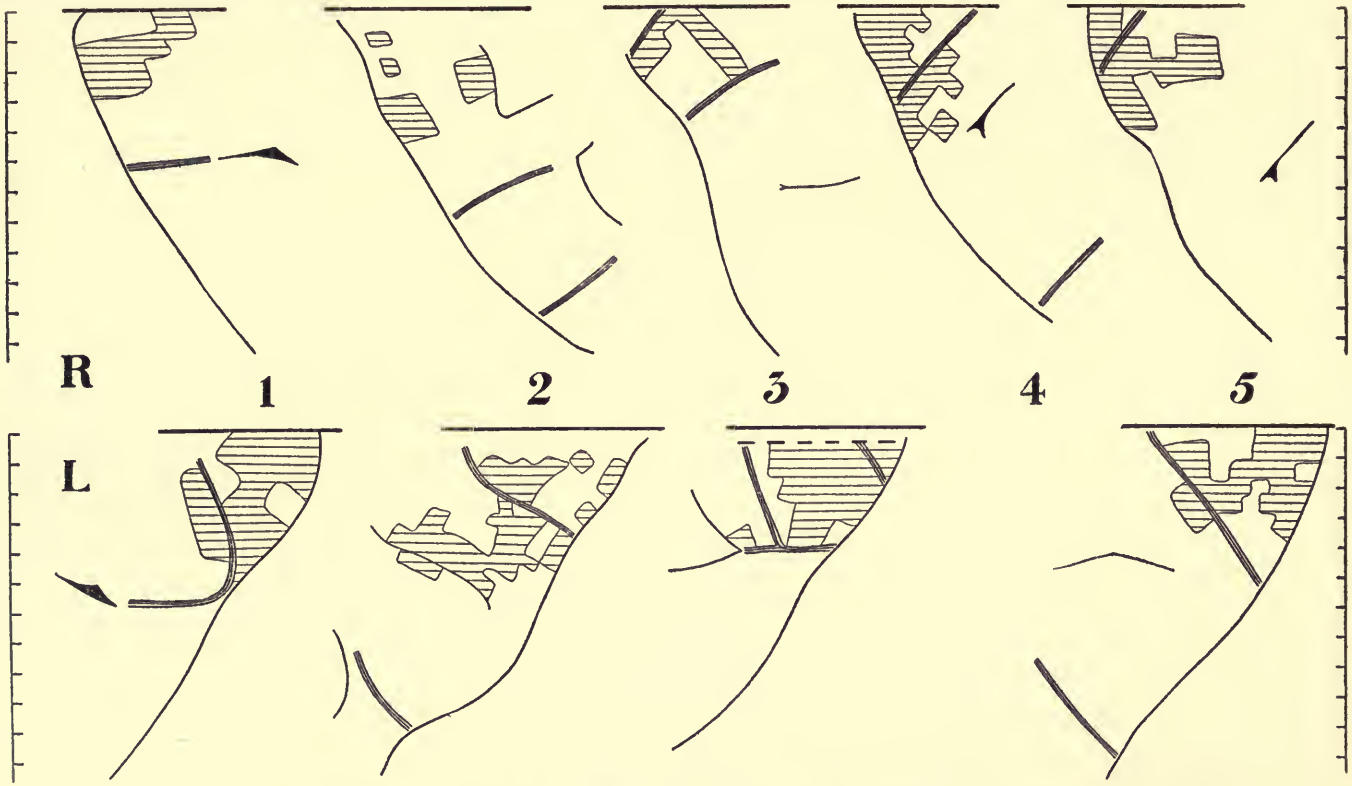

FIGURE 6. The extents of the cerebral stimulable areas for the toes. Designations the same as in Figure 2.

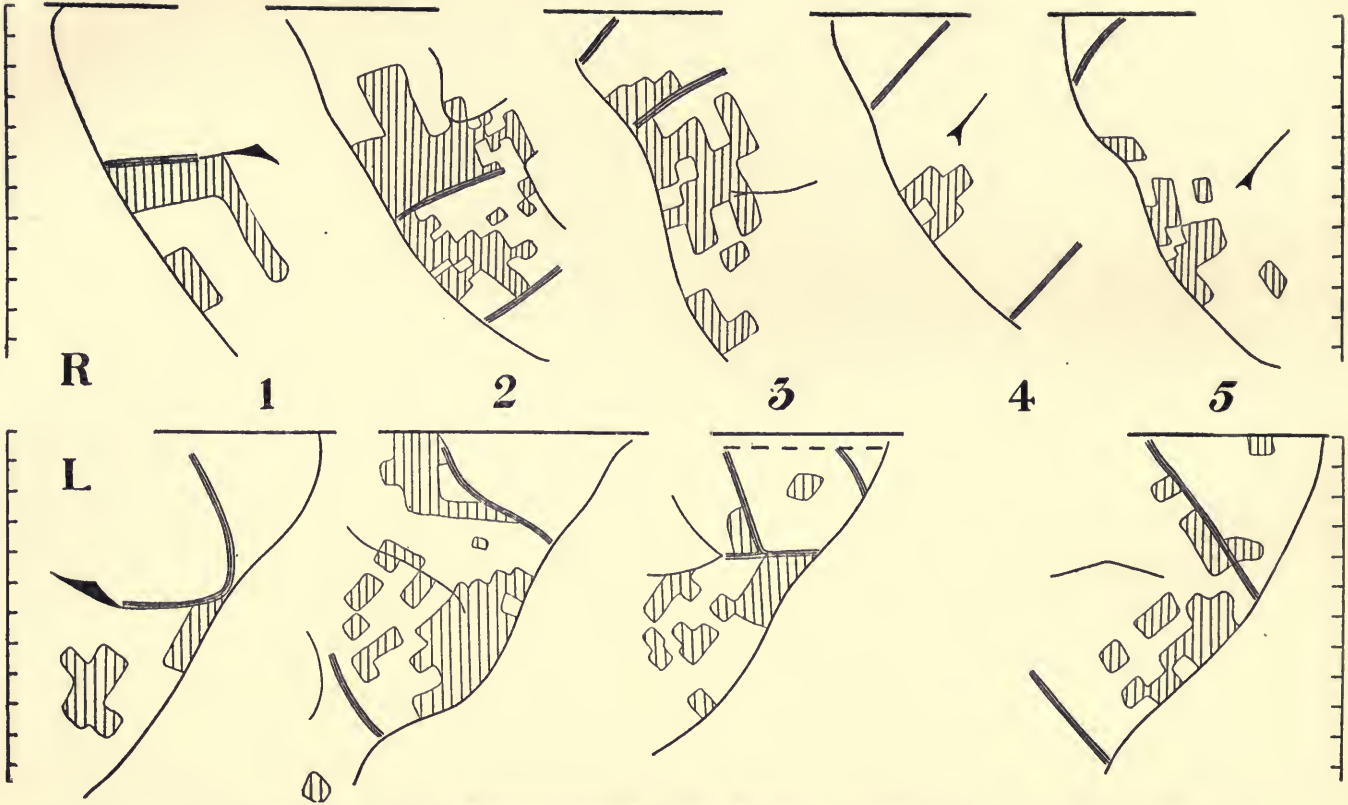

FIGURE 7. The extents of the cerebral stimulable areas for the shoulder. Designations the same as in Figure 2.

TABLE VII. Measurements of the extents of shoulder areas.

Monkeys	1		2		3		4	5	
Hemispheres	R	L	R	L	R	L	R	R	L
Areas in square mm.	37.0	25.0	80.5	79.5	67.5	32.0	11.5	26.0	48.0
Percentages R/L	148		101		211		—	54	
Percentage relations of averages, Monkey 2 = 100.	39		100		62		14	46	

areas in the five animals are greater than in any previous area and also greater than any of the areas for the other arm segments. The amounts and the illustrations of the distributions of these areas are shown in Table VII and in Figure 7. In relation to the four leg segments which have already been considered there are four hemispheres in which the shoulder area exceeds each of the leg segment areas (1R, 2R, 3R, and 5L), there are two hemispheres in which the shoulder area is less than each of the leg segment areas (4R and 5R) and three hemispheres in which two of the leg segment areas exceed and the other two are less than the shoulder areas.

The variations from hemisphere to hemisphere parallel those which have already been discussed for other segments, the greatest difference being found in monkeys 3 and 5, where the differences are approximately 100 per cent.

In addition to the differences which have been mentioned, the wide-spread distribution of the shoulder areas, especially in hemispheres 2L, 3R and 5L, is noteworthy. At the same time the discreteness of the zones is a prominent feature in the illustrations. There is also to be noted the relation of the areas to the central fissure. In regard to this it will be observed that the areas have the same general features as do those for the thigh movements in that some of them appear to be outcropping

or projections from the concealed fissural areas, whereas others are less apparently related to those hidden areas. At the same time in some hemispheres there is an apparent sharp definition of the areas by the principal blood vessels and by fissures other than that of Rolando. While from the facts now at hand it cannot be said that these divisions by fissures and by the principal blood vessels have any special physiological significance the finding of this in relation to several areas gives an indication that these landmarks may have some physiological as well as anatomical meaning. An examination of all the diagrams is suggestive of this conclusion, but the matter needs a more extensive and a more careful study with a definite question in view.

Forearm.—The apparent outcropping of the zones for the forearm from similar areas located within the infoldings of the fissure of Rolando is more noticeable than in any other previously considered segment. In every hemisphere there is a considerable extent of forearm area bordering upon the central fissure and moreover the areas appear more solid than those for the shoulder movements. This does not mean, however, that the phenomenon of diffusion is lacking for in fact an examination of the diagrams of Figure 8 reveals a marked degree of separation of the areas in 2R, 2L, 3R, and 5R.

Table VIII gives the measurements of these forearm areas

TABLE VIII. Measurements of extents of forearm areas.

