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The University of Chicago
Founded by John D. Rockefeller

A Study of Cutaneous After-Sensations

A Dissertation
Submitted to the Faculty
of the
Graduate School of Arts and Literature
In Candidacy for the Degree of
Doctor of Philosophy

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(DEPARTMENT OF PSYCHOLOGY)

By

MARY HOLMES STEVENS HAYES

Published as No. 60 of the Psychological Review Monographs
1915


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CONTENTS.

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The writer wishes to express her thanks to Professor James Rowland Angell for his help and interest throughout this work, as well as to those others who served as subjects,—Drs. June E. Downey, Grace M. Fernald, Florence Richardson, Joseph Peterson, and Clarence S. Yoakum, whose services through a long and tedious series of experiments are fully appreciated.

I. HISTORICAL STATEMENT.

The phenomenon of cutaneous after-sensations has received its most elaborate treatment at the hands of Albert Goldscheider and J. Gad; Urbantschitsch, Dessoir, and Thunberg have given the matter some careful consideration, and perhaps a score of other writers have touched upon this problem in connection with their work in neighboring fields.

The cutaneous after-sensations, as will be further described, fall naturally into two classes—the primary and secondary,—but this distinction is not specifically recognized until 1892. The early authors speak sometimes of "Nachdauer der Empfindung", which would seem to indicate the primary after-sensation, but quite as frequently we find the term "Nachempfindung" without sufficient context to determine whether the primary or secondary phenomenon is intended.

This survey will be made as far as is practicable in chronological order.

In connection with an experiment on skin localization made by Kottenkamp and Ullrich[19] as early as 1870 it is stated that the subject did not attempt to localize the spot until "nachdem die Nadel entfernt war und die durch sie verursachte Nachempfindung aufgehört hatte". This casual recognition of the phenomenon would seem to indicate that it was at this time a well known fact, but I have been unable to find any extended discussion of the subject in the writings of Czermak, Weber, Fechner, and other of the older authorities.

In 1880, Funke[11] speaks of the long duration of pain sensations and the persistence of pressure after a "skin compression".

In 1881, Preyer,[28] seeking to compare the phenomena of color and of temperature, writes as follows with regard to the positive and negative after-images of these: "Nach Beendigung der Erwärmung oder Abkühlung bleibt zunächst eine positive oder gleichsinnige Nachempfindung zurück". This persists for

a long time: "Wenn man aber weiter beobachtet, dann bemerkt man leicht, dass regelmässig die kalte Haut wieder warm, die warm kalt wird, indem die positive Nachwirkung schwindet". These cutaneous after-sensations are, he says, more enduring than those of the eye on account of the greater inertia of the skin.

In 1882, Goldscheider[12] describes a phenomenon which he later refers to as an after-sensation. "Wenn man nämlich mit einer Messerspitze schnell, am besten die Hohlhand berührt, so tritt momentan nur die Tastempfindung auf, welcher dann erst der stechende Schmerz folgt. Dasselbe kann man bei einem leichten Schlage mit der flachen Messerklinge wahrnehmen."

In the same paper Goldscheider also mentions the long after-sensation of the tickle feeling which in diminishing loses its characteristic quality and assumes that of a single contact feeling. In 1884, he again speaks of the long after-sensations of tickle which go off in a "breath-like" contact. In that same year and again in the following, he states that if a part of the skin be stroked lightly so as to produce an after-sensation of tickle and a moderate pressure stimulus be then given in the center of this region it will cause the tickle feeling to disappear. In a similar way these after-sensations can be stopped by rubbing the stimulated spot—i.e. by a further arousal of the touch nerves.

In 1882,[12] Goldscheider describes the after-sensations of temperature and most of his papers for the next four years contain some reference thereto. No effort is made to report these references in order. The excitations of temperature nerves are, he says, revealed through their long after-sensation. This is true for both warm and cold stimuli although cold are especially favorable. In connection with his description of temperature points he states that the temperature sensations obtained there, do not disappear with the cessation of the stimulus but have an after-duration which shades off into an indefinite, indescribable feeling. This phenomenon is very insignificant in some regions and overwhelmingly distinct in others. From continued pressure on a temperature spot the temperature sensation may persist for a long time and on especially favored spots leave behind it a clear

after-sensation. This phenomenon is, however, rare. As an explanation of the process he says "Allein diese Nachempfindung muss Ich für einen rein nervösen Vorgang halten, der mit der objectiven Temperatur der Hautstelle nichts zu thun hat". And this is proved by the fact that a momentary contact with an object only moderately cool will give so intense and prolonged an after-sensation that it cannot be due to any objective cooling of the skin, and also by the fact that temperature after-sensations can be produced by mechanical stimuli.

Goldscheider, in 1885,[13] makes a brief reference to the after-sensations of pressure, saying that on certain regions of the body, notably the back and thighs, there are many pressure spots whose after-sensations are so vivid as to obscure the perception of new pressure spots when stimulated.

Blix,[1] in 1884, noticed the persistence of pressure after cessation of the stimulus: :"Dazu kommt, dass der sichtbar statische Zustand, welcher durch einen andauernden Druck auf die Haut eintritt, daselbst eine ebenfalls andauernde Druckempfindung zu Stande bringt, während die Nervenfaden nur bei denn ersten Eintreten des Drucks auf sie gereizt werden".

In 1885, Dr. Donaldson,[5] in his paper "On the Temperature Sense," remarks this phenomenon as follows: "It was of course noticed with these spots (cold), as with the whole skin, that the thermal sensation when roused lasted some time after the removal of the stimulus, in some cases several minutes. This is often a disturbing element in certain experiments, for it is not always clear whether a given sensation comes from the spot at which the stimulus is acting, or from the spot at which it just acted. It is this fact which contributes largely to the continuity of the sensation of temperature when a stimulating body is drawn over the surface of the skin." This after-effect, he agrees with Goldscheider, is a purely nervous phenomenon quite independent of any objective change of temperature.

In the same year, Dr. Donaldson in collaboration with Professor G. Stanley Hall[6] published the results of certain experiments on the cutaneous perception of movement. Here they found cases where the sensory after-image of a moving point

fades in consciousness very slowly. In a test on varying the rate of movement, or the distance which must be traversed before the judgment is made, these authors state that "Down to the lower limit of velocity here used (1cm. covered in .012") it would seem that the after-image of the sensation caused by the moving point, from the beginning, persisted in consciousness as vividly, or at least as effectively, for 40" as it does for 4/10 of 1", or else that the two were judged in different ways". This is interesting as indicating the duration of the persisting sensation.

In 1887, Victor Urbantschitsch[36] in a clinical investigation of the sensitivity of parts of the face inflamed from an ear disease, describes the appearance of tactual after-sensations; and in the same paper reports certain observations made on temperature after-sensations with normal subjects. These tactual stimulations were given with a sharp-pointed instrument, but their after-sensations can, he states, be easily obtained by pressure from a blunt point or by light stroking of the skin. These cutaneous phenomena show the primary and secondary phases common to vision. "Das Nachbild schliesst sicht einerseits unmittelbar dem vorausgegangen Sinnes-eindruck an und bildet mit diesem eine gemeinsame ununterbrochen Sinnesempfindungen, oder das Nachbild taucht anderseits nach einer vorausgegangenen Empfindungspause wieder auf und verschwindet nach einer individuell verschieden langen Zeit, um vielleicht noch ein, 2 und 3 mal wiederzukehren." Both types may appear in a given experiment, or either may appear alone. The secondary after-sensations proved too erratic to be used as a test of the relative sensitivity of the diseased and normal parts, but the primary were found to be quite consistent and afforded a very good test of cutaneous sensibility. It was learned in this connection that there were six cases where the primary after-sensation was of longer duration on the normal than on the inflamed side as opposed to one where the conditions were reversed. This difference in duration tended to be equalized as the patient recovered. By application on the forehead of cold and warm metal surfaces, after-sensations were obtained which either (1) disappeared instantly, returned weakly after 15-25", gradually grew stronger and remained so 33-60";

or (*2*) persisted after the removal of the stimulus 35-50″, returned after a latent period of 12-23″ and then remained 4-25″. Essentially the same results were obtained from touch stimulations on the normal skin, except that the secondary after-sensations were more numerous. For example, after a touch stimulation a primary after-sensation was felt followed by a latent interval of 12″, then a secondary after-sensation of 2″, latent interval 16″, after-sensation 10″, latent interval 72″, after-sensation 16″, latent interval 15″, after-sensation 37″, latent interval 10″, after-sensation 30″, latent interval 15″, after-sensation 13″, latent interval 17″, after-sensation 65″.

In 1890, Goldscheider published an experimental paper dealing exclusively with the subject of the cutaneous after-sensations obtained from mechanical and electrical stimuli, together with his physiological explanation of the process. A year later, he repeated and amplified this research in collaboration with Professor J. Gad,[14] and this later work is the most elaborate and systematic treatment of the subject to be found in the literature. The first paper is but a brief outline of the other and, as it contains nothing of importance not contained in the second, it will not be treated separately in this survey.

This paper, published in 1891, begins with that familiar description of a cutaneous after-sensation. "Uebt man mit einer Nadelspitze einen leichten Eindruck auf die Haut aus, so hat man ausser der ersten sofort eintretenden stechenden Empfindung nach einem empfindungslosen Intervall eine zweite, gleichfalls stechende Empfindung, welche sich in ihrem Charakter dadurch von der ersten unterscheidet, dass ihr nichts von Tastempfindung beigemischt ist, sie vielmehr gleichsam wie von innen zu kommen scheint." This phenomenon will appear likewise with very weak stimuli, even with those lying close to the threshold. With stimuli intense, but not painfully so, the secondary sensation may be painful; but if the stimulus *is* painful, the secondary sensation is weaker than the primary and appears less clearly, the latent interval being partly filled up by the persistence of the primary. The stimulation for these after-sensations can be given equally well by a dull point. This phenomenon, Gold-

scheider specificly identifies with the one quoted above, where by the prick of a knife blade a touch sensation appeared, followed by a pricking pain.