Monkeys	1		2		3		4	5	
Hemispheres	R	L	R	L	R	L	R	R	L
Areas in square mm.	55.0	56.0	89.5	92.5	80.5	63.5	24.0	54.0	52.5
Percentages R/L	98		97		127		—	103	
Percentage relations of averages, Monkey 2 = 100.	61		100		79		26	59	

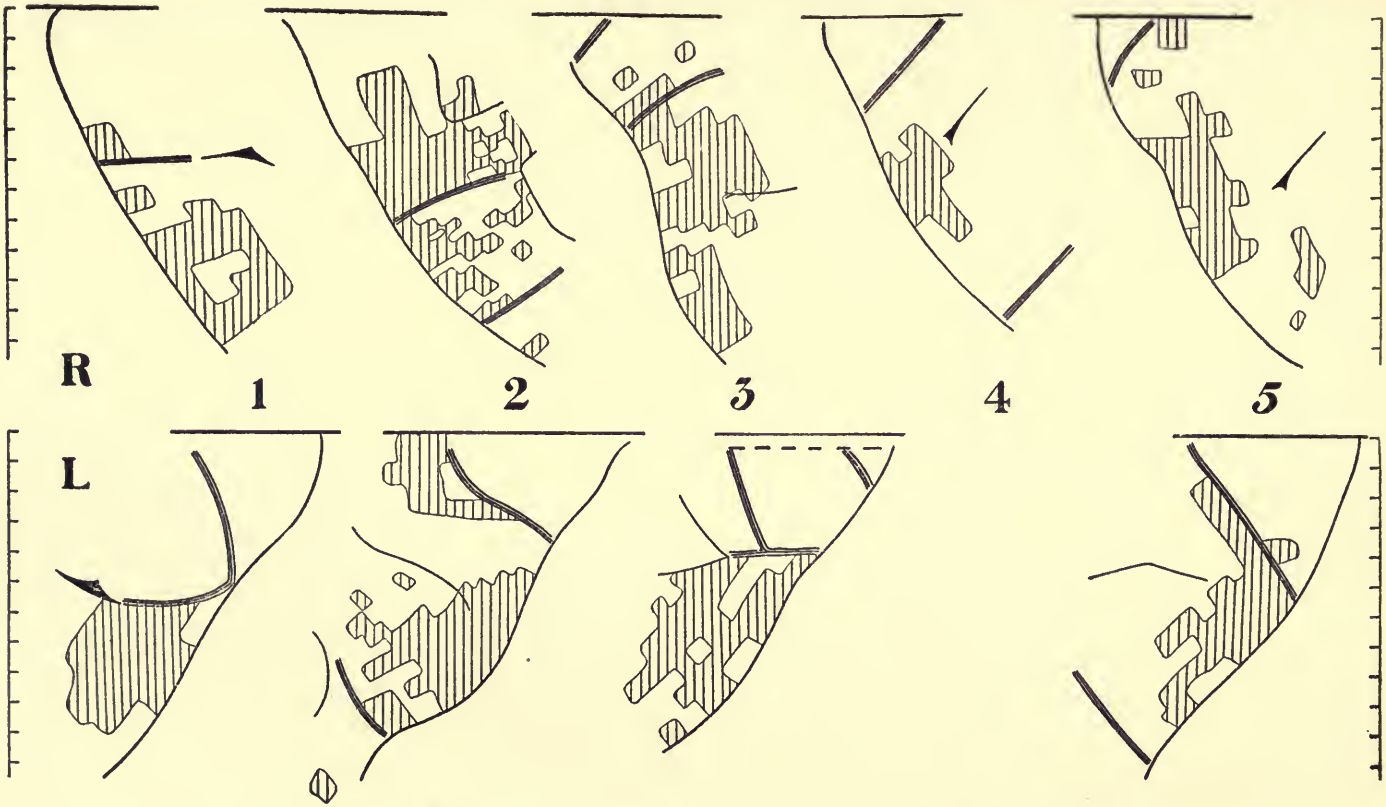

FIGURE 8. The extents of the stimulable areas for the forearm. Designations the same as in Figure 2.

in the nine hemispheres. Here are shown almost as great differences as have been shown to exist for the other areas already dealt with, for in one case (monkey 4) we find the area only about one-quarter the size of that in monkey 2. In two animals (monkeys 1 and 5) the areas are not only nearly equal but the two hemispheres are also approximately of the same size. This is the closest correspondence which is to be found in the whole series but I hesitate to conclude that it has any great significance.

In three animals the proportions R/L are nearly equal (monkeys 1, 2 and 5) which again is a condition not found for any other area, but which I also doubt has any well marked significance. The reason for this is to be sought in the varying relations of the extents of these areas to the net total (leg plus arm segments) areas. When this comparison is made it is to be observed that no close correspondence exists except for the two hemispheres of monkey 5. By this comparison the two forearm areas of monkey 1 differ by 25 per cent., those of monkey 2 by an almost equal amount, and the differences in the relations of the hemispheres of monkey 3 are also approximately equal.

Hand.—The data regarding the extensions of the areas controlling movements of the hand are given in Table IX and in Figure 9. Unlike many of the areas which have previously been considered these areas are not massed but are widespread

TABLE IX. Measurements of extents of hand areas.

Monkeys	1		2		3		4	5	
Hemispheres	R	L	R	L	R	L	R	R	L
Areas in square mm.	39.0	39.5	42.0	58.5	37.0	18.5	11.0	32.0	16.5
Percentages R/L	99		72		200		—	193	
Percentage relations of averages, Monkey 2 = 100.	78		100		55		22	48	

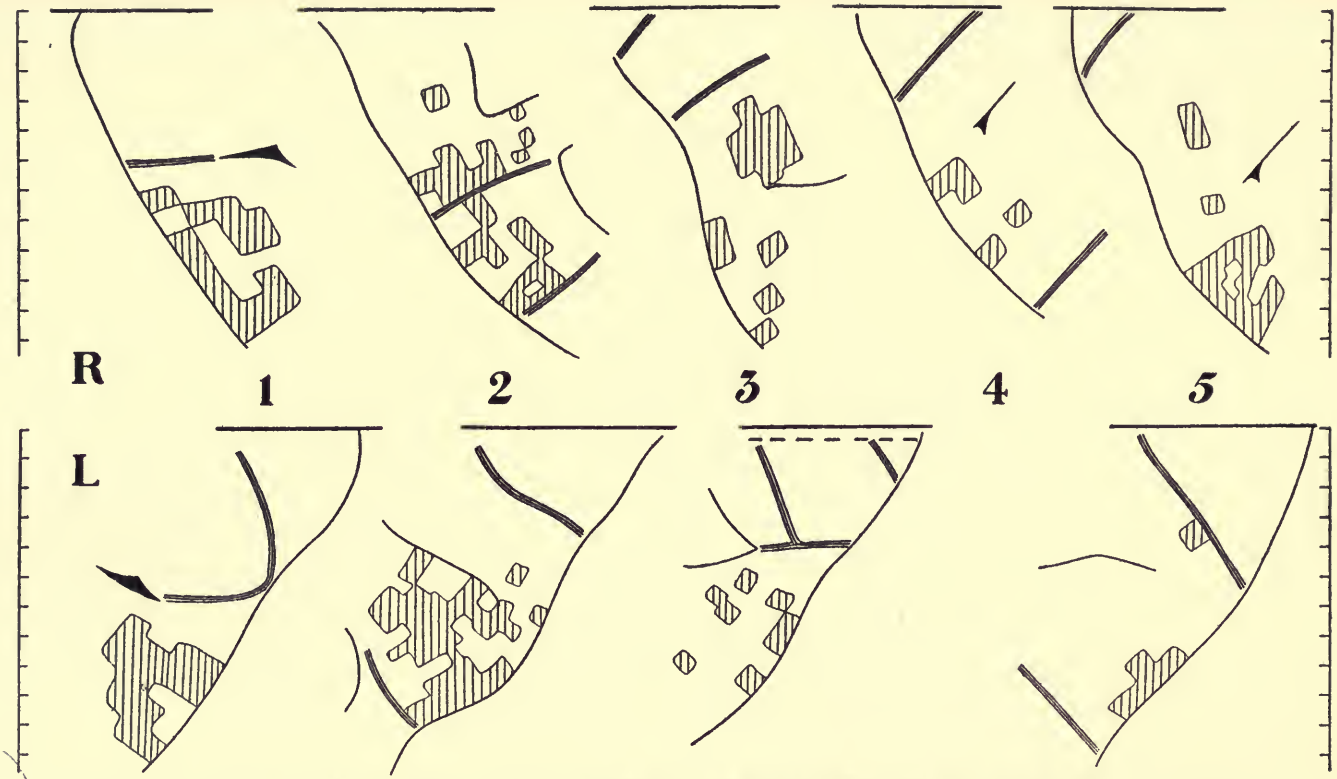

FIGURE 9. The extents of the stimulable areas for the hand. Designations the same as in Figure 2.

and divided relatively more than any of the leg segment areas and the arm segment areas with the exception of those for foot movements. The average extent of this area for all hemispheres (32.7 sq. mm.) is less than that of the other segment areas with the exception of the foot areas (average 31.7 sq. mm.) and the variations are considerable. Although the average extent of this area is among the smallest it has wide variations, for in monkey 1 it is exceeded in each hemisphere by but two of the other areas, in monkey 2 it is exceeded in each hemisphere by four other areas, in monkey 3 it is exceeded on the right by three areas but on the left by six areas, in the one hemisphere of monkey 4 it is exceeded in extent by seven areas, and in monkey 5 on the right by seven areas and on the left by all other areas.

The variations in absolute size in different hemispheres are great, from 11 (4R) to 58.5 sq. mm. (2L), a ratio of 1 : 5.3. Its relation to the net total is less variable, from 11 (5L) to 34 (1R), although the ratio is slightly greater than 1 : 3. In only one animal (monkey 1) are the areas for the two hemispheres nearly equal in size, although in relation to the net totals the equality is greater in a second animal (monkey 2).

The percentage relations of R/L show only one instance which has previously been considered (shoulder area of monkey 3) in which the difference is as great as is found in monkeys 3 and 5 for the hand areas. These figures should, however, be considered to be no more than suggestive for in many previous cases (for example, thigh areas of monkeys 1 and 2, foot areas of monkey 1 and 3, toe areas of monkeys 1, 2 and 3, etc.) if the reverse percentages L/R had been used as a basis of comparison the differences would have been much greater in these other hemispheres.

The apparent punctiform character of the area under consideration is obvious in a number of the hemispheres. Although exceeded in size in most instances by the other areas the number of divisions greatly exceeds those for the leg and toes, slightly exceeds those for the thigh and fingers, and is exceeded only slightly by the foot and forearm areas and to a greater degree

by the shoulder areas. For such a relatively small area this wide-spread distribution is noteworthy.

In form the areas under consideration are widespread, the scattering being such as to make the different hemispheres appear to be without resemblance, and this statement is true for the two hemispheres of the same animal as well as for the hemispheres of different animals. The relation of the areas to the central fissure is not constant, not more than one-half of the areas in the nine hemispheres having close association with this fissure. With the exception of a slight relation to a subsidiary fissure in 2L the areas do not appear to bear a close relation to the other fissures and principal blood vessels, and to employ again the figure of speech which has previously been used it may be said that most of the cortex which responded with movements of the hand appears to be outcroppings from the depths or upward projections from possible underlying areas.

A comparison of the total areas in Table IX with those in Tables VII and VIII shows that in all hemispheres the hand area is less in extent than that for the forearm and in monkeys 2 and 3 less than that for the shoulder, but in monkey 1 it is greater than that of the shoulder area while in monkeys 4 and 5 the relations are irregular or undecided.

If the data which have been given were to be interpreted in a manner which is not infrequent we might conclude from the relative measurements that in general the hand of these monkeys has only the same amount of cerebral control as the foot, but that in specific instances the hand has a greater amount of cerebral control and in other cases the foot is the part best represented in the cortex. Such a conclusion appears to me obviously premature, for even though it may prove to be true, at present we do not know exactly what cortical stimulability means and I believe we should not conclude from a comparison of two sets of measurements that we are dealing with information regarding lesser or greater cerebral control. The movements of the hand areas, it will later be noted, are more often associated with movements of the other arm segments than are those of the

foot with the other leg segments, and the matter of greater or lesser cerebral control appears to me to be bound up with the character of the distribution as well as with the superficial extents of the areas from which such movements may be produced by stimulation methods. It seems to me, therefore, that the element of complexity is an important factor, and that the question of the greater or less control should be considered only in the light of all the data for all the segments.

Fingers.—Figure 10 and Table X contain the results relative

TABLE X. Measurements of extents of finger areas.

Monkeys	1		2		3		4	5	
Hemispheres	R	L	R	L	R	L	R	R	L
Areas in square mm.	55.5	15.0	40.0	57.5	41.0	46.5	10.0	35.5	40.5
Percentages R/L	370		70		89		—	88	
Percentage relations of averages, Monkey 2 = 100.	72		100		90		21	78	

to the areas for finger movements. Although some of these areas are smaller than the corresponding areas for the hand they average about fifteen per cent more than the latter. In only a few cases are the differences great enough to warrant note, the variations in hemispheres 1L and 3L and 5L being the greatest.

The comparative range of the areas for all hemispheres is approximately 1 : 6, which is nearly the same proportion obtained for most of the areas which have previously been dealt with. The diagrams of Figure 10 show the closer relation of the areas to the central fissure than is to be found with some of the other areas, since comparatively large portions of this area border upon this fissure. This, in other cases, has been considered to be an indication of the possibility that large or small cortical areas

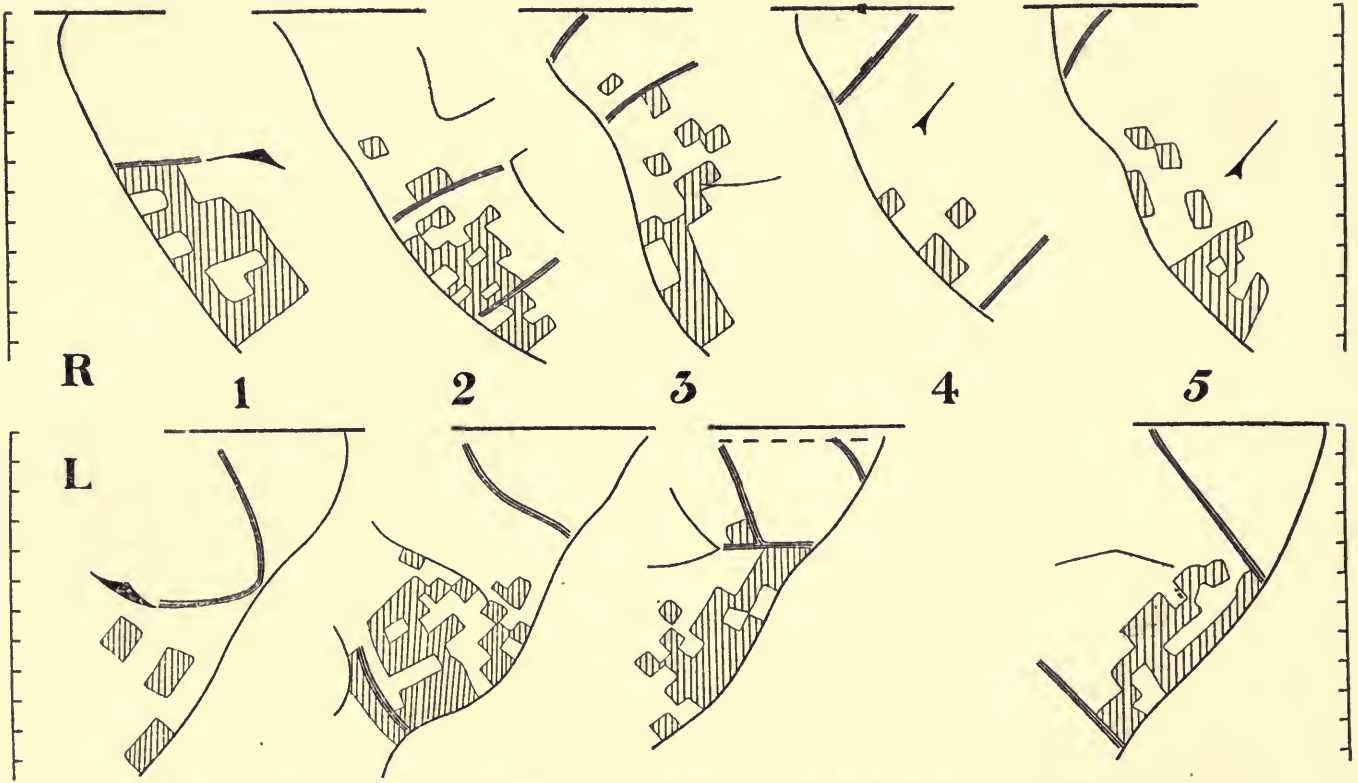

FIGURE 10. The extents of the stimulable areas for the fingers. Designations the same as in Figure 2.

for such movements may be concealed within the Rolandic fissure. If this be true the sizes of the finger areas would be much greater than those which are shown in the diagram and in the table.

General.—For purposes of comparison I think we are justified in combining the totals of the stimulable areas regardless of overlapping, especially since these totals in relation to the net totals will give some indications of the extents of the overlappings from area to area, and consequently they also give indications of the complexities of the movements of the different hemispheres. The general relations are shown in Table XI. In this table

TABLE XI. The overlapping of areas for the leg and arm segments. The totals of all areas were obtained by adding the totals for each hemisphere, and the amounts of overlapping by subtracting from these figures the "net totals" given in Table II.

	1		2		3		4	5	
Hemispheres	R	L	R	L	R	L	R	R	L
Totals of all areas	249.5	256.0	411.0	589.0	294.0	287.0	155.0	348.0	333.0
Net totals	115.0	157.0	152.0	215.0	124.0	132.0	78.0	139.0	144.0
Overlappings	134.5	99.0	259.0	374.0	170.0	155.0	77.0	209.0	189.0
Per cent. overlappings in relation to net totals	117	63	170	174	137	117	99	150	131

are shown (*a*) the totals of the areas which have been considered, that is the sum totals of the thigh, the leg, the foot, etc., areas for all nine hemispheres, (*b*) the net totals, that is the amount of superficial space covered by the areas, (*c*) the differences between these sets of figures, which give the total amounts of overlapping of the individual areas, and (*d*) the percentage relations of the amounts of overlappings to the net totals of the hemispheres. It is obvious that if the series of stimuli on one hemisphere produced a combined movement of all the segments which we have been considering there would be a total of over-

lapping amounting to 700 per cent of the net total for that hemisphere, because each of the segments would be totally represented in the grand total. The greater percentage of overlapping is, therefore, an indication of greater complexity of movement. In the next section we shall deal with the special overlappings of the arm segments in the leg area and of the leg segments in the arm areas and here we shall confine ourselves to the consideration of the special overlappings of the arm segments among themselves and of the leg segments among themselves. This includes at the same time the borderline overlappings, since these border areas cannot be considered to be distinctively either arm or leg areas.

The smallest amounts of overlapping was found in 4R and in 1L, the greatest in 2L and in 2R. The differences in this respect range from 77 to 374 sq. mm., or approximately 1 : 5. In relation to the net totals, probably a fairer means of comparison of the individual hemispheres with one another, the range is from 63 to 174 per cent, or approximately 1 : 3. An interesting fact is that in 1R, in which it has been noted (p. 96) that no overlapping of leg and arm areas occurred, the total amount of the overlapping exceeded that of 4R, in which leg-arm overlapping was found, and the total amount of the overlapping is not markedly less in 1R than in 3L in which the amount of overlapping of the leg and arm segment areas is considerable. At the same time the percentage relations give equally interesting figures regarding the same thing, for it is to be observed that the percentage of overlapping in 1R is greater than that of 4R, equal to that of 3L and is not greatly exceeded by that of 5L, in all of which hemispheres the amount of overlapping of the leg-arm areas is not especially small. This indicates that in hemisphere 1R there has been a more general complexity of movement for the two segments we have considered than for the other hemispheres just mentioned since a certain percentage of the overlappings in the other hemispheres is due to combinations of arm and leg movements. The low percentage in 1L may be considered a typical example of what may be expected when the two segments have not overlapped.