The after-sensations obtained from electric stimulation are first described. These stimulations were given by means of an induction current rhythmically interrupted at certain intervals so as to form a series of similar stimuli separated by equal intervals. These series were varied as regards the number of induction shocks given in a series, the length of the interval separating them, and the intensity of the stimulus. The intervals varied from 10-200 σ, and to obtain such there was introduced into the primary circuit a tuning-fork oscillating 100 times a second (thus giving 10 σ intervals) and a fast and a slow-swinging electro-magnetic hammer which cared for the intervals of 16-200 σ. A few experiments were made on one subject with intervals of 300-950 σ and for these a metronome was used. To vary the length of the stimulus-series and hence the number of induction shocks given, three appliances were used, descriptions of which can be found in the paper mentioned. The intensity of the electric current was easily varied by the sliding up and down of the secondary coil. The electrodes were enclosed, at a distance of 1 mm., in a rounded hand-grip of wood which the subject held, pressed against a constant spot on the palm of the hand. The duration of the latent period was measured by means of Pfeil chronographs and a Beiss contact-maker.

The general results of the experiments may be stated briefly as follows: "Fur die Erklarung des Phanomens der secondaren Empfindung ist nun von grundlegender Bedeutung, dass dieselbe vollkommen fehlt, wenn ein einzelner Oeffnungsschlag auf die Haut applicirt wird, dagegen durch eine Reihe solcher Reize hervorgebracht wird. Ein einzelner Oeffnungsschlag giebt an denselben Hautstellen, an welchen man das beschriebene Phanomen mit der Nadel sicher erzeugen kann, nur eine primare Empfindung und zwar im ganzen Bereich der Reitzstarken ein, vom Schwellenwerth bis zum Auftreten excentrischer Empfindungen . . . Lasst man jedoch mehrere Inductionsschlage auf einander folgen, so tritt, durch ein leeres Intervall getrennt, die secondare Emp-

findung ein, welche im Allgemeinen denselben Charakter hat wie die primäre, nur mit dem Unterschiede, dass sie nichts discontinuirlich ist."

All gradations of secondary sensations were obtained, from those just noticeable to those which were very strong and clear, and from those preceded by a clear latent interval to those in which the secondary sensation was continuous with the primary. This variation of quality and intensity was directly dependent upon the conditions of stimulation. There were certain individual differences, and even in the same individual, under identical conditions, the results sometimes vary, but these variations are unimportant and commonly found in all subjective phenomena. As has been stated, a single induction shock produces only a primary sensation. Two shocks may, however, call out the secondary sensation but in a "sehr undeutlicher und inconstanter Weise", and three stimuli give similar results. Four stimuli, on the contrary, will produce the phenomenon with great clearness, provided the intervals be of the proper length (30-60 σ); but with intervals above or below this length, the secondary sensation becomes progressively less clear. These conditions hold likewise for five, six, and seven stimuli; but by further increase of the number of shocks the interval must be constantly shortened to obtain the best results. So, in general, it may be said that if the length of the interval is increased the number of stimuli must be decreased, and if the number of stimuli is increased the interval must be shortened. To cite extreme examples, 3 stimuli require an interval of 190-200 σ to produce the secondary sensation clearly, while with 40 stimuli a 10σ interval is sufficient to make the secondary sensation appear distinctly. This reciprocal relation applies best, however, to the middle regions and is only generally applicable to such extreme cases as those just mentioned, although it may be generally stated that the *total duration* of the series remains approximately the same throughout, secondary sensations being obtained by 50 stimuli with 10σ intervals and by two stimuli with an interval of 620σ. The facts most noticeably brought out in this connection, however, indicate that there is a mid-region, both of stimulus-number and stimulus-interval,

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within which the after-sensation is most marked and that "Dieses Feld zieht sich aber sowohl nach unter wie nach oben spitz aus".

With regard to the effect of the intensity of the stimulus on the appearance and clearness of the after-sensations, it may be said in general that a moderate intensity is most favorable, although it is very difficult to give any exact figures on account of the increase in intensity of a stimulus when it is applied in series. The most favorable intensity was, therefore, empirically determined in each case. It was found that by decreasing, and especially by increasing, this intensity the secondary phenomena became less clear.

It appeared in the course of the experiment that certain regions, varying with the two subjects, were more favorable than others for producing the phenomena in question,—the volar side of the hand and wrist, for example, being more suitable than the dorsal,—and this is attributed to the local sensitivity of the skin, because on these spots, also, the primary sensation was sensed more clearly.

The quality of the after-sensation obtained under the best conditions is described as "ein schnell auftauchendes und kurz dauerndes fein-stechendes Gefühl von nicht schmerzhaftem Charakter." With too strong intensity the sensation may irradiate and this irradiation have a "tickle" quality. With a small number of stimuli (2-3), likewise, the sensation tends to spread. Again, under certain conditions, the after-sensations lose their pricking and quick-disappearing quality and persist for a long time as a tingling, burning sensation. The qualitative changes may be further described as follows: "Bei einer noch mässigen Reizzahl, etwa 10 Reizen zu 40σ Intervall, beginnt die secundare Empfindung stechend, wird aber statt abzufallen schneidend. Bei grosserer Reizzahl bez. Vermehrung der Reizstärke, beginnt sie gleich schneidend Bei noch weiterer Vermehrung der Reizzahl, besonders wenn gleichzeitig die Gesammtdauer der Reizreihe vergrossert wird, ist sie nicht mehr durch ein leeres Intervall von der primären Empfindung abgesetzt, sondern schliesst sich unmittelbar an diese als eine schneidende, langgezogene, allmalig abklingende Empfindung an."

In general, it was found that the time which elapsed between the end of the stimulus-series and the appearance of the secondary sensation was nine-tenths of a second. This time was found to be approximately constant as long as the stimuli were given within the limits of what is termed the "Auslösungswerte", i. e. those conditions of stimulation which will produce the secondary phenomena most clearly and easily. That is to say, the number of stimuli may be three or fifteen, the interval 10σ or 70σ, (and the total duration of the series 30σ or $370\,\sigma$), but the space between the end of the series and the beginning of the after-sensation will remain the same except for certain irrelevant fluctuations. If, however, the boundaries of the "Auslösungswerte" are overstepped the secondary sensation makes its appearance independent of the duration of the stimulus but at its old "time-moment", i.e., the interval is correspondingly shortened. If the duration is still further extended,—to 800σ or over,—the secondary sensation flows into the primary, or does not appear at all.

As an apparatus for applying the mechanical stimuli so as to vary their intensity, duration, and "abruptness" of application and withdrawal, the following arrangement was used. A sort of Marey tambour, operated by a handle, contains a needle fastened perpendicularly to the membrane and this is connected by tubing with a second tambour which registers the curve, while a time-curve is written below. The intensity of the stimulus is thus a function of the ordinate value and the abruptness of application, as well as the entire duration of the stimulus, is given in terms of the abscissa. For the more intense stimuli this apparatus was found too frail and another was constructed. This consisted of a spiral spring, to one end of which a needle was fastened. Inside the spiral of the spring there was a glass tube one end of which was connected with a Marey tambour, the other being covered by a membrane against which the head of a needle rested lightly when the spring was not in action.

The record of the results here obtained is obscure and it is necessary to turn to the shorter paper for a clear statement. It appears, however, that with mechanical, as with electrical stimu-

lation, there is a certain range of optimal conditions within which any change of intensity, duration, or abruptness is without significant effect upon the latent interval. The intensity might vary from an ordinate height of .5-2 mm. (with the stronger stimulus apparatus) and from 3.5-8 (with the weaker), without any appreciable change in the latent interval. With stronger stimuli, however, it became shorter. By varying the abruptness of application, it developed that if the interval were measured from the *beginning* of the stimulus to the appearance of the secondary sensation the time was somewhat shortened, but by measuring from the *end* it remained about the same. The varying durations of the stimuli gave approximately equal results unless the duration exceeded 500σ, in which case the interval was lessened. It is significant that with optimal conditions the latent time is practically the same as that obtained by electric stimulation. The length of the latent interval seems to be influenced to quite an extent by the clearness of the secondary phenomena. When the stimulation is given on the volar side of the wrist—an especially favorable spot—the empty interval is much shorter; and on the sole of the foot it is increased by 400-500σ beyond its duration on the palm of the hand.

The last third of the paper is devoted to an explanation of the phenomenon. Goldscheider maintains that it is without doubt a summation process. This summation takes place in those cells of the grey matter which come into relation with the fibers or collaterals of the spinal root fibers ascending in the posterior columns. With a single induction shock the excitation which reaches these cells is not sufficient to "break through" to a conscious center, but is instead stored up in these cells, until, by a series of successive stimuli, the process of continual storing up results in a changed condition which causes the cells to "unload" their energy; and this cellular excitation breaks through to the center by a path of its own. This is termed the Summation Path. The primary sensation is in every case the result of an immediate conduction through the posterior columns and is therefore responsive to even a single stimulus. This Summation Path is identified with the Pain Path of earlier authors, and the

pain of a primary sensation is explained by saying that a stimulus of great intensity is able immediately to break through the Summation Path. This identification is supported by clinical cases of spinal-cord disease where a series of non-painful stimuli result suddenly in pain, i.e. in a new sensation. A close analogy is likewise drawn between this phenomenon and that of delayed pain under pathological conditions. Schiff, Funke, and Wundt are quoted as the authority for locating this summation phenomenon in the posterior horn, and the pathological finding of analgesia in gliose favor this localization. In order to explain the appearance of a secondary sensation by a single mechanical stimulus, under such a summation hypothesis, the idea is advanced that a mechanical stimulus must in itself be looked upon as a *series* of stimuli. The justification for such an explanation is given in the following paragraph which is the only discussion of the matter. "Bezüglich der mechanischen Hautreize hat sich das bemerkenswerte Ergebniss herausgestellt, dass dieselben in ihrer Wrikung niemals einem einfachen Reiz, sondern stets einer Reihe von Reizen entsprechen. Dies bleibt bestehen, unabhängig davon, ob unsere Auffassung von der Summation richtig ist oder nicht. Die Vergleichbarkeit des mechanischen Reizes mit der Reizreihe ging so weit, dass auch die Beziehungen des Auslösungswertes zum Zeitpunkte der secondären Empfindung und zur Art und Dauer der Reizwirkung sich als ähnliche herausstellten."

In 1892, Max Dessoir,[4] in a monograph on the skin sensations, devotes a page or two to the after-sensations of temperature. In speaking of the cutaneous after-sensations in general he states that they are of two sorts, those which are uninterrupted, which follow the stimulus without a break, and those which make their appearance after a short sensationless pause; and these two kinds he designates by the terms Continuous and Intermittent.

In his experimentation on the temperature after-sensations he obtained the following data; "Das Nachbild eines Kälte—oder Wärme—Reizes wird durch die entgegengesetzte Erregung aufgehoben, durch eine neue gleichartige Erregung verstärkt". For example on withdrawing the finger from cold quicksilver the persistence of the cold sensation is noticeable for some time; if

however, immediately on the withdrawal, the finger is plunged into *warm* quicksilver, the cold immediately vanishes and the thermal sensation becomes neutral, but when the finger is again brought out into the air the cold sensation reappears as though entirely uninterrupted. In this experiment the average duration of this persistence was 534σ and the phenomena were not observable in the neighborhood of the threshold,—that region tending rather to produce Intermittent after-sensations.

The Intermittent after-sensation he states has been observed in the fields of optics and acoustics and by Goldscheider, in the cutaneous realm. This Goldscheider phenomenon should not, however, be identified with the other two for the touch after-sensation only makes its appearance after a *series* of stimulations. This same dependence on a serial stimulation is to be found likewise with the temperature sense, for this after-sensation makes its appearance most clearly if 4 very light temperature stimuli (of .5″ duration) are allowed to fall on the same spot. One can then clearly differentiate the primary sensation, a sensationless interval of about a second, and then the secondary sensation. With the application of stronger stimuli this fluctuating phenomenon does not appear, but, on the spot stimulated there immediately comes a steady after-image joined to the stimulus sensation. To determine the duration of this after-sensation a "Sensibilometer" was used. This consisted of a metal cylinder, 1 cm. in diameter, heated for 15″ in quicksilver of 50-55° C. and then placed on the skin of the back of the hand and on the pulse of the left radial artery. On sensing the warmth the subject turns on a chronoscope and the experimenter at the sound immediately removes the cylinder; with the cessation of the resulting after-sensation the subject turns off the drum. From this total time the author desires to subtract the time necessary for the auditory reaction of the experimenter as during this time the stimulus was still applied. For this purpose he assumes the average time-reaction of 138σ obtained by Jastrow in his Time Relations of Mental Phenomena, subtracts this from the total time and calls the remainder the duration of the after-sensation. With the one subject tested the duration (ex-

clusive of the auditory-reaction-time) varied from 316-807σ. If the temperature of the stimulus was so intense as to produce pain, this time increased to 1513-1889σ.

Ladd,[22] in his Physiological Psychology, published in 1891, speaks of the temperature after-sensations as follows: "After-sensations of temperature seem to exist. But when a surface of the skin has been warmed or cooled and the after-image has faded quite away, it is said that it can be called back by light mechanical irritation; this is especially true of sensations of cold."

Wundt,[39] in a note in the 4th edition (1893) of his Grundzüge [omitted in the 5th edition] cites Goldscheider's secondary phenomena and says of it: "Es ist nicht unwahrscheinlich, dass es sich hier um eine durch die Doppelheit der sensibeln Leitung bedingte Erscheinung handelt, wobei die primäre Empfindung durch die directe, die secundäre durch die den Umweg über die graue Substanz einschlagende Leitung vermittelt wird, um dieselben Bedingungen also, die der verschiedenen Leitungsgeschwindigkeit von Tast und von Schmerzreizen zu Grunde liegen". In the 5th edition of this work (1902) he records (1) von Frey's persistence of pressure after skin deformation and, (2) the persistence of a cold sensation after removal of the stimulus.

Külpe,[21] (1893) in his Outlines, makes several references to the phenomena of cutaneous after-sensations. Goldscheider's research is cited together with his physiological explanation of the same: "but these after-sensations of pressure would seem to appear only under very special conditions, hardly realized by normal stimulation".

"After-sensations of heat have been observed, of a kind similar to those of pressure. The blank interval between primary and secondary sensation amounted to about 1 sec. It is, therefore, conjectured that the thermal excitation also undergoes dispersion into the gray substance of the cord and that there summation and retardation of stimulation take place." . . . "The effects of temperature stimuli may persist for a certain time, but always (so far as we know) in the quality of the original sensation."

On page 85, he mentions the discovery of sensory nerve fibers with centrifugal conduction which have been found in the optic and "may be presumed to exist in all sensory nerve trunks". And of the connection of this discovery with the phenomena of after-sensations he says: "It has been noticed, in almost all the sense departments, that a brief stimulation of the peripheral organ gives (a) a 'primary' sensation, (b) then a short pause, occupying a fraction of a second, and (c) finally, a 'secondary' sensation, of the same quality as the other. The succession becomes readily intelligible, if we conceive of the first, centripetal excitation, as arousing a second, centrifugal. We have no need of the special hypothesis proposed for the sense of pressure" (Goldscheider's).

In 1893, Dresslar,[7] in a paper on the Psychology of Touch, takes the precaution to change the region of stimulation and to allow sufficient time to elapse between successive applications "in order that the after-sensations shall be as little confusing as possible". And at the end of his paper he devotes a little space to the consideration of these *per se*. In order to test Goldscheider's results he asked a number of his students to touch the skin repeatedly with small cork pencils and to note the resulting sensation. The following are examples of the results obtained. A more or less ticklish sensation at first appeared, some time after, when it was supposed that all sensation had gone, a sharp somewhat painful sensation flashed out and disappeared nearly as suddenly; after quite a period of time it again appeared but with less force. After stimulation, in addition to the feeling of contact, in about one half the cases, there came a distinct secondary sensation of a more or less painful character, and diffused over a greater area than the primary sensation. In cases where the primary sensation was somewhat painful the after-sensation did not come out so clearly. After touching the back of the hand there arose as an after effect a slight drawing sensation. After a slightly painful stimulation a sharp fine sensation appeared later which was located somewhat nearer the wrist. With a light pressure the sensation was a more persistent one of a sticking quality which faded slowly with several recurrences. These examples

were typical of all the rest. The after-images of touch could, he said, be facilitated if the surface be stimulated by tickling, in order to increase the blood supply in that region, and this facilitation could not be assigned to a generally increased sensitivity to touch, for, under these conditions, the primary sensations were unaltered. In addition, it was noted that the appearance of the after-sensation was coincident with the return of blood to the spot stimulated and "this rush of blood is the chief and, as far as I can distinguish, the only direct stimulating agent for the production of this after-sensation". Goldscheider's summation theory he therefore considers needlessly difficult.

In 1893, Krohn,[20] in a paper on the Simultaneous Stimulations of Touch, says of the after-images of touch that they are often more clearly felt and localized than the original stimulus—the subjects sometimes correcting their localizations by the "dawning of images". These after-sensations are more lasting in some localities than in others, the hairy portions, especially when shaved, being very favorable. The regions in which the after-sensations are especially intense and distinct would be graded as follows—calf of leg (behind), ankle-bone (outside), shins, nipples, instep and tendons. The duration of the after-sensation on the calf of the leg amounted, in some cases, to 5 minutes.

Pillsbury (1894)[27] in connection with his investigations on cutaneous sensibility, says that only one experiment was made on each skin area during a series "as it was found that the after-effect of pressure exercised a disturbing influence upon the judgment. Before this precaution was taken it was often noticed that the after-effect of the preceding experiment was mistaken for the impression given to be localized, or at least gave rise to a confusion."

Henri (1896)[17] in his experiments on skin localization, states that it is necessary to take account of two types of response. The first of which is where the contact produced by the experimenter has not completely disappeared, and in this case the subject guides himself throughout by that trace and seeks to touch the spot where he still feels a faint contact.

Parrish (1895)[25] in a series of similar experiments, says that

"not more than 10 experiments were made at a sitting and thus the after-effects of pressure were eliminated".

In his paper of 1896, von Frey[8] noticed, in connection with a determination of the pressure threshold, that in some cases where the application and the continuance of the stimulus was distinctly perceived its removal was unnoticeable. "Uebrigens kommt es unter diesen Umständen auch vor, dass die Wegnahme gar nicht bemerkt wird und die Empfindung des vollen Druckes, nur ganz allmählich abnehmend, den Reiz für längere oder kürzere Zeit überdauert", . . . "Nun ist bekannt, dass eine längere Zeit dauernder, nicht zu schwacher Druck auf der Haut ein Abbild des druckenden Korpers hinterlässt oder ein Druckbild, wie man es nennen konnte." And this pressure after-image is erroneously considered a continuation of the stimulus. The explanation of this phenomenon is to be sought in a certain "after-working" of the nervous process conditioning the pressure sensation. This "after working" and its consequent pressure image are further dependent on the rapidity with which the skin is restored from the depression caused by the pressure stimulus. This is shown by the fact that this persistent after-pressure is not produced by weights of minimal intensity, i.e. those too light or too briefly applied to cause a deformation of the skin. The common illusion of the coin pressed upon the forehead is cited as analogous here, for although temperature after-images may be active in such a case the same results may be obtained with cork or woollen objects having a neutral temperature. In a later paper (1899), written in collaboration with Kiesow,[9] it is again stated that after strong and not too brief weighting of the skin the sensation outlasts the outer stimulus and this is again attributed to a "ruckstandige Deformation,—ein sog. Druck-bild auf der Haut".

In the first mentioned paper there is described the phenomenon of a pressure sensation and a later pain sensation arising as the result of a single stimulus; and Goldscheider's similar observations are cited but the phenomenon is given a wholly different explanation. Goldscheider's conception of the pain sensation as a summation of pressure stimuli is refuted by the following results obtained: (1) On pain-free pressure points the painful

after-sensation fails to appear; (2) On pain spots situated in the neighborhood of pressure spots the phenomena occurs in the manner described by Goldscheider; (3) On isolated pain spots the accompanying pressure sensation is absent, while the painful after-sensation appears clearly. Goldscheider's experiments tend, therefore, rather to show the dissimilar manner of response of the two forms of nervous apparatus to the same stimulus. Von Frey's own explanation is based on the hypothesis of separate end-organs for pressure and pain, the latter having a higher threshold of response, especially for weak stimuli, and a great inertia especially for oscillatory stimuli, which assumes the form of a "Nachhinkens" and has been erroneously considered a secondary sensation.

In 1896, Kiesow[18] confirmed von Frey's results on the after-persistence of pressure. "Il semble donc que chaque fois qu'une charge est suffisamment grande, on qu'elle reste assez longtemps pour produire une deformation sur la peau, la sensation survit le stimulus."