The complications or the combinations of movements are also

shown by the number of cases in which the areas for one segment overlap those of the other segments. These data for the leg segments are shown in Table XII and those for the arm segments

TABLE XII. Overlappings of leg segment areas. Digits represent the numbers of hemispheres in which overlapping occurred. The total possibilities are nine in each case.

Segments	Toes	Foot	Leg	Thigh
Toes	—	8	8	7
Foot	8	—	9	9
Leg	8	9	—	9
Thigh	7	9	9	—

in Table XIII. In these tables there are shown the total numbers

TABLE XIII. Overlappings of arm segment areas. Digits represent the numbers of hemispheres in which overlapping occurred. The total possibilities are nine for each case.

Segments	Shoulder	Forearm	Hand	Fingers
Shoulder	—	9	9	8
Forearm	9	—	9	9
Hand	9	9	—	9
Fingers	8	9	9	—

of cases in which overlappings occurred, not the individual points in the areas, and consequently not the totals of the areas or the total portions of the cortex representing the areal distribution of movements of the segments. If one area, for example that of the shoulder, should have an overlapping in all hemispheres it is clear that the table would show a total overlapping in nine hemispheres. Similarly for the other segments. When the number is less than nine, it means that in one or more hemispheres at no time in the whole series of experiments upon those hemispheres did combined movements of the two segments occur. The tables show that in two cases (1R and 1L) there was no overlapping of the thigh and the toe areas, in one case (1R) there was no overlapping of the foot and toe areas, and in one case (1L) there was no overlapping of the toe and leg areas. In view of the fact that in 1R no overlapping took place of thigh

and toe, and foot and toe, the small percentages of overlapping is understandable, and this is the more noticeable also because of the failure to find from cortical stimulation in this animal combined movements of the arm and leg.

The almost universal overlapping in the arm segments areas indicates the general complexity of the movements which were obtained by the stimulation of the cortex in this area, and at the same time it shows that the complexity is found in all hemispheres with the exception of shoulder-finger relations of hemispheres 1L. It does not show, however, that there is the same degree of complexity for all other hemispheres, for to settle the latter matter there must be a comparison of the individual points which it is not possible to make at this time. It may be said, however, that there are considerable variations in complexity (hemisphere and animal) shown by the examination of the protocols of the individual tests, and these are partly indicated by the differences in the totals of overlappings which are shown in Table XI. It may be repeated that the results in Tables XII and XIII do not mean that there has been a total overlapping of all segments in all hemispheres for all the points which were stimulated. In fact from Table XI we can conclude that at the most (2L) there has been less than two-thirds of the total possible amount of overlapping and in most cases the amount of the overlapping is not more than two-sevenths of the possible total, and usually much less than this amount. If there were no overlapjpings of arm and leg segments and there was a complete overlapping of the areas for the individual parts of the segments, which would mean that when any motor point was stimulated the resulting reaction would be a movement of thigh + leg + foot + toes, or a movement of shoulder + forearm + hand + fingers, we should have a total overlapping of 300 per cent. A considerable amount of overlapping occurs in relation to the leg and arm segment areas so that the greatest recorded amounts (2L, 374 per cent) are made up of extra-segmental overlappings and of inter-segmental overlappings. Table II, column 6 (p. 98) shows the amount of extra-segmental overlappings, and the figures should be subtracted from those in Table XI. It should also

be remembered that the figures in Table II do not represent the totals of extra-segmental overlappings but only those of total-leg and total-arm, for such overlappings may be of two or more parts of each of the two segments (arm and leg) with which we have been dealing. When, however, the subtraction which is suggested has been made we find that there is a noticeable reduction in some of the figures in Table XI. At the same time it should not be thought that in dealing with the relation of the cerebral cortex to complexities of movement such subtractions should be made, for in general it is true that the greater the overlappings the greater is the degree of movement complexity.

Thus, stimulation of the cortex at the border of the two large areas produced complex movements of the two totalized segments. We found for example movements of all the arm segments towards the leg and at the same time complementary movements of the leg towards the arm. Such movements are well represented by those of the intact animal when he wishes to scratch his leg, but makes only part of the movement, that pertaining to the approach of the hand and fingers to the leg and a similar approach of the leg towards the hand so that the latter has a better chance for scratching. Also, such a movement as the transfer of food from the hand to the foot is of this complex type, and similarly with movements which simulate or resemble those of the simultaneous use of the arm and leg segments in the act of taking hold of the bars of the cage. Such movements are on the other hand not always simultaneus, not infrequently it was found that after the arm had made a definite movement the leg would make a movement succeeding that of the arm.

Summary.—The data show that in different animals and in different hemispheres a variety of distribution of the areas concerned with the movements of the individual segments of the leg and arm. In addition to this variation in distribution, variations in the total amounts of the different areas were found, which when averaged for all hemispheres show the forearm area of greatest size, with the foot area of the smallest average size, and between these extremes and in serial order the areas for

the shoulder, the leg, the thigh, the fingers, the toes, and the hand. It will be noticed that in all cases the average of a segment of the arm exceeded in areal size that of the corresponding segment of the hind limb, *i.e.,* the area for the shoulder movements was on the average greater than that for thigh movements, that for forearm movements greater than that for leg movements, etc. In the individual hemispheres such relations do not exist, in some cases the leg areas being correspondingly larger than the arm areas. At the same time the serial order for the segments is not the same for all animals, in one case the thigh area being the largest, in another hemisphere the forearm area being the largest, etc. The shapes of the corresponding areas in the nine hemispheres did not approximately correspond nor was there a correspondence of the spatial relations of the areas to such well marked anatomical landmarks as the central fissure, the longitudinal sulcus, etc. In a few cases the anatomical dividing lines appeared to have a certain physiological significance, but in other cases, and especially in relation to certain areas, this was not indicated. In all hemispheres excepting those of one animal there was found a greater or less overlapping of the areas for the leg and arm segment movements, which was shown by the production of combined reactions of these segments. In all hemispheres without exception there were found overlappings of the areas for the individual segments of the leg and arm, which was shown by the complex movements of these parts. These overlappings varied in all hemispheres, by which is meant that the stimulation of the cortex of some hemispheres resulted in more of the complex movements than did that of others.

IV. ANOMALOUS DISTRIBUTIONS OF THE STIMULABLE AREAS

Arm movements within the leg areas.—In the broadest sense we may consider that the leg segment area is that area within which stimulation produces leg movements, and the arm area that area within which stimulation produces arm movements. Taking this definition of the areas we should need to consider that the leg areas or the arm areas are not massed but are spread over the precentral cortex as widely as the zone in which a stimulation at any point produces such movements. For a better limitation of the areas we must not deal with the widely spreading areas in this manner, but limit the designation of the individual areas to those solid-like combinations of zones in which the special character of movements are uniformly or nearly uniformly obtained. By thus dealing with our results we can say that in general there is a leg area separate and distinct from, but contiguous to, the arm area, and that there is a similar arm area, but that between the two areas there is an intermediate zone which is allied to both, or which is both, and which can be considered to be a combined arm and leg area.

By the limitation or the definition of the areas in this manner we find that there remain certain areas or points within each of the principal areas which are associated with the production of movement of another segment separate from the segment with which the area has definite connections. Thus we find that arm movements are sometimes produced by the stimulation of areas which are enclosed on all sides by zones which are distinctively leg movement areas since only leg movements are produced by the stimulation of the cortex in these regions and at the same time there are arm areas within which stimulation sometimes produces leg movements. These areas are different from the bordering areas in that the results are unlike those for the surrounding zones, and are therefore to be considered anomalous, while the bordering areas are "normally" the combinations which are expected in view of the continuity of the whole stimulable zone.

An examination of Figure 2 shows that there are no bordering combination areas in the hemispheres of monkey 1 but that such areas are found in all the other hemispheres. It will also be observed that there are no anomalously distributed areas in the hemispheres of monkey 1 and none in 2R, but that the other six hemispheres show anomalous areas. In 2L we find an area of this character with a considerable extensity having its upper border contiguous to the longitudinal sulcus and extending downwards towards the fissure of Sylvius along the principal blood vessels which is illustrated in the diagram. We also find in this hemisphere a small area which is related to arm movement control, for movements of the shoulder were produced by the stimulation of this area although the stimulation of the same points gave leg movements and the stimulation of the surrounding areas also gave purely leg movements. Similar zones were found in the hemispheres of monkey 3; on the right at the extreme frontal border of the area points were found the stimulations of which were followed by movements of the forearm as well as of the leg segments, and on the left side a similar zone in the center of the leg area the stimulations of which produced simultaneous movements of the segments of the leg and of the shoulder. In monkey 5 there were also found on the right side a combined area bordering upon the longitudinal sulcus which stimulations showed was associated with the production of forearm movements as well as with leg movements, and a second area somewhat lower in the field which gave similar combinations of forearm and leg movements, in the left hemisphere of this animal the combined area bordering upon the longitudinal sulcus gave movements of the shoulder in addition to the leg segment movements which were noted in the protocol of the experiment as follows: "extension of toes, followed by extension of the leg and thigh, and a movement of the tail to the right, with a mass movements of the arm such as is made when lifting the shoulder."

The general results regarding the amounts of overlappings of the arm and leg segment areas are shown in Table XIV. This table shows only the general view of the relations as indicated by the overlappings of the different areas, without considering the

TABLE XIV. Overlapping of leg and arm segment areas. Digits represent the numbers of hemispheres in which overlapping occurred. The total possibilities are nine in each case.

Segments	Toes	Foot	Leg	Thigh
Shoulder	3	4	4	5
Forearm	4	4	6	5
Hand	1	2	3	3
Fingers	0	0	2	2

spatial character of the overlappings. Thus, for example, the total number of possible overlappings is nine in each case, and we find that in no case do we get an overlapping of the toe area onto the finger area, that in general the segments close to the trunk show the greatest number of overlappings, both with respect to one another and also with respect to the more peripheral segments. This would indicate a possible closer relation of the thigh movements and the movements of the hand and fingers, and a possible closer relation of movements of the shoulder with movements of the foot and toes. Until the movements are analyzed to a greater degree than is done at this time this can be taken only as a suggestion.