In 1897,[23] Lay, in connection with a discussion of Mental Imagery, states that he has himself experienced "what might be called tactual after-images".

In 1897, there appeared a brief paper by F. N. Spindler[32] on the After-Sensations of Touch. These after-sensations of touch, or more properly pressure, are very difficult to obtain, by reason of their tendency "to mingle with the general and common muscular and organic feelings". While, he says, these after-illusions may occur they could never be mistaken for actual tactual stimulation if subjected to a careful analysis. The after-sensation is at best vague, indefinite, and irregular and hard to distinguish from the subjective sensations which arise when the attention is directed to a particular skin-spot. In his introduction he specially states that he intends dealing not with the secondary sensations succeeding a sensationless interval, but "with those varying sensations which follow the cessation of a more or less prolonged stimulation of the skin by means of pressure". (Evidently those after-sensations which elsewhere have been distinguished as Primary.) In one of his tables, however, he records the "inter-

val between the end of the stimulation and the appearance of the after-sensation". An interval which always occurs and has an average duration of 36.5". (It would seem, therefore, that he is treating of those secondary sensations which make their appearance unpreceded by a primary after-sensation, and this appears probable in view of the very long stimulations given.)

The method of stimulation consisted of weights varying from 25-1000 grs. placed upon a holder having a base of 7/8 of an inch, and applied to the back of the hand for intervals varying from 5"-10'. The following results were obtained from his experiments.

(1) The briefest duration of stimulation which would give rise to an after-sensation was 5", the weight in this case being one of 150 grs. (2) There appeared to be little relation, either between the duration of the stimulation and the length of the "interval", or between the length of stimulation and the duration of the after-sensation. (a) The interval seemed to increase up to a stimulation of 3' duration and then, decreasing slightly, remain about the same. (b) With stimulations of from 1-3' the duration of the after-sensation is about 5', while a 5-10' stimulation gives about a 10' after-sensation. (3) The effect of different weights on the duration of the after-sensation seems to indicate that weights of 150-500 grs. give the best results, and that 1000 grs. always give shorter after-sensations than those obtained by 500 grs.. (4) The quality of the after-sensations is described by the author, in his own case, as simply a feeling of skin contraction, as if the surface were painted with collodion or mucilage, but other subjects obtained more varied results such as touch and temperature sensations, itch, a sort of external smarting, and a deep dull ache.

In 1898, Vintschgau and Durig,[88] in the course of an investigation of the least noticeable interval between two successive electrical skin-stimuli, chanced upon a contradiction of Goldscheider's hypothesis that a secondary sensation is not to be obtained from a single induction shock. It was found that with a single induction shock the subject frequently got beside the first sensation a second, sometimes stronger, sometimes weaker, or again of equal

intensity with the first. Frequently the location was changed, the second sensation appearing to the right or left of the first. This phenomenon would appear to be identical with Goldscheider's secondary sensation, the description of which the authors quote at some length. To prove that this difference was a function, neither of the strength of the stimulus, nor of the region tested, nor of the construction of the electrode the intensity of the stimulus was varied through many gradations, and the stimulations were given on the same skin areas used by Goldscheider and Gad and with a similar electrode. A secondary sensation was under these conditions frequently obtained by a single shock.

Sanford,[30] in his Manual (1898), records the after-sensations of touch, i. e. Goldscheider's phenomena, and interprets the same by Goldscheider's explanation. He mentions also the temperature after-sensations, both continuous and intermittent,—all being, however, of the same quality as the stimulus—and the long after-effect of tickle.

In 1898, Crawford,[3] in a study of the Temperature Sense, criticises Donaldson's method of locating hot and cold spots by drawing the stimulating point along the skin on the ground that it gives rise to after-sensations.

Clark[2] (1898) in a paper on the Sensations of Pressure, states that "the sensation may outlast the stimulus, probably as the result of the deformation of the skin which lasts for some time". Later, in connection with his tabular results, he quotes the introspection of one subject: "Pressure rather strong, soon diminishing, after 20″ apparently gone, then again perceived, finally definitely vanishing," but makes no comment on the same.

Titchener,[34] in his Instructor's Manual (1901), records Goldscheider's after-touch phenomena but accepts von Frey's explanation of the same. Later, he speaks of the pressure after-sensation varying with different observers, and being recalled, after its disappearance, by a second stimulation.

In 1902, there appeared a paper by Torsten Thunberg[35] in which is described the phenomenon of two "stechenden" sensations resulting, under certain conditions, from a single thermal, mechanical, or electric skin stimulation. Thunberg quotes at

some length the results of Goldscheider and Gad and comments critically upon their identification of the phenomenon noticed by Goldscheider in 1882 (where a touch sensation is followed by a stinging pain), with this later one (which consists in a stinging sensation followed, after an interval, by a second similar one). In opposition to Goldscheider's hypothesis of the same nerve serving for pain and pressure, on which he bases his explanation, the author quotes von Frey's more recent theory that there exist separate nerves and nerve-endings for these two sensation qualities, and that the delayed pain sensation, which is what Goldscheider was probably describing in his early paper—is due to the greater inertia of the pain spots. Von Frey's theory, while it explains the first case would not, he contends, apply to the other phenomena described by Goldscheider and Gad, where the primary and secondary sensations were similar and neither was painful. It is with this double "stinging" sensation of Goldscheider's that Thunberg is concerned in the present investigation. These sensations are best described by the adjective "stechende", and they contain no painful nor unpleasant feeling tone. They can be called out by weak mechanical (needle-prick), thermal, or electric stimuli; while with a greater intensity of these stimuli the sensation will change to one of pricking, burning pain. These two sensations then, one "stechende" and indifferently toned, and the other nearly identical in quality but having a distinctly painful tone are mediated by the same nerves (pain nerves) and correspond simply to differences in the intensity of the stimulation.

Two methods of thermal stimulation were used, one providing for differences in intensity with the duration of application remaining constant, while the other had a constant intensity and could be applied for different lengths of time. The first consisted in the application of what he terms "Reiz-lamellae", and these were flat plates of metal 4 cm. square and varying in thickness 10–150μ. They were taken from boiling water and placed on the skin, and the amount of heat given off was measured in terms of the thickness of the Reiz-lamellae. The second apparatus—which is spoken of as a "Temperator"—consisted of a hollow metal vessel with a rounded surface 3 cm. in diameter, through

which water of a given temperature flowed in a continuous stream so that the temperature of the vessel remains constant. The results obtained by this first method are best given in his own words. "Die schwächsten Reize ein einzige schwache Empfindung stechenden Charakters entstehen lassen, die bei erhöhter Reizintensität an Stärke zunimmt. Die Empfindung hat eine ziemlich lange Apperceptionzeit. Wird nun die Stärke des Reizmittels noch weiter erhöht, so erhält man zwei derartige Empfindungen, eine schnell sich einstellende und eine mit längerer Apperceptionzeit. Die erstere ist die schwächste, schwächer sogar als die, die als einzige bei etwas gegeringerer Reizstärke erhalten wird. Wird die Reizintensität noch mehr erhöht, so werden beide stärker, ziehen sich in die Länge und fliessen schliesslich zusammen. Schon hieraus scheint sich zu ergeben, dass die bei schwacher Reizung allein auftretende Schmerzsensation dem zweiten der beiden bei stärkerer Reizung auftretenden "Stiche" entspricht. Der erste scheint sich vor dem bereits bestehenden einzuschieben." By the second method it was found that—(1) With long application, i.e. when the Temperator was held against the skin until a pain sensation was felt, there appeared, with water of 50°C, a fine "sting" which lasted a very brief time and then vanished completely. With stronger stimuli this "stinging" became stronger and more lasting. There was, however, no secondary sensation. With the water raised to 56-57°C, a weak "stechende" sensation was obtained which swelled directly into an abrupt, quite strong pain, but there was no repetition of the same. (2) If, with water of 58-60°C the Temperator was raised the instant one began to feel the "stinging" sensation, a very brief sensationless interval was perhaps perceived, followed by a second "stechende" sensation. With 60°C, the only indication of the double sensation was that the pain which appeared began somewhat weak and increased abruptly. (3) With brief contact, where the instrument was raised before the "stinging" sensation appeared, the double pain sensation was easily called out with temperatures above 60°C, provided the time of contact was suitable. With too brief applications, no pain sensation or only a single one was called out, or if the stimulus endured too long, the

strength of the pain was lessened and the "Zwischenzeit" diminished or disappeared entirely. These experiments were performed on different persons and on different parts of the body to preclude the objection that the phenomenon was due to some local or individual peculiarity. To measure the apperception-time for warm sensations of different intensities, a simple apparatus was used, consisting of two fine parallel wires stretched across the skin, through which is passed a current too weak to be conducted by the skin. With the application of the metal temperature stimulator the circuit is closed and with its removal is broken again at the moment when the sensation is perceived. The majority of his results in this connection are not of importance for this study, but it is stated that on the average the length of the "Zwischenzeit" is .87 of a second, and that this interval is quite constant.

The appearance of two "stechende" sensations with punctiform and areal mechanical stimuli was next investigated. For areal mechanical stimulation the following apparatus was used. A steel spring was set up having one end fastened to a block and the other lying free and bearing on its tip a flat plate. By raising the free end to any determined height and then releasing it in a uniform manner any intensity of stimulus may be given. With increasingly intense stimuli one gets the following corresponding sensations: (1) pure contact; (2) contact which after an interval is followed by pain; (3) momentary and delayed pain sensations; (4) with still stronger stimuli, the later-appearing sensation becomes weaker until only one strong momentary sensation appears.

For punctiform stimuli an entirely different apparatus was used. A fine-pointed needle was hung by a thread to the upper arm of a pair of forceps. By pressing on the spring of the forceps the needle would be forced against the skin and as soon as the pressure ceased would be lifted again by the power of the spring. To prevent lateral oscillation the needle moved up and down in a glass tube. The changes in intensity were brought about by means of a cross-bar the longer end of which rested on the needle and upon this bar weights of different sizes were hung. The dorsal side of the hand was used, and the results

obtained varied, on different points of the skin, in the following manner. (1) There were certain spots on which only a contact sensation appeared regardless of the intensity of the stimulus. (2) On some spots there appeared a contact feeling followed after a sensationless interval by a "stechende" sensation; with stronger stimulation on these spots the contact feeling was covered up by a "stinging" sensation which was followed as before by a second similar one. (3) On other points, with weak stimuli, the same results were obtained as in 1, while by increasing the stimulus, a stinging sensation replaced the contact but the secondary sensation was lacking. (4) On still other points, the results are in general the same as in 2 but here the stimulus must be very intense in order to obtain the stinging sensation. The early and late pain sensations are therefore only called out on certain points—von Frey's pain points. The early and late "stinging" sensations are not exactly alike, for aside from the fact that the early "stinging" sensation is usually mixed with contact, the late sensation is "auch nicht so momentan und hat einen Charakter, von dem ich, um ihr zu verdentlichen, sagen möchte, dass er voller ist als der der augenblicklichen".

To measure the reaction times of these sensations a slight modification was made in the punctiform apparatus. A small metal plate was arranged in such a way that the head of the needle would come in contact with it when rising from the skin. Both this plate and the needle were connected with a battery by fine wires so that by their contact the circuit was established. The exact application of the devise is not stated; but the results obtained show that the average reaction-time for the first contact was .21″ and for the late "stinging" sensation .88″; for the early "stinging" sensation .18″ and for the second "stinging" sensation .96″. This corresponds to the time for the early and late "stinging" sensations aroused by thermal stimuli. The number of tests taken in this connection were not numerous, but the author regards them as conclusive.

With electric stimuli especial attention was given to the effect of brief contact and of extremely punctiform stimulation, i.e. with a finer electrode than was used by Goldscheider. The mechanical-

punctiform apparatus was used here, the needle being connected with a battery by a fine wire, while the indifferent electrode was a paper-covered copper plate and was held in the palm of the hand. The spots stimulated were on the finger and back of the hand—a region where muscle twitching could best be avoided. In order to maintain a constant point of stimulation the needle was sunk slightly into the epidermis. This operation was generally painless and spots where a painful sensation was produced thereby, were discarded.

With single induction shocks, Thunberg found that, contrary to Goldscheider and Gad, a delayed sensation could be obtained on certain favored skin spots. On most spots, there appeared with this stimulus, only a single contact sensation, which became painful if the stimulus was increased. On certain spots, however, the delayed sensation appeared, but weak and unclear; while on certain others,—although these were few in number—it appeared quite clearly but was always of lesser intensity than the first sensation.

With a series of induction shocks (the apparatus for giving these being essentially identical with Goldscheider's), it was found that the appearance of the secondary sensation was again much concerned with the spot stimulated. On some spots the secondary stinging sensation was clearly obtained, on others it appeared weakly and on others not at all, the primary sensation being in all cases the same. The same individual spot differences were noticeable in the stimulations given by a brief constant current. With this method the duration of the stimulus also proved of importance. Spots, which with a brief duration gave the delayed sensation only weakly, became stronger and clearer if the length of the stimulation were increased; and the same results occurred where several brief stimulations were applied on the same spot.

In summary, three quotations will perhaps best explain the author's conclusions. "Wie es sich mit den näheren Einzelheiten auch verhalten möge, sehr wahrscheinlich ist also, dass die mechanische und thermische Reizung einen Zwischenprocess verursacht, der seinerseits die Nerven-reizung vermittelt. . . . Bei An-

wendung einzelner Inductionsschläge hat die frühe Empfindung das niedrigste Minimum perceptible. Erst bei starker Reizung kommt auf gewissen Punkten eine verzögerte Sensation. Wenn man von der eben gegebenen Annahme ausgeht, dass nämlich die frühe Sensation durch directe Nervenreizung, die verzögerte durch einen durch den Reiz verursachten Zwischenprocess bedingt ist, muss diese Thatsache so gedeutet werden, dass der Inductionsschlag kräftig reizend auf den Nervenfaden selbst wirkt, aber ein sehr geringes Vermögen hat, den Zwischenprocess auszulösen. . . . Der Hauptinhalt unserer Erklärung ist also der, dass die freien Nervenenden besonders empfindlich für schwache thermische und mechanische Reize sind, aber mit langer Latenzeit reagiren. Bei directer Nervenreizung fällt die Latenzeit fort. Gleichzeitige Reizung auf diesen beiden Wegen bedingt die doppelte Schmerzsensation."

In 1903, Marillier & Philippe,[24] in a topographical cutaneous study, mention the necessity of a time interval between stimuli on account of fatigue and the persistence of previous contacts.

Haines[18] (1905) in a paper on Tactual Space Perception, states that he guards against the confusing effect of after-sensations by avoiding the successive stimulation of neighboring points.

In 1905, Urbantschitsch[37] published a paper dealing with after-sensations of various sorts but giving especial emphasis to the after-appearance of auditory and temperature stimuli. Early in this paper he cites the individual reports of his 12 subjects, from which he subsequently deduces his conclusions, without, however, attempting any tabulation of his data. In a more or less introductory way he first notes the fact that sensations incompletely or incorrectly perceived at the moment of stimulation may be corrected in the after-sensation. For example, the application on the forehead of the flat surface of an opened scissors was sensed merely as a cold wide surface but in the after-sensation was perceived as two cold strips placed at an angle.

The results of his research are included under the following headings.

(1) *Localization of Sensations.*

The after-sensations of touch and temperature were not always

limited to the place of application of the stimulus but were diffused beyond, and in some cases did not appear at all at the point of stimulation but upon some neighboring spot. As an example of the first case,—a metal strip 1 cm. wide was applied to the forehead for several seconds, the cold sensation was at first limited to that point, but several seconds later it diffused itself from the center of the forehead to the eyebrows and to the bridge of the nose, there it gradually increased in intensity and then disappeared, was gone 1 minute and then reappeared near the nose. Here, the secondary sensation arose at the point where the primary ceased, but in other cases of similar spreading the secondary sensation arose at the *original* point of stimulation and followed the same course as the primary. As an example of the second case,—the center of the forehead was pricked with a needle, the pain became more intense, then suddenly disappeared and some seconds later a painful after-sensation appeared on a point above the one stimulated. In some cases the succeeding secondary sensations *each* arise in a different place. In many cases, however, both the primary and secondary sensations appear on the point of application.

(2) *Manner of Reappearance.*

Frequently the after-sensations appear first at one end of the stimulated region and from there radiate over the rest of the surface. Sometimes this radiation occurs and then the sensation retracts until it persists only on the original starting point. Or again, instead of this wave-like progression the movement may be one of oscillation, i.e. the sensation starts and then goes back.

Usually when this spreading occurred it was present with both types of stimuli but in some cases only with one. With subject 1, for example, the warm sensations were restricted to the point of contact but the cold overstepped this, while with subject 2 the overstepping occurred only with the warm sensations. In some subjects it was found that the direction of spreading always remained constant, i.e. always toward the scalp, or toward the nose. In other subjects, this constant direction depended upon the kind of stimulation, i.e. warm or cold. In subject 7 for example, the cold after-sensation always began on the upper

border of the stimulated region, moved down and then up; while the reverse order was the case with warm stimuli. This phenomenon was very marked on the forearm, where with the great majority of subjects, the cold sensation always spread down and the warm upward. This observation, however, when subjected to careful examination, showed the interesting fact that by applying the stimulus—say cold—nearer and nearer to the elbow the tendency to radiate downward became less and less until a neutral zone was reached within which the area and the intensity of the sensation is limited. By passing beyond this neutral zone the direction of radiation becomes reversed, i.e. in this case it would be upward. This neutral zone was found to cover a space of from .5-1.5 cm. and was located from 9-11 cm. above the wrist joint. This reversal of direction occurred in some subjects without the intervention of this neutral zone.

(3) *Double Application Experiments.*

If, simultaneously with the application of a stimulus on a given spot a second stimulus was set down upon a neighboring spot the normal direction of spreading was usually reversed. This reversion did not occur if the second stimulus was applied on the side toward which the normal spreading inclined, i.e. if the accessory cold stimulus were placed between the original stimulus and the wrist, the spreading would continue its normal downward course. But if the accessory cold stimulus be given near the elbow, the spreading will usually be upward, and the space between the two applications will remain neutral. With the removal of the accessory stimulus, in this case, the spreading assumes its normal direction. This reversal of direction sometimes occurs if a contrary or similar stimulus be applied on the other arm or some more distant part of the body. With other subjects, however, both sensations spread in their normal directions and occupy thus only the space between their points of application; of this space the cold always occupies the greater part.*

* It is interesting to compare these data with the results obtained by H. J. Pearce," in a paper on Normal Motor Suggestibility, where it was found that the application of a second tactual stimulus increased or reversed the direction of error in localizing a skin spot previously stimulated.

(4) *Influence of a Change of Position.*

The raising or lowering of the arm was found to be of influence. With some subjects the change of position always caused a reversal of the normal direction of spreading, while with others the spreading was always upward when the arm was raised and downward when it was lowered.

(5) *Contrary After-Sensations.*

With the stimulation of one form of temperature sensation there frequently occurred the arousal of a temperature sensation of the opposite form, either acting simultaneously as a sort of contrast phenomenon or following after in the manner of a contrary after-sensation. Subject 7 showed a case of the contrast effect, where in the after-sensation one half the field was hot and the other half cold. And an example of the contrary after-sensation is given in subject 6, where a cold primary sensation is succeeded after an interval by a secondary warm sensation. Where this contrary after-sensation appears, the spreading, if present, follows the normal direction of the after-sensation rather than that of the original sensation.

(6) *The Intensity of the After-Sensations.*

"In der Mehrzahl der Fälle nimmt die Temperaturempfindung nach Unterbrechung der Temperatureinwirkung auf die Haut bald rasch, bald allmählich ab, bis zu ihrem vollständigen Verschwinden, und so zeigt sich auch die Nachempfindung meistens in der früheren Stärke oder etwas abgeschwächt. Bei mehreren Versuchspersonen fand jedoch nach Entfall der betreffenden Temperatureinwirkung ein Ansteigen der Empfindung statt, oder die secundäre Nachempfindung zeigte eine grössere Intensität als die ursprüngliche Temperaturempfindung während der Einwirkung des kalten oder warmen Körpers auf die Haut. Diese Erscheinung betrifft bald das ganze Applicationsfeld, bald bestimmte Stellen innerhalb dieses."

(7) *The Sympathetic Arousal of Earlier Stimulated Spots.*

The sympathetic arousal of earlier stimulated spots may occur with the stimulation of a neighboring spot: or if the after-sensa-

tion is in progress the second stimulation may serve to increase its intensity. This is especially true with cold sensations.