Leg movements within the arm areas.—The number of anomalous movements of this character is less than that of the arm movements in the leg areas. In 2L, on the outer border of the arm area, there is a small area the stimulation of which produced movements of the thigh and of the leg, and at the frontal edge of this area the stimulation was followed by knee flexions independent of any movement of the parts of the arm segment. At the lower portion of the arm area, far removed from the main mass of the leg area, two small areas were discovered which gave movements of the thigh and leg as well as movements of the arm segments, in one case the leg movements being combined with movements of the hand and fingers and in another case with movements of the forearm. In 4R thigh and leg movements were found to accompany stimulation of the area in the central portion of the large arm area where the latter bordered upon the fissure of Rolando.

Only two hemispheres, therefore, showed the presence of leg movements within the arm areas while five hemispheres of the total of nine showed arm movements within the leg areas. Although it is not possible at this time to determine the import of these variations it appears probable that they indicate a greater degree of ease of liberation of the arm movement impulse or a greater degree of complexity of arm connections. Allied to the results which have been considered in the preceding paragraph similar results were obtained which indicate the complexity of these movements and of the movement control. In 3R head movements in combination with movements of the shoulder were obtained by the stimulation of the cortex at the uppermost part of the arm area although the characteristic area for head movements lies lower in the field, approximately below that for the arm segments. In the same hemisphere head movements were found to follow the stimulation of the area close to the bifurcation of the subsidiary fissure which is shown in the diagram. This is far removed from the principal head area. At the same time mention may be made of the fact that in 4R the stimulation of the area which is shown as a blank space bordering upon the fissure of Rolando, and which is surrounded by arm areas, also gave movements of the tail whereas in the other animals in which movements of this organ occurred they followed stimulations of the areas bordering upon or near the longitudinal sulcus.

Relatively non-stimulable zones.—In the diagrams of Figure 2 there are to be found blank spaces within the cross-lined areas, or separating the cross-lined areas. This indicates that these areas are unlike the surrounding areas in that they are non-stimulable or relatively non-stimulable. This was mentioned in a previous section (p. 84), where it was also said that when an apparent non-stimulable area was found the strength of the stimulating current was increased to see if the area was really non-stimulable. At times it was found that we were dealing with an area with heightened threshold because the increased stimulus produced characteristic responses similar to those of the surrounding regions, but at other times the increased stimulus did not produce any response. Whenever the latter was

found it was concluded that we were dealing with a silent or a relatively silent area on account of the fact that any further increase of current strength can be objected to on the ground that the spreading of the current is more likely to take place and to stimulate not only at the spot at which the electrodes are placed but also adjacent collections of cells. Some objection may be raised against the universal application of this method of determining the silent character of the areas, and I do not press the point at the present time although the conclusion appears to me to harmonize with a number of other facts which have previously been reported by others. Whatever explanation we may select for the findings, whether we consider them to be indicative of a non-stimulable character of the special regions or of a relative lowering of irritability, it is of special interest to note that similar phenomena were not observed in the results of the series of stimuli to all the hemispheres which were tested. At the same time in a comparison of the hemispheres for which this phenomenon was noted there is found great variation. Thus we note the leg area in 1R to be divided into smaller areas, which division is probably of the character described above although not obviously so. The amount of space covered by this dividing area is great in the case of 2R, and the relatively non-stimulable zone in this hemisphere almost divides the arm area into two separate areas. Fewer of these non-stimulable areas were found in the leg areas than in the arm areas, which may be an indication of a greater fixity or of a higher degree of exactness in the development for the former. In this connection the diagrams of the other figures are of interest since they show similar phenomena associated with the areas for the individual segments. It will be observed that in most of the diagrams of the arm areas (shoulder, forearm, etc.) these divisions occur and that they are less frequent in the leg areas. It may be expected that the divisions would be more evident in the arm segment areas on account of the multiplication of the blank areas in each of the diagrams, but a careful comparison of all the diagrams referring to the arm areas shows that the divisions are more numerous than those of the leg areas even when the non-stimulable zones that are common to all are omitted.

Summary: In the hemispheres which were investigated there was found a number of points, or areas, the stimulation of which gave movements unlike those of the surrounding regions. This was especially marked in some of the hemispheres while others showed none of this crossing or combination of control. The number of cases in which arm movements were found to be associated with the stimulation of leg areas, or arm movements associated with leg movements when the surrounding areas gave only leg movements, is greater than that of arm movements from the stimulation of leg areas. A number of non-stimulable or relatively non-stimulable zones were found surrounded by normally stimulable areas.

GENERAL DISCUSSION (THEORETICAL)

The results of these experiments lead to certain conclusions which have widespread application regarding the functions, or functional connections, of all portions of the cerebrum. It is apparent that in this area, which has very generally been considered to have neural connections directly (or indirectly through intervening neurones) with the efferent cellular elements in the spinal cord, there is not the definiteness of localization, and therefore of connection, which has been supposed. The fact that there is a variation in the extent of the leg or the arm area in different animals indicates that motor cells located in similar locations may send impulses in different directions. The fact that the stimulation of certain spatially located points in an area which usually gives rise to movements of the thigh may, for example, result in combined movements of the arm as well as of the thigh is also an indication of a complex mechanism. This becomes more evident when we realize that such combined movements are obtainable upon stimulation of the cortex of one animal and not when the cortex of another is stimulated (or if obtained in the second animal the combined movement differs in quality). Furthermore, although the data in regard to the differences of control from the two hemispheres of the same animal are not as complete as they might be, the facts from the four monkeys of which both hemispheres were investigated indicate that there is a considerable difference in the connections which are established from each hemisphere. All the varying results are, however, of interest in that they lead to rather definite theoretical conclusions and in that they lead to a better understanding of the variability in control which are evidenced by the normal behavior of different animals and by that of different individuals and of different races of man.

In connection with the results of the present series of tests, the results of the recent experiments of Brown and Sherrington (**3**)

on the reversibility of action of allied centers[7] in the cortex are of very great importance. These investigators found that in the monkey's cerebral cortex there were several centers, or groups of cells, the stimulation of which normally brought about flexion, and other adjacent groups or centers which, stimulation showed, were normally concerned in the production of extension movements. The stimulation of one of the flexion centers, it was furthermore found, would bring about a slight or medium degree of flexion, while that of another would produce an extreme degree of flexion. Similar results were obtained upon stimulation of the extension centers, or groups of cells. When, however, a flexion center was stimulated repeatedly it was discovered that the flexion reaction did not remain of the same intensity as that which was originally found. There were changes in the degree of the muscular contractions in a series of stimulations of the same cerebral spot and in certain cases flexion eventually was replaced by the opposed movement of extension. From the results of this experiment we see that the repeated stimulation of one area may result in a reversal of the function, such a reversal, however, being probably only an exaggeration due to the normal connections and perhaps only a magnification in certain respects of the normal functions of such a center. After pointing out this fact the authors conclude (page 277) that "the frequence of reversal as a phenomenon attaching to the reactions of points in the motor cortex suggests that one of the functions of the cortex may be the performance of reversals, and that the greater predominance of reversal under cortical than in purely spinal or decerebrate reflexes is because reversal is one of the specific offices of the cortex cerebri."

In the same series of experiments Brown and Sherrington also noted another result which is of great interest, namely the variation in the degree of activity accompanying the stimulation of the different centers at different times. When on the cortex of an ani-

[7] The term center in the discussion implies no metaphysical assumption. It is a convenient and short designation for "a collection of cells the stimulation of which may result in certain reactions and the extirpation of which may bring about certain deficiencies of activities or behavior."

mal the center for extreme flexion was definitely located (*i.e.*, spatially in relation to the other flexion centers) and the animal was permitted to recover for some hours before a second experimental determination of this center was made, it was discovered that the second determination of the point for extreme flexion did not always correspond with the point originally determined. In other words, repeated stimulation of the same center, or group of cells, did not always result in the production of the same quantity or grade of movement. Thus, the center which on the first stimulation gave the greatest amount of reaction might be found to give a less amount of reaction at another time and the area which gave the small amount of flexion or extension at the time of the original or first experiment was sometimes found to give a greater amount of flexion or of extension in a second test.

A phenomenon or reversal of another character was also found. When the stimulation of a center resulted in a continued or epileptiform contraction a second stimulation of the same center might cause an inhibition of this movement. In the same series of experiments it was found that "in one case the same point which yielded primary extension with much regularity, on re-examination twenty-eight hours later in the same animal, yielded at first primary flexion instead of the primary extension" (page 252).

Closely allied to the results of the present work is the fact, which Brown and Sherrington note, that "in some experiments, the area whence extension points could be chosen has been distinctly larger than in others" (page 252). These authors conclude that "this variability signifies less a difference in the permanent arrangement than a difference in the condition of the nervous system from time to time," but this conclusion does not appear to be in line with the facts which have been recorded here, nor does it appear to me adequate to explain all of the facts which these authors have recorded.

Most of the recent work on the recovery of voluntary control following various forms of nerve anastomosis also shows that there is not the degree of definiteness of control from a particular portion of the cerebral cortex which has been assumed. Were a

particular cell endowed with the particular function of sending impulses[8] to bring about only one special movement of the arm, it could never be used to bring above a movement of the face. Were the activities of such a cell associated with or, as some clinicians hold, due to "memory images" of shoulder movements, for example, there would probably never be the possibility of moving the face except by thinking of it as the shoulder. In man, as far as our knowledge goes, the acquired ability to move the face when there has been an anastomosis between the peripheral portion of the facial nerve and the central end of the accessory nerve is not associated with any "memory images" or thinking about the shoulder. This conclusion is also forced upon us because of the recovery of the facial mimetic movements, which are reflex in character.