(8) *Intervals.*

The temperature after-sensations, especially cold, may have an interval of 10-15 minutes before their appearance, and they may be sympathetically called up after an even greater period. (In the individual reports earlier mentioned, however, the author often refers to an interval of "a second" or "several seconds".

(9) *After-Sensations of Touch.*

The following points are noted with regard to the after-sensations of touch. (a) They may show a change in location. After a pin prick the secondary sensation may appear not on the point of application but on a neighboring point, and successive after-sensations may likewise vary their position. Sometimes, many "stinging" sensations are said to appear so that in the after sensation the subject feels "as if a bundle of needles were set down on the skin". (b) The after-sensations may also show a change in quality from that of the original stimulus. For example, after a needle prick the after-sensation took the form of an itching, tingling sensation which extended over the whole forehead. (c) The touch after-sensations may sometimes be greater in intensity than the original stimulus.

In the first volume of his "Textbook" (1909) Titchener[34] says of the after-sensations of temperature: "A long-continued and intense cold stimulus is also followed by an after-sensation of cold. Intense stimuli, of brief duration, give a positive after-image,—the removal of a continued warm stimulus, on the other hand, leaves a sensation of coolness". After describing certain tests of thermal adaptation he says: "The after-image of cold following long-continued and intensive cold stimulation is a little paradoxical; we should rather expect an after-sensation of warmth. The cold may, in fact, be the paradoxical cold sensation, aroused in this case by the rush of warm blood to the cold-adapted regions".

II. INTRODUCTION

During the winters and springs of 1907 and 1908 the writer undertook, at the suggestion and with the advice and assistance of Professor J. R. Angell, a study of the phenomena of cutaneous after-sensation.

STATEMENT OF THE PROBLEM.

In beginning such a study it is necessary to recognize clearly those two types of phenomena which are variously treated as after-sensations. In the Dictionary of Philosophy and Psychology Titchener defines them briefly as follows:

"I. In the various senses brief stimulation of the peripheral organ results in (1) a primary sensation, (2) a short blank interval after the stimulus ceases and (3) a second sensation called an after-sensation.

"II. The name (after-sensation) is also given to the continuance of the sensation without pause after removal of the stimulus."

These definitions would seem perfectly applicable to the cutaneous phenomena if the statement were added, as Urbantschitsch suggests, that both types may be present in a given experience or either may appear alone. The phenomenon mentioned in II has been termed the Primary After-Sensation, or the Continuous After-Sensation of Dessoir, and this would have to be described as a sensation which *lasts after,* rather than one which *comes after* the stimulus. It is here defined as an uninterrupted continuation of the stimulus which persists for a variable time with equal or diminishing intensity. These primary after-sensations are much the more frequent in occurrence, often being the only after-effect noticeable and usually preceding the secondary sensation in cases of its appearance.

The other type of after-sensation, the one first defined by Titchener, is designated here, as elsewhere, the Secondary After-Sensation. It may make its appearance either identical in quality

with the stimulus-sensation or quite different from it. This change may show as marked a difference as the contrary sensations of Preyer and Urbantschitsch, but it is more frequently associated with an intensity change, and is therefore, a change of quality rather than a change of modality,—as for example, where a tingling itching after-sensation succeeds a pure pressure stimulus-sensation. (This is of course assuming the tickle-itch complex to be due to slight stimulation of the pressure nerves as over against those authors who would provide separate nerves for each.) This secondary sensation may appear very faintly and gradually increase in intensity, or it may come into being at its maximum strength with a sudden swell or throb. It may disappear likewise in this sudden manner or it may fade away gradually. In intensity, it may be equal to that of the stimulus or it may be so faint as to be barely distinguishable.

There have been found cases where, with the removal of the stimulus or during its application, the stimulus-sensation disappeared, so that the latent period ensues immediately upon, or even previous to, the removal of the stimulus. This then, is followed by a secondary sensation, thus giving a secondary after-sensation unpreceded by a primary. Other cases are found where the secondary sensation appeared without the interruption of a clear latent interval and these cases would seem to partake of the characteristics of both the primary and secondary sensations. An example will perhaps best describe such a case. Stimulus areal cold: after removal of the cylinder the stimulus persists for a little while with rapidly diminishing intensity and is succeeded by a period of cool tingling over the whole area, so faint as to be scarcely discernible. Then there recurs a sudden pulse of cold, identical in quality with, and almost as intense as, the stimulus-sensation. Here is an instance of an after-sensation uninterrupted from the removal of the stimulus to the moment of its final disappearance, and as such it should be classed as primary. But quite as important to the definition of the primary sensation is its "diminishing intensity" and such a recurrence of vivid cold would therefore exclude it from this class. This fact would seem to outweigh the consideration of the lack of an absolute

clear latent interval, so that such cases will be ranked in the tables as secondary sensations. We should therefore have to amplify our definition of the secondary after-sensations to include those which make their appearance after a clear latent interval or after a period of diminished intensity.

The short blank period preceding the secondary sensations has been termed the latent interval. Its relations to the primary sensations have just been described. It is here defined as a clear sensationless pause before the secondary sensation and is not intended to include those periods of diminished intensity just mentioned.

NON-ILLUSORY CHARACTER OF AFTER-SENSATIONS.

The criticism has sometimes been urged that these secondary after-sensations are, in reality, nothing more than the perception of those common muscular and organic feelings which ordinarily pass unnoticed, but which can be called out by concentrating the attention on a given portion of the skin. In order to determine whether the after-phenomena involve anything beyond such a subjective concentration, the re-agents of the following experiments were given a series of test experiments in which they were told to concentrate all attention possible on an indicated skin area and to record the resulting sensations. This test was given at the beginning of the experimentation and again, on the chance that the practice thus obtained in cutaneous introspection might have some effect, later on in the series. The results in the two cases were essentially similar and are summarized below. The subjects were asked to compare these results with those of cases where after-sensations were clearly obtained.

I. Gets no sensation. With the eyes closed gets only vague visual images of the region. In no way similar to after-sensation phenomena.

II. No sensation at all. Very different from after-sensation.

III. No sensation at all. Very different from after-sensation.

IV. Feels unlocalized tendinous strain and pulsation. None of the definiteness of after-sensation.

V. Feeling of slight superficial strain; wholly different from after-sensation.

VI. Feels a vague warmness over the area. Much more vague and diffuse than the after-sensation of warmth.

It would likewise seem probable that if these phenomena were of purely subjective nature there would be some individual type of response,—that is to say, with one subject all the secondary sensations might make their appearance gradually or might always come in waves, while with another the returns would tend to be abrupt. From the qualitative tables (vide infra) it will be shown however, that such is not the case; that the after-sensations tend to show differences characteristic of the various stimuli rather than differences characteristic of individual subjects. (Cf. Individual Tables.)

INFLUENCE OF ATTENTION.

It is likewise open to contention that these phenomena may be explained simply in terms of attention. The primary after-sensation followed by a latent period, then the secondary sensation followed in turn perhaps by a succession of after-sensations, each separated by a sensationless pause are strikingly comparable to the phenomena described by Sergi, Grandis, Kiesow, and others and attributed by them to the oscillations of attention. While it is not to be denied that in the investigation of cutaneous after-sensations the influence of attention was found very considerable, the phenomena as a whole cannot be so summarily disposed of. In the first place, the methods used by the investigators mentioned were either (1) by means of a continuous stimulation, in which the effects of partial adaptation must surely have been effective as well as the attention factor, or (2) by the use of minimal stimuli—while all the stimulations given in our experiments were well above the threshold. Although, as was just stated, the stimuli employed here were always of sufficient intensity to be clearly and easily perceived, that does not prohibit the possibility of many of the after-sensations making their appearance with considerably lessened strength. In such cases, it is undoubtedly true that the apperception of these at their moment of entrance probably depends largely on the direction of the attention at that instant, and, it is this fact that makes any exact measurement of the latent period impossible. It is very probable that there may

have been cases where the secondary sensation, being of this minimal intensity, and being likewise brief, may, by reason of the oscillations of attention, have been completely overlooked; so that many, or possibly all, of the cases recorded as giving "primary after-sensations alone" may be of this nature. Thunberg states that he finds it more difficult to understand the cases where these secondary sensations do not appear than those where they do, and such an explanation might perhaps serve. The percentage of cases, however, in which the fading primary sensation, the clear sensationless interval, and the sudden recurrence of the secondary sensation stand out clearly and intensely, together with the subjects' introspective certainty of the process, makes any explanation of the phenomena as dependent upon purely central factors, of the nature of imagination, quite impossible.

In order, however, accurately to test the matter a limited number of experiments was given to subjects II, V, and VI, as follows: The stimulus was given, then, as the primary sensation was dying away, the subject was instructed to begin reading aloud from a relatively unfamiliar book and to indicate any recurrence of sensation. It was found that with subject V, out of ten stimulations of areal pressure given under these conditions, three recurrences appeared with such vigor as to break into the field of attention. With subject II, the same occurred twice with contact cold, and twice also with subject VI, where the stimulus was punctiform pain.

There were also many cases throughout the experiments where a subject, thinking the secondary sensation had exhausted its recurrences, or was not to appear at all, had begun to record his introspection when the after-sensation appeared with such vividness as instantly to call back the attention to the stimulated area

III. EXPERIMENTATION

No attempt was made to make this investigation an exactly quantitative one, for the reasons given below, but rather a comparison was sought of the relative strength and frequency of the after-sensation in various fields, and of the relative preponderance of primary or secondary after-sensations.

METHOD OF INVESTIGATION.

Six subjects, three men and three women, were used for these experiments, all of whom were graduate students in psychology and competent introspectionists.

The experiments were carried on during a period of ten months, each sitting not exceeding half an hour in duration in order to avoid fatigue. The number of stimulations given at a sitting varied with the kind of stimuli in use and with the individual subject, as it was essential that the after-effect of previous stimulation should be completely dissipated before the next was given, and the relative persistence of the same varied with the two factors just mentioned. More than ten experiments were never given in a series and at times the number of tests was as low as three. During each sitting the subject signified the progress of the experiment by a series of prearranged words or movements—the record of which was taken down by the operator with the aid of a split second stop-watch. After each test, the subject gave a full introspective report of the entire process which was transcribed verbatim. The majority of the tests were given on the hands and forearms. The arm rested comfortably on a cushioned table and the temperature of the room was kept as nearly as possible normal.