The experimental work on animals gives us many facts of value in this connection. Kennedy (**8**), it will be remembered, crossed the nerves for the flexor and the extensor movements of the dog's leg and noted that after a time the animal was able to move the leg quite properly. He also found that when the motor areas of the cerebrum were stimulated, the stimulation of the portion of the cortex which is considered to be a flexion "center" was accompanied by an extension, and vice versa, indicating that new brain conections had been formed because of the peripheral anastomosis. The observation that the animal recovered to a very great extent the normal power of the use of the leg in locomotion demonstrates that there has been a rearrangement in anatomical distribution of the individual neurones. The results of the cerebral stimulation experiments on the brain of this dog are, however, not conclusive evidences of the rearrangement of function in the neighboring cerebral areas because the flexor and the extensor centers are anatomically very intimately related. The recent work of Brown and Sherrington, which has already been described, has well demonstrated that there may be a reversal of function of these areas, and it is theoretically, and practically, possible that the re-

[8] The use of the term impulse in this connection is convenient, although it is recognized that some physiologists object seriously to its use, because it appears to imply something more than physico-chemical changes.

sults of the cerebral stimulation experiments of Kennedy were due to the normal physiological relationships of the flexion and the extension centers.

When, however, we deal with the altered innervations of parts which are not as closely associated physiologically the same probabilities do not exist. The further experiments of Kennedy (**7**) are, therefore, less open to question, for he found it was possible to obtain the return of function in the appropriate parts when he connected the central portion of the cut spinal accessory or the central portion of the cut hypoglossal with the distal portion of the cut facial nerve. After these operations it was found that the first movements in the area innervated normally by the facial nerve came in 58 and 32 days respectively, and in about 100 days there was found to be a recovery of the voluntary control of the closure of the eye and of other parts.

Other motor areas of the cerebral cortex which are spatially less closely allied are also found to have the ability to assume functions not originally pertaining to them. Thus Osborne (**9**) and Kilvington, in their very suggestive research, found that if one brachial plexus was served and some strands were carried over from the opposite plexus and united with the distal parts of the one which had been severed regeneration of the nerve took place. This nerve regeneration was accompanied by a complete, or almost complete, return of function in both forelimbs. It was furthermore determined that if the cerebral cortex in the forelimb area was stimulated on the side contralateral to the completely cut nerve (which normally innervates the limb supplied by the nerves of the brachial plexus which had been cut), no reaction resulted, but if the cortex of the homolateral hemisphere was stimulated, movements of both forelimbs were produced. This is a clear and convincing demonstration of the fact that the function of a particular area depends more upon the connections that are made than upon any hypothetical inherent or innate function, and further, that the functions of a particular area may materially change in accordance with the paths which are formed. The recovery of normal function also indicates that the impulses received from the receptive areas of the cerebrum, which are considered to be

necessary for the proper performance of voluntary movements, are not singularly direct. Such impulses, following the assumption of their necessity and importance, must in an intact animal go in certain directions and in the operated animal in other directions by other paths.

The experimental work of Boeke (**1**) is also of suggestive importance, showing as it does that there is a possibility of regeneration even in those cases in which the cross-sutured nerves differ by as much as they do in the case of the sensory and the motor nerves. In some cases Boeke found that if the central end of the cut hypoglossal nerve was joined to the distal portion of the sectioned lingual nerve regeneration of the fibers took place. He has also been able to demonstrate that under these conditions some of the efferent fibers of the hypoglossal actually progressed to the surface of the tongue and made connections with taste buds.[9] It is not definitely proven that these connections resulted in a return of the ability to taste for those areas of the tongue which had been deprived of his function by the section of the lingual nerve. More experiments and more crucial tests respecting this matter are necessary before we may say there has been a complete demonstration of the functional regeneration. The fact remains, however, that the possibility of anastomosis between a sensory and a motor nerve has been demonstrated. What variations in sensory or motor activity have been the result of these tests will doubtless later be determined. That the normally efferent fibers may regenerate and pass to the sensory end organs as well as to muscle cells is a fact weighted with suggestions regarding many practical, but especially theoretical, problems.

Variations in the motor responses to cerebral stimuli have also been recorded by the Vogts (**11**), not only in different animals of the same species but also in different species of animals. It seems to me probable that many of the discussions of the physiologists and of the clinicians of the past in which there

[9] At the present stage work of this nature has more definite interest in connection with the peripheral distribution of the nerve fibers. It can readily be understood, however, that the possible central (*i.e.*, cerebral) relations are most important. Confirmations of Boeke's work are urgently needed, especially in relation to the variations in behavior of the operated animals.

were charges and counter-charges of ignorance, or of misstatement, or of technical defects were due to the fact that these variations were not known or were not recognized. I believe that if this fact had been known and understood many acrimonious discussions would have been prevented.

The Vogts hold to the view that the variations are due "in part to special development of other pallium fields, and in part to variaitons in the functional capacity of performance." They furthermore assert that nothing prevents the "connecting causally all variations in the number of foci and in the extension and to a certain degree also variations in the excitability of a certain field of stimulation with differences in the specialization of its motor functions."

On the other hand Sherrington (**10**) has written: "Every increase in the number of links composing the nerve cell chain seems to increase greatly the uncertainty of its reaction in artificial excitation. . . . A cortex cerebri might well therefore have been expected to yield under artificial excitation only extraordinarily inconstant results. To Hitzig and Fritsch, and to Ferrier, we owe the pregnant demonstration that as regards the motor region this expectation is not well founded." That this constancy is not a veritable one is, I think, fully shown by the researches of the Vogts as well as by the results of the present study. There is not the degree of constancy in the motor response which the earlier investigators, as for example those which are cited by Sherrington, contended there is. Moreover, the later results obtained by Sherrington in conjunction with Brown which have been discussed above must also be taken into account, for it appears to me they amply demonstrate the opposite of that which Sherrington wrote eight years ago, and prove that the stimulation of the same cerebral point at different times produces varieties of action.

Whether or not the variations in movement associated with cerebral stimulation are to be correlated with normal individual activities, an explanation which is only slightly advanced beyond that of the Vogts, is a question for the solution of which the closest observations and correlations of the normal activities and the extents and the variabilities of the motor cerebral control

of individual animals must be accumulated. At present such a view appears to be in harmony with all the facts which are known to me and is tentatively put forth pending further studies. It may also be remarked that this view, in a special form, has been suggested by Bolton (**2**) in relation to his anatomical studies of cases of "amentia" and of "dementia," for he writes that the anatomical variations indicate "the likelihood of a structural origin for individual differences in mental endowment,"[10] and on the other hand he says the histologically differentiated areas indicate the "limits of educability."

The results of the present research, in conjunction with the data of others which have been recorded above, indicate that the connections which are made by way of the cortical motor cells are not definite in the sense, for example, that there is a passage of an impulse from a Betz cell in the anatomically defined cerebral motor region to another particular efferent cell in the spinal cord, but that the connection is, in special senses of the terms, promiscuous or irregular. By these last terms I mean only that the connections which one particular efferent or afferant cell makes are connections with a great number of neurones, and that the impulses resulting from the activity of a cell body may affect many other cells. Or, in other terms, an impulse arising in one cell may activate or influence only one, or any number, of the cells which are anatomically associated with the particular cell with which we deal. It is quite generally admitted that a certain cell has the possibility of sending its impulses along the main neuraxon and this is the view which is implicitly apparent in most discussions of cerebral function. But it is also obvious that since this neuraxon gives off, as it passes to its final goal, certain collaterals it is quite as reasonable and quite as logical to conclude that it has also the possibility of sending impulses along any one of these, or along the main neuraxon and any number

[10] This is not quoted as an indication of sympathy with the methods and other conclusions of Bolton, who has, in fact, introduced forms of expression in regard to cerebral-mental relations which are obviously grossly inaccurate. Thus, to be specific, he says that by means of language "it is possible to perform the highly intricate processes of cerebral association," and that "if words spontaneously arise in a cerebral center," whatever these things mean.

of the collaterals, or along one or more of the collaterals to the exclusion of the main trunk. It is this later method of looking at the activities of the cerebral cells which appears to me to solve some of the great difficulties of the exclusive neuraxon activity hypothesis.

The illustration which is presented here (Figure 11) is one

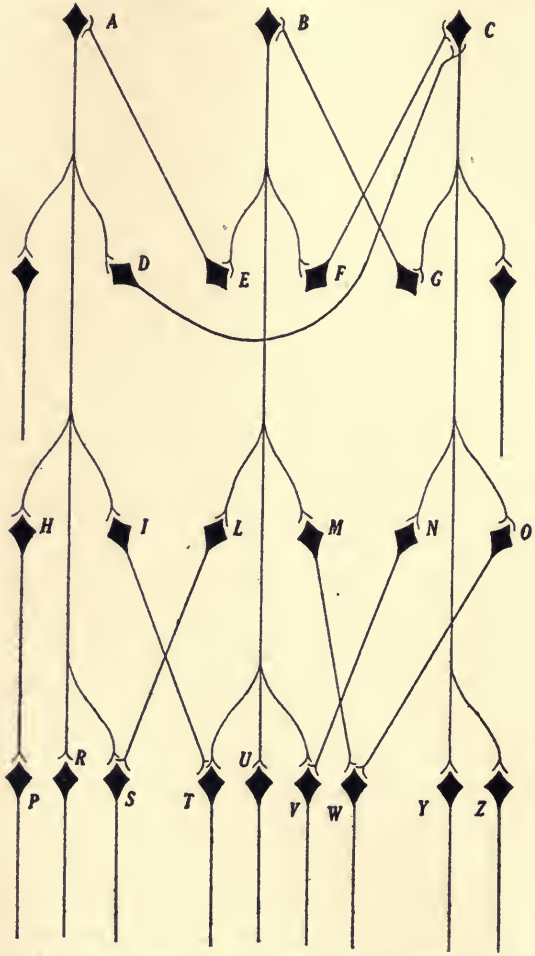

FIGURE 11. Illustrating the conception of the possibility of impulses in one cell influencing different cells, thus resulting in different reactions or different behavior. The primary cells *A*, *B*, and *C*, may be equally well considered to be afferent, efferent, or associational. Each cell may also be considered as a simplification of a group of cells.

which gives a diagrammatic conception of this view.[11] The activity of the cell *B* in its discharge may be represented as passing in any one or more of the directions taken by the branches of its neuraxon. Thus the activity of this cell may result in the stimulation of the cell *U*, or the cell *T*, or the cell *V*. In turn the activities of these cells (*T, U, V*) may result in the stimulation of muscles. On the other hand the activity of cell *A* may through its collateral acting upon cell *I* result in an activity of cell *T*, and the activity of cell *C* acting through its collateral on cell *N* may also bring about activity in cell *V*. Or, cell *C* acting through its collateral on cell *G* may activate cell *B* so that the characteristic *B* activities may be obtained. In turn the activity of cell B may influence those of cells *A* and *C* almost directly, thus bringing about reactions in parts which are normally controlled by those cells, for example those parts connected with cells *P* and *R*, and those with cells *Y* and *Z*. When it is considered that cell *B* may be taken as a representative of a so-called sensory cell, or an efferent cell which is normally made active when it received the effect of an impulse from some other cell or cells in other portions of the cerebrum, for example from a sensory or associational center, and that there may be many of these which exert an influence upon it, it will be realized that the behavior resulting from the activity of a primary receptive cell may greatly vary from time to time.