Eleven forms of stimulation were used,—Areal pressure (contact), punctiform pressure (contact), radiant heat (no contact), areal heat (contact), punctiform heat (contact), electrically stimulated punctiform heat, radiant cold (no contact), areal cold

(contact), punctiform cold (contact), electrically stimulated punctiform cold, punctiform pain (pricking).

The technique employed for each form of stimulation was as follows:

I. *Areal Pressure.* Rounded cork points 1/8 and 1/4 in. in diameter, thermally neutral, applied carefully by hand, with a varying velocity and an intensity ranging from approximately 20-200 gr. for intervals of time varying from 1-10″.

II. *Punctiform Pressure.* Rounded wooden points 1/32 in. in diameter, and von Frey's "pressure hairs". These were applied, in the usual way, upon pressure spots which had been located and marked several days previous.

III. *Radiant Heat.* Brass "temperature cylinders," 6 cm. long and ½ cm. in diameter, were heated 3-5′ in a Bunsen burner, and brought as close as possible to the skin without touching it. Metal discs warmed to "red heat" were also used in the same manner.

IV. *Areal Heat.* Temperature cylinders of III, heated until the metal is distinctly but not unpleasantly warm to the touch, and applied to the skin with as little pressure as possible. These were removed as soon as a clear sensation of warmth was felt.

V. *Punctiform Heat.* Brass temperature cylinders, 1 mm. in diameter, heated and applied as in IV, to "hot spots" located and marked several days previous. The cylinders were removed when a clear sensation of warmth was felt.

VI. *"Electric Heat."* "Hot spots" were located by temperature cylinders, these were marked and after a 24-hr. interval were stimulated by means of the Du Bois-Raymond induction coil, a copper wire, 1 mm. in diameter being used for a stimulation-point. The shock was graduated to avoid undue muscular twitching.

VII. *Radiant Cold.* Temperature cylinders, cooled for 10-30′ in ice and salt were approached close to the skin. A metal tube 3 in. in diameter, having a base of sheet rubber was filled with finely chopped ice and salt and used in the same way. These were removed as soon as the coldness was sensed.

VIII. *Areal Cold.* Temperature cylinders and a metal disc 1

in. in diameter were cooled as in VII. These were carefully wiped dry and applied to the skin with as little pressure as possible. They were removed as soon as the cold was clearly felt.

IX. *Punctiform Cold.* Same method used as with punctiform heat. Cylinders cooled as in VII.

X. *"Electric Cold."* Same method used as in VI.

XI. *Punctiform Pain.* Pain spots were located and marked, a 24-hr. interval was allowed and then they were stimulated by sharpened hog bristles and fine needle points.

Under each of three type headings, three sets of tables are given which will attempt to state the results obtained in (A) Numerical, (B) Quantitative, and (C) Qualitative form.

The Numerical table (A) shows in every case, (1) the number of stimulations given, (2) the number of primary, and (3) the number of secondary after-sensations obtained. (4) Shows the number of cases where the primary sensations appeared alone, i.e. unsucceeded by a secondary, (5) the cases where the primary sensation ceased with, or during, the stimulus so that the secondary sensation made its appearance after a latent interval unpreceded by a primary sensation. (6) Shows the number of latent intervals, i.e. clear sensationless pauses which precede the secondary sensation. (7) Indicates the number of times the secondary sensation recurred more than once. It is not intended to indicate the actual number of recurrences. (8) Records the number of times when after-sensations failed to appear, i.e. where the sensation disappeared with or during the stimulus and did not recur. (9) Shows the percentage of primary, and (10) of secondary after-sensations obtained from the total number of stimulations.

Table B, is intended to show in a general way the quantitative measurements of the primary and secondary sensations and of the latent interval. As was earlier stated, it was found impracticable, if not impossible, to give any exact measurements as to the duration of these phenomena. The primary after-sensation was found the most easy to gauge introspectively, and the moment of cessation of the secondary could be indicated without much difficulty. The moment of appearance of the secondary sensa-

tion, however, and in consequence the moment of departure of the latent interval, was in many cases tremendously difficult of analysis, because this sensation appeared so gradually and was, at that moment, so easily to be confused with the general sensations present over the whole area. It has seemed best, therefore, to include in this table only those cases where the secondary sensation "appeared suddenly", "welled up", or "blazed out" in its full intensity. The stop-watch method is admittedly inexact, especially in comparison with the apparatus used by Goldscheider and Thunberg, but in view of the fact that (1) the measurable cases comprised less than a third of the total number of secondary sensations obtained; (2) that any slight noise, such as that of a kymograph, was found to be very distracting, and (3) most especially in consideration of the fact that our object was to obtain a comparative record of the *relative* persistence and intensity of the different types, rather than exact figures on any one, and, since this method was identical in all cases, it amply served that purpose and any further elaboration seemed unnecessary.

It has seemed in fact that this is not a field where quantitative measurement is at present possible. Considering first the stimulus—its objective strength may be carefully equated in each experiment but the relative sensitivity of different areas, even of the same general region, would cause its subjective perception to vary in a manner incalculable in physical units. Or if, as has been done, the same spot is used in every case, the well known rapid fatigue of the cutaneous sense organs would have the same effect before enough tests were taken to give any quantitative certainty. The duration of the stimulus, likewise, will vary subjectively, for the difference in the apperception-time of the different skin areas would serve in some cases to alter an objectively equal time of stimulation. In the matter of the primary after-sensation, the moment of beginning is arbitrarily fixed by the removal of the stimulus, but in those cases where the sensation fades out gradually its actual intensity at the moment of passing below the threshold does not always coincide with the intensity of the secondary sensation at the moment of its emer-

gence, because, we have in one case a series descending to a conscious limen and in the other case one ascending to the same limen from below; and the threshold in the first case would be lower. The moment of ending of the latent interval and in consequence the moment of appearance of the secondary sensation is likewise questionable. For the intensity with which the secondary sensation returns is widely variable, so that the time of apperception of an after-sensation would follow the same laws as the apperception of a sensation, i.e. would vary with the intensity of the same,—at least throughout the range with which we are dealing here.

The figures given in the quantitative table are all subject to these objections and are therefore to be regarded as general indications rather than exact measurements of the phenomena in question. It has seemed best to group the durations of the after-sensations under the heading "very brief", i.e. under 2″, "brief", i.e. 2-15″, "moderate", 15-60″, and "long" over 60″; and to tabulate the latent periods as "short", i.e. under 1″, "moderate" 1-30″, and "long" over 30″.

Table C deals with the qualitative nature of the after-phenomena. (1) Indicates simply the quality of the secondary sensation. (2) Records the changes in quality which may occur. (3) Shows the intensity of the after-sensation and, (4) its localization or change in location, (5) Indicates the manner of appearance of the secondary sensation and, (6) the manner of disappearance of, (a) the primary and (b) the secondary after-sensation.

In the accompanying inserts there is given the report of each individual subject obtained by each form of stimulation used. These, like the combined tables, are grouped under the headings Numerical, Quantitative and Qualitative.

Supplementary to our main experiments a limited number of others were made as follows: (1) Experiments in which corneal pain was the stimulus and the author the sole reagent. (2) Experiments in which a linear pressure stimulus was contrasted with that of a pressing point moving over a space equal to that of the linear extent (3 subjects served here). (3) Experiments in

which subjects were tested with the stimuli of heat, cold, and pressure on skin areas anæsthetised by ethyl chloride. (4) Experiments in which an attempt was made to reproduce Goldscheider's conditions (Cf. Historical Statement) of electrical stimulation (2 subjects were here used). Descriptions of the technique employed in these tests are given on pp. 65, 72-73, 74-78, and 84-86 respectively.

DIGEST OF COMBINED RESULTS.

By reducing the individual data (cf. Individual Tables) to general percentages we obtain the tables which follow:

A. Combined Numerical Tables.

TABLE I.

PERCENTAGE OF AFTER-SENSATIONS. (PRIMARY AND SECONDARY.)

Areal Cold	94.8%
Punctiform Pain	93.5%
Areal Heat	89.3%
Areal Pressure	88.4%
Punctiform Cold	84.7%
Punctiform Pressure	79.3%
Punctiform Heat	79.3%
Radiant Heat	74.5%
Radiant Cold	67.9%
Electric Cold	59.3%
Electric Heat	58.3%

Such a table seems to indicate—(1) that after-sensations result from the given stimuli in the following order of frequency,—areal cold, punctiform pain, areal heat, areal pressure, punctiform cold, punctiform heat and pressure, radiant heat, radiant cold, electric cold, and electric heat; (2) that when punctiform and areal forms of the same stimulus are given, the areal is more productive of after-sensations; (3) that with temperature stimuli the contact method is more reliable than the radiate or electric; (4) that the order is cold, heat, pressure for both punctiform and areal stimulations and that the percentage difference between cold and heat is greater than that between heat and pressure in both cases: (5) that radiant heat is the only case where a heat stimulus is more effective than a cold of the same type.

TABLE II.

PERCENTAGE OF PRIMARY AFTER-SENSATIONS.

Areal Cold	92.7%
Areal Heat	86 %
Punctiform Pain	85.2%
Areal Pressure	82.8%
Punctiform Cold	80.6%
Radiant Heat	76.6%
Punctiform Heat	74.1%
Punctiform Pressure	73.6%
Radiant Cold	67.9%
Electric Cold	59.3%
Electric Heat	58.3%

(1) For primary after-sensations the order of precedence is,—areal cold, areal heat, punctiform pain, areal pressure, punctiform cold, radiant heat, punctiform heat, punctiform pressure, radiant cold, electric cold, electric heat. This arrangement is identical with that of the first table with the exception of radiant heat, which is here given a higher percentage than punctiform heat and pressure. (2) The order cold, heat, pressure, with the greater interval lying between cold and heat, holds true for both areal and punctiform stimulations. (3) Areal forms are likewise more suited than punctiform to the production of primary after-sensations but (4) punctiform heat by giving a lesser percentage than radiant is an exception to the rule that contact stimuli are more favorable than radiant or electric, but the difference is very slight. (5) Radiant heat is the only case where a heat stimulus is more effective than a cold of the same type, but the greater radiate energy of this form of stimulus may account for this discrepancy. (6) As to the actual figures it will be seen that the percentages of primary after-sensations of the different stimuli correspond very closely to those of Table I. The greatest divergence is in the case of punctiform pain and punctiform pressure.

This table is to be compared with one showing the percentages of Secondary After-Sensations.

TABLE III.

PERCENTAGE OF SECONDARY AFTER-SENSATIONS.

Punctiform Pain	73.8%
Areal Cold	71.9%
Radiant Cold	70.8%

Areal Heat	65.3%
Punctiform Cold	63.9%
Punctiform Heat	60.3%
Areal Pressure	54.2%
Punctiform Pressure	47.2%
Electric Cold	40.7%
Electric Heat	37.5%
Radiant Heat	34 %

(1) In this table the order stands—punctiform pain, areal cold, radiant cold, areal heat, punctiform cold, punctiform heat, areal pressure, punctiform pressure, electric cold, electric heat, radiant heat. This differs from the first two in giving punctiform pain a greater percentage than areal cold and in making both forms of contact temperature stimuli more effective than areal pressure. (2) Areal forms are in every case more suitable than punctiform, although the difference between them is less than with the primary. (3) Cold stimuli are more effective than similar heat stimuli, and (4) the order cold, heat, pressure is true for both punctiform and areal stimulations although the greater interval here lies between heat and pressure. (5) The figures in this table show a marked lessening from those of the primary after-sensations. Numerically they are on an average about a third less,—that is to say, for every case where a secondary after-sensation was obtained there were approximately two instances of primary after-sensations. A table of the relative preponderance of primary over secondary is given below in descending order.

TABLE IV

THE RELATIVE PREPONDERANCE OF PRIMARY OVER SECONDARY AFTER SENSATIONS

Radiant Heat	42.6%
Areal Pressure	38.6%
Punctiform Pressure	36.4%
Radiant Cold	22.6%
Areal Cold	21.9%
Areal Heat	21.4%
Electric Heat	20.8%
Electric Cold	18.6%
Punctiform Cold	16.7%
Punctiform Heat	13.8%
Punctiform Pain	11.4%

This table indicates that—(1) areal stimulations in every case show a greater preponderance of primary over secondary sensations than do the punctiform and electric stimulations of the same type, and that (2) radiant heat shows this preponderance much more strongly than any of the other forms.

The presence of a clear latent interval preceding the appearance of the returning sensation was, it will be remembered, only present in certain cases, its place being taken in the remainder by a considerable diminishing of the primary after-sensation.

TABLE V.

PERCENTAGE OF LATENT INTERVALS.

Areal Pressure	38.3%
Punctiform Pressure	30.2%
Punctiform Pain	29.5%
Punctiform Heat	27.6%
Punctiform Cold	25 %
Areal Heat	16 %
Areal Cold	11.5%
Radiant Heat	8.5%
Electric Heat	8.3%
Electric Cold	7.4%
Radiant Cold	0 %

This table shows rather a reversal of previous conditions in that; (1) pressure and pain stimuli seem most favorable for this type of response; (2) heat, in all its forms, is more effective than cold and that; (3) with the temperature stimuli, although such is not the case with pressure, punctiform stimuli give better results than areal.

TABLE VI.

PERCENTAGE OF SECONDARY AFTER-SENSATIONS ALONE.

Punctiform Pain	8.2%
Punctiform Heat	5.2%
Areal Pressure	5.2%
Punctiform Cold	4.2%
Areal Heat	2.7%
Areal Cold	2.1%
Punctiform Pressure	1.9%
Radiant Heat	0 %
Electric Heat	0 %
Radiant Cold	0 %
Electric Cold	0 %

(1) The order of preponderance in this table is not unlike that in the preceding, punctiform pain being here given first place and the pressure stimuli, especially punctiform pressure, being ranked lower down. As in table V (2) heat appears more effective than cold and (3) again with the exception of pressure, the punctiform stimuli are more favorable than the areal. (4) Neither radiant nor electric stimuli produced a secondary sensation unaccompanied by a primary. (Table V shows the percentage of latent intervals obtained by these stimuli to be very small.)

TABLE VII.

PERCENTAGE OF RECURRENT SECONDARY AFTER-SENSATIONS.

Punctiform Cold	26.4%
Punctiform Heat	13.8%
Punctiform Pain	13.1%
Punctiform Pressure	11.3%
Radiant Heat	8.5%
Electric Heat	8.3%
Areal Pressure	7.5%
Radiant Cold	7.5%
Electric Cold	7.4%
Areal Cold	7.3%
Areal Heat	4 %

From this it is to be seen: (1) that punctiform stimuli give the best results—cold being especially favorable—although (2) the other forms of contact temperature stimuli, i.e. areal, were found less effective than radiate and electric,—areal heat giving a strikingly low percentage.

The last table in this series gives the percentages of primary after-sensations unaccompanied by secondary; it is to be compared with table II.

TABLE VIII.

PERCENTAGE OF PRIMARY AFTER-SENSATIONS ALONE.

Radiant Heat	38.3%
Areal Pressure	33.4%
Punctiform Pressure	28.3%
Areal Heat	22.7%
Areal Cold	21.8%
Electric Heat	20.8%
Punctiform Cold	20.8%
Punctiform Pain	19.7%

Punctiform Heat .....19 %
Radiant Cold 18.9%
Electric Cold 18.6%

(1) This follows the general rule of table I in having areal stimuli more effective than punctiform but otherwise differs from it. (2) Heat and pressure, except for the punctiform types, are more suitable than cold,—radiant heat being preëminently favorable. (3) Punctiform pain gives a relatively low percentage.

B. Combined Quantitative Tables.

The following tables contain percentages of the quantitative measurements. These are submitted with some hesitation, because, for the reasons earlier given, the figures represent but a small part of the total results (pp. 37-39).

TABLE IX.

PERCENTAGE OF THE DURATIONS OF PRIMARY AFTER-SENSATIONS.

	VERY BRIEF (-2")	BRIEF (2-15")	MODERATE (15-60")	LONG (60"+)
Areal Pressure.....	13.7%	27.3%	45.4%	13.7%
Punctiform Pressure.	17.2%	24.1%	31 %	27.6%
Radiant Heat.....	4.3%	30.4%	43.5%	21.7%
Areal Heat.....	3.7%	11.1%	33.3%	51.8%
Punctiform Heat.....	4.2%	20.8%	37.5%	37.5%
Electric Heat.....	0 %	42.8%	0 %	57.1%
Radiant Cold.....	0 %	40 %	40 %	20 %
Areal Cold.....	6.2%	8.3%	33.3%	52.1%
Punctiform Cold.....	8.1%	10.8%	40.5%	40.5%
Electric Cold.....	0 %	33.3%	41.7%	25 %
Punctiform Pain.....	0 %	19.4%	30.5%	50 %

The question at once arises whether those stimuli most suited to the production of primary after-sensations give also the greatest percentage of "long" or at least "moderate" durations; and from a comparison of this table with Table II this is shown, in general, to be the case. Areal pressure, it is true, is here given only 13.8% of "long" durations but the percentage of "moderate" is very large. This is true likewise for radiant heat. Electric heat is also ranked above its place in the numerical table but in this case there are no sensations of "moderate" length so 57% represents all the after-sensations which endured beyond 15".

TABLE X.

PERCENTAGE OF THE DURATIONS OF LATENT INTERVALS.

	SHORT (-1")	MODERATE (1-30")	LONG (30"+)
Areal Pressure	54 %	29.7%	16.2%
Punctiform Pressure	20 %	40 %	40 %
Radiant Heat	0 %	0 %	100 %
Areal Heat	66.6%	33.3%	0 %
Punctiform Heat	50 %	0 %	50 %
Electric Heat	0 %	0 %	100 %
Radiant Cold	0 %	0 %	0 %
Areal Cold	25 %	25 %	50 %
Punctiform Cold	20 %	40 %	40 %
Electric Cold	0 %	0 %	0 %
Punctiform Pain	33.3%	8.3%	58.3%

From such a table the most evident conclusions to be drawn are, —(1) that areal heat stimuli are most apt to give brief latent intervals, while (2) cold, on the contrary, more generally produce long intervals; (3) that secondary sensations of pressure, especially areal pressure, usually make their appearance after short or moderate intervals, and (4) after-sensations of punctiform pain are generally preceded by long intervals but more often by short than by moderate. (5) Radiant and electric heat seemingly give a high percentage of long durations but it is to be remembered there were very few latent intervals reported with either of these stimuli. (6) The latent intervals do not show any striking difference in duration between punctiform and areal forms of the same stimulus except in the case of heat where an areal stimulus gave 0% long intervals and a punctiform 50%

TABLE XI

PERCENTAGE OF THE DURATIONS OF SECONDARY AFTER-SENSATIONS

	VERY BRIEF (-2")	BRIEF (2-15")	MODERATE (15-60")	LONG (60"+)
Areal Pressure	10.4%	16.7%	41.7%	31.2%
Punctiform Pressure	20 %	20 %	20 %	0 %
Radiant Heat	0 %	0 %	100 %	0 %
Areal Heat	0 %	18.2%	36.4%	45.4%
Punctiform Heat	0 %	0 %	61.6%	38.4%
Electric Heat	0 %	0 %	0 %	0 %
Radiant Cold	0 %	0 %	0 %	0 %
Areal Cold	0 %	0 %	50.0%	50.0%
Punctiform Cold	0 %	0 %	11.2%	88.8%
Electric Cold	0 %	16.7%	50.0%	33.4%
Punctiform Pain	0 %	11.8%	54.8%	33.4%

From such a table it is seen that: (1) Pressure is the only stimulus which calls out a form of almost instantaneous after-sensation, i.e. "very brief"; (2) Pain stimuli give almost equal proportions of brief, moderate and long after-sensations; (3) Cold gives by far the greatest proportion of long after-sensations and none at all under 15″, and as regards this duration it is a matter of indifference whether the areal or punctiform method be used; and (4) with punctiform heat stimuli all the after-sensations are long or moderate and with areal heat 80% of them. Comparing this table with the numerical table of secondary after-sensations we see very little similarity between the stimuli most frequently producing after-sensations and those giving the longest durations. It may be said, however, that cold ranks above heat in order of their duration and both above pressure. Comparing this table with the table of latent intervals it can be seen: (1) that the pressure stimuli which give the greatest proportion of brief after-sensations give also the least proportion of long latent intervals; (2) that one third of the latent intervals from pain stimuli are short as are also one third of its after-sensations; (3) that