This neurological conception may be applied to the understanding of the behavior differences of individuals and also of the same individual from time to time. It appears probable that the variations in behavior of different animals and of the same animal at different times to the same form of stimulation are dependent upon the great number of connections and upon the variations in activity which the connection variations make possible. On the hypothesis that the connection between cortical cells is definite, in the sense that one cell acts solely or

[11] A few words of caution may be said regarding the diagram and its accompanying paragraph of text. Neither should be taken too literally, neither should be considered to be more than an indication of a possibility, and neither should be judged without the preceding and the following context.

principally upon one other cell, we shall have great difficulty in explaining the phenomena in man or in animals which are grouped under the general heading of habit formation. To show this, let us briefly consider the facts regarding the formation of habit in several animals. We shall then realize how the same stimulus may result in different reactions in different animals, and how in one animal at different times different reactions may result from the same stimulus. Conversely also we shall get some neurological insight into the possible reason for similar reactions in different animals from different stimuli. On the assumption of definite connections and definite paths of discharge such facts are neurologically almost unexplainable.

Let us take for consideration a young cat, four to six months old, since an animal of this kind is readily "educable." If the animal is hungry it will be better, since the formation of the habit is then more readily obtained if the habit has one of its elements concerned with the obtaining of food. We prepare for our experiment a box with narrow slats in the front and a small door which is closed with a bolt. The knob of the bolt is attached to a cord which runs along, but an inch under, the top of the box and which the animal can reach either with its claws or by arching its back, or by biting with its teeth. When the cord is pulled downwards or pushed upwards or moved sideways the bolt is also moved. Any one of these actions (there may be others and also combinations of two or more of these actions) will, if sufficiently strong, result in the loosening of the bolt which keeps the door closed, and when the door is thus opened the cat is enabled to escape and to get a particle of food which is placed outside.

When we place a cat in an enclosed space of this character there is a very decided change in the behavior of the animal. It usually becomes very active. This activity we may describe, in terms which are not directly scientific in their psychological aspect, as being due to the desire on the cat's part to escape from the uncomfortable situation of being in an enclosed place of such small compass, and perhaps partly to the desire for the food which in some experiments it may see outside. The actions

of the particular cat under these conditions are about the same as those of other animals of the same species which are placed in such a situation. The animal begins to scratch at the front of the cage, at the door, at the sides, at the top. It turns here and there, it takes hold of everything or anything which it can reach. These movements are not performed in any apparently logical order or in any apparently intelligent manner since the animal may at first try one corner, then the top, perhaps next the door. If these movements do not result in the escape of the animal from the "unpleasant" situation the cat may remain quiet for a time and begin all over again scratching at a front corner or a back corner, trying the top, the door, the slats at the front. Even though the special movements do not result in the release which is sought the movements are continued, and if the cat tries one thing and does not escape by so doing it may return to the first which it had previously found unsuccessful. The random movements, if they are continued for a sufficiently length of time, eventually result in the animal's moving, either by clawing or by arching its back or by biting, the cord which holds the bolt. When the bolt has thus been lifted the activities of the animal may be continued for some seconds or minutes before it realizes or recognizes that the door is open and there is a possibility of escape. When the animal escapes from the situation it finds the food or it is given a small piece of food. When it is returned to the box which is again bolted it goes through the same kinds of activities, clawing here, biting there, resting, performing movements which are apparently purposeless since they are not directed to the part of the box by which escape becomes possible, or towards the mechanism whereby the door can be opened. In its random movements it again scratches the cord, and again escapes and gets food. At the next trial the animal goes through the same sort of movements. Finally it claws the cord, gets out, and in succeeding tests it is found that this animal which at first escaped because of biting the cord and then later by arching its back against it, and again by clawing at the cord eventually acquires the habit of escape by utilizing only one of these types of move-

ment, namely the scratching or clawing at the cord. Furthermore it is found that when an animal is placed in this situation it eventually acquires the habit to such a degree, or the reaction is facilitated to such an extent, that immediately the animal is dropped into the box it goes to the particular location, claws at the cord thus opening the door, escapes and obtains the food.

Another animal goes through the same general kinds of activities in its escape or its attempts at escape, but instead of acquiring the habit of escaping by means of clawing at or by pulling the cord, it acquires the habit of arching its back and rubbing against the cord, thus putting the cord on a stretch and raising the bolt. A third animal learns to escape from the box by biting and pulling upon the cord.

It will be observed that as far as we can determine all three animals have been stimulated by exactly the same primary forms of stimuli. They have been stimulated by the sight of the box, by the appearance of the slats in the front, by the closed door, by other ill-defined sensations which are obtained from the confinement, perhaps from the stimulation of a variety of organs which go to make up, in human perceptual terms, the general feeling of being enclosed in the box. The sensory elements which are present in these three cases we most likely have the right to conclude are the same. The emotional elements or concomitants we do not know, if any exist, and we have at present no means of determining the similarity or variety of these mental conditions if they exist. It is to be noted however that although the sensory stimuli are the same the behavior to which the stimuli lead differs in the three animals. The reactions, it will be observed, have one thing in common, namely that they result in the escape of the animal. The actual means, however, of producing this desired situation differs for the three animals. Neurologically it is not only likely but it is almost certain that the impulses from the sense areas, those so-called associational impulses which start from the cells in the sensory regions of the brain, eventually concentrate in these three animals in different motor areas, or to put the matter in more probable terms, that the impulses originating in similar sensory cells in all three

animals reach (*a*) the same or (*b*) a different frontal lobe cell or group of cells in all animals, and that (a) this similar frontal cell or group of cells discharges into different cells in the precentral area, or that (b) the different frontal cells influence motor cells.

Now it will furthermore be found that if an animal which has acquired the habit of escape from a box of this character, either by clawing or biting or rubbing against the cord, be placed in the same box and the movement which it has been accustomed to make results in no food or in no release, this movement is gradually given up. The situation becomes different, although the sensory stimuli remain the same. By holding the bolt or by making some external change in the mechanism (which is not seen by the animal) to prevent the escape by any movement of the cord, but to permit the escape whenever the animal sits quietly and licks itself, or washes its face by the characteristic series of paw movements, or scratches itself, the animal soon gives up the first habit which it had formed and replaces it by behavior which in itself has not apparently any direct bearing upon the desired result. We then have a similar primary series of stimuli which at one time results in a particular mode of activity (clawing the cord), and at another time in a different mode of activity (licking itself) in the same animal. Both lead to what may be considered the desired result, namely the escape from the enclosed box.

It should be understood that the sensory stimuli in two experiments of this character are not the same in their totality. The initial or primary sensory stimuli are, however, the same. When after the receipt of the primary sensory stimulation a reaction is produced the reaction results in an additional sensory stimulation, and this secondary stimulation, or the combination of the secondary with the primary, may give rise to another reaction. The animal which claws first at the front of the cage after the receipt of the primary stimulation has thereby a character or combination of stimulation different from that of the animal which first reaches for the top of the cage and tries

to climb out in that way. Each animal however does have the same primary stimulation, or at least the same general primary stimulation, visual, tactile, organic, etc. To go back to the original stimulation we may even wonder why such similar primary stimuli have produced such diverse methods of behavior as that of clawing at the slats at the front of the cage and that of trying to bite the slats at the top. In either case, whether we consider the primary stimulus or the collection of stimulations which make up the whole experience of the animal in the box the sensory stimulations are sufficiently alike to presuppose (on the basis of exactness of neurological connections) an approximate similarity in the activity of the cerebral sensory areas, and to suggest (on the same hypothesis) that the efferent cerebral activity should be the same. This is, of course, on the very generally accepted belief that the impulses from corresponding sensory cells will always go to corresponding efferent cells.

On the hypothesis that there are definite connections established by means of certain cerebral neurones, and the hypothesis that when the stimulation reaches a particular sensory center it flows into other areas, eventually reaching the motor area and resulting in a particular type of movement, the varying activities of these animals are not understandable. It is not an explanation to say that one animal has certain sensory stimuli like those of another, but that there are different activities. Neurologically, there must be a basis for the different kinds of behavior. When we consider the possibility that the discharge from a certain cell may pass not only along the main neuraxon but also along any one or all of the collaterals and that in this manner we have the neural activity diffused, we have a possible explanation of the variety of the actions of the same animal under similar conditions. If the receiving cell were definitely and solely (anatomically and physiologically) connected with a special cell or group of cells, the same sensory stimulus should result in the same kind of reaction in different animals and in the same animal at different times. But we find that at first the cat makes many random movements. In other words, neu-

rologically we are led to conceive that the discharge of the sensory or receptive element is not only along the main neuraxon but is along all of the collaterals as well, and each in turn acts upon its cells or group of cells, producing impulses which eventually result in movements. These movements are random, i.e., not directly correlated with the stimuli nor with the desired result, but as the experience is repeated the animal gives up all but a certain amount of the reaction. Its behavior has changed. It is not only believable but probable that in the development of a particular type of activity or in the production of a particular association or habit, such as that of scratching or of biting or of arching the back, we may have two different neurological conditions. To use the simplified diagram which has been given above we may say that at first the discharge takes place along all the branches of the neuraxon, but this diffuse discharge eventually gives place to a discharge along one of the collaterals or along the main branch. The variation in behavior of two animals may then be due to the primary stimulation of corresponding cells, but in one case the habitual reaction is determined by the flow of the impulses from these cells along the course of the main neuraxon and in the other case the habitual reaction is determined by the passage of the impulse along a collateral These impulses reaching different efferent elements produce the varieties of behavior.

The results of the preceding study (**5**) of the variation in symptoms accompanying similar cerebral lesions in the insane have also a bearing upon the present work. In that study it is shown that in four collections of cases of patients suffering from different mental diseases, in whose brains atrophies of the frontal or anterior regions of the cerebrum were detected at autopsy, there is no apparent relation between the symptoms and the localization or the degree of the cerebral damage. On the assumption that there are definite, in the sense of singular and similar, functions and functional connections in each hemisphere in all individuals such divergencies in the symptomatology are not readily understandable.

At the same time the accounts of my experiments on the

functions of the frontal lobes (**4**) contain material of importance for the understanding of the cerebral functional relations. In that work it was shown that after an animal had been trained to react in a certain way, or had acquired a certain habit, the habit was lost when parts of the frontal lobes were separated from the remainder of the brain or when they were destroyed. Even after the loss of a great amount of the frontal regions such an animal could, however, reacquire the lost habit. The reacquired habit could again be destroyed (or lost) if additional portions of the frontal lobes were extirpated, and in some animals it was possible to show that the same habit could be again acquired.

It is neither satisfying nor sufficient to say that in the latter experiments there has been an inhibition, for this can only give to the facts another name. Nor does it suffice to say that there has occurred a sort of "diaschisis," since this also is only another means of expression of the generalized fact of loss of function. What must be concluded from these facts is that at the time of the first extirpation there was a "diaschisis," or blocking, or break, in the normal chain of cerebral activity (or neurologically and anatomically, of the cerebral connections). After the second learning of a habit and its loss subsequent to a second and more extensive extirpation, "diaschisis" may again be taken as the explanation of the fact. Another explanation beyond those of "diaschisis" or inhibition is demanded, however, for the phenomena of learning after the first extirpation of the cerebral area through or by which learning or habit formation normally is possible. It is obvious that the normal (*i.e.*, the first) paths cannot be traversed again, for these have been interrupted, or perhaps abolished. It is obvious that new paths or new possibilities of connections must be available. In other words for a reasonable explanation we are thrown back upon the assumption that the paths for reactions are not the simple anatomical unities which have been commonly believed in but that these paths are diverse and that anatomically as well as physiologically they are complex.

If the neurological path for the formation of a habit is a

fixity—from a certain sensory center to the frontal lobes and thence to the motor cortex—a break at any portion of the path (diaschisis, if you will) would prevent for all time the reacquirement of the lost association. That there is no such fixity is evident from the fact that relearning is possible. The explanation of the fact must, I think, be sought in another direction, and the one which has been suggested above appears most reasonable. It appears probable that in the acquirement of a habit certain paths are traversed and that they have a certain fixity, but it is also probably true that these paths are not the only ones that may be used to bring about the desired connection or association between the sensory and motor end stations. Most probably other subsidiary paths, if it be considered necessary or advisable to differentiate between the first path and other paths, or relatively subsidiary tracts, are available when "diaschisis," or inhibition, or other similar conditions supervene to prevent the normal course of the cerebral impulses.

The conditions of variability and the conditions of variation in the particular responses which come from rather definite sensory stimulation in different individuals lead us to a better understanding of the neurological conditions which we must believe are present in individual cases. It is not sufficient to say, as is commonly said, that past experiences determine reactions, for this is only a consideration of the matter from the external viewpoint. It gives no conception of the neurological conditions which enter into the matter. At present I think it will be admitted that we are quite ignorant of the conditions which result in the selection (not necessarily conscious of course) of a definite path in the nervous system. It is undoubtedly true that certain paths are fixed in the sense that one neurone has fairly direct connections, synaptic, however, with other neurones and also that one neurone may have connections with a half-dozen or more other neurones. Why the stimulation of one neurone should usually give rise in one individual to a particular reaction and the stimulation of what we believe to be a corresponding neurone in another individual results in a reaction which differs somewhat from the first, we

are not aware. It is, however, of some consequence and of some importance to realize that there are greater possibilities of connections than have hitherto been assumed or believed in. Only on the ground of the assumption of variations or possibility of variations in the connections or in the patency of collateral and main tracts may we understand the behavior phenomena to which the same stimuli give rise in different individuals. Only on this basis can we understand the various activities of different races and of different individuals. The different races have, it is well known, different types of reaction. Anatomically we have no good reason to believe that the neuronic connections differ widely in different races, nor anatomically have we any good reason to believe that the neuronic connections in different individuals of the same race or of the same family differ very widely. It is apparent, however, that physiologically these connections are very greatly different for the activity of the neurones gives rise to behavior of quite different characters.

Thus far we have been considering what is doubtless the most simple neurological system, a system much simpler by far than that which is active in the production of any form of behavior higher than that of a reflex. When we deal with a system containing more than the two elements, afferent and efferent, or receptor and effector, the complexities of connections and the possibilities of variation in the physiological connections become apparent.

In this respect the cerebral cortex, or the cerebrum as a whole, may be looked at as a very labile organ because of the numerous possibilities of connections which may be made. One cell, let us say, may have close connections with a half-dozen or a dozen other cells, and the activity of the primary cell need not always be through all the branches. There is a possibility of a change in the direction of the impulse within the neurone. Thus at one time the main effect may be due to the influence exerted through a certain collateral, and at another time the effect may be due to the impulse passing through the main axon or through a second collateral. If this be true, it helps

to understand why there is a possibility of change in reaction and a variability of reaction in the same individual from time to time. At one time the individual may have a discharge from a cortical motor cell along the main neuraxon acting upon a definite cell located in a definite region of the spinal cord. At another time the discharge may take place not only along the main neuraxon, but along one or more of the collateral branches, the actions resulting from the impulses passing through the collaterals being added to that due to the impulse along the main fiber, and the actions along these collaterals producing effects on other cells which either inhibit or alter in character the actions which were formerly produced, or new reactions may entirely replace the original activity by an activity of a very different character.

Nor does it appear necessary to believe that once a path, by way of the main trunk or by one of the collaterals, has been fixed that this fixity is a permanency. There may be a greater tendency to use this particular path after it has been used a number of times, but it may be said with certainty that the impulse may under suitable conditions traverse any one or all of the other collateral paths. In a state of "mental panic" a man acts very differently to a particular stimulus than at other times. His actions may be more diffuse or they may be the opposite of those which he habitually performs at normal times. Thus, the sounds of a rifle-shot heard at two different times although both be of equal intensity may give rise to varying reactions. Especially when there is an affective condition, such as fear or apprehension, do we find such changes taking place in the reaction.[12] Neurologically, however, it is not satisfying to say that the emotional condition gives the "set" to the discharge of a particular cell, or that it directs the character of the discharge, for we know nothing of the neurological conditions which give rise to or accompany affective states. But,

[12] Particularly those of diffusion. Neurologically perhaps we may consider such diffusion to be due to the passage of impulses from a cell not only along the path commonly traversed, but along all the collateral paths as well.

should we admit that the emotional state can alter the character of the motor response due to such a simple stimulus as that of the sound of a rifle-shot, we are admitting at the same time that the impulse from a sensory cell, or group of cells, may pass through certain paths at one time and through other paths at other times. Such a condition may also be well illustrated by a difference in behavior when no affective state intervenes to alter the reaction or when the affective state remains the same with the presentation of the stimulus at different times. An illustration of this is that of the differences of speech, which are special reactions or forms of behavior, when the same picture of an object is shown at different times. At one time such a stimulus (the picture of an apple) may bring forth the reaction *"Apple,"* at another time *"Apfel,"* and at a third time *"Pomme."*

It seems most likely that these variations in activity are due to physiological variations in the traversing of the axon or the collaterals. It is not unlikely that as conductors the axon and the collaterals are physiologically equal, that they may be utilized equally well or equally often if occasion demands it, and that the definiteness of response to any particular stimulus is only a relative definiteness.

In considering the functions of the cerebrum, therefore, we must rid ourselves of any preconceived notions regarding the fixity or definiteness of connections. Fixity or definiteness of an anatomical nature there undoubtedly is, but this fixity or definiteness is on the physiological side a multiplicity of fixities and definitenesses. One cell undoubtedly communicates with many others, and while this is an anatomical fixity it does not result in a physiological definiteness since at one time such a cell may be conceived to discharge in one direction along one collateral and at another time in another direction along another collateral. At present we may not have sufficient information to guide us in determining the reasons for the discharge in this or that direction but the facts at hand indicate that discharges do take place in this manner.

Somewhat similarly we must explain the facts of differences

in symptoms which are associated with similar cerebral lesions which have been referred to in a preceding paragraph. If we conclude that the cerebral paths for habits (or in a gross phrenological sense, for mental operations) need not be the same for all individuals such symptomatological dissimilarities in connection with like lesions become clearly understandable. If all individuals do not use the same limited portions for the same activities (or again in a phrenological vein, for the same mental processes) the destruction of similar portions of the cerebrum in different individuals need not produce the same symptoms. There are at hand sufficient facts in clinical neurological literature to support the contention that similar lesions do not always produce similar clinical symptoms or do not result in similar mental alterations. There are also at hand sufficient facts to warrant the conclusion that dissimilar lesions may produce similar symptoms. From the extreme viewpoint of body-mind relations (to which, however, I do not adhere) such facts are sufficient to lead to the conclusion that the same mental operations are not always due to the activities of the same parts of the brain. From a more conservative standpoint the facts warrant the conclusion that the same forms of behavior are not always due to the activities of the same cerebral cells. That the variability in the functional cerebral connections should ever have been considered doubtful is probably due to the phrenological views which have influenced, and in fact pervaded, all neurological literature for many years.

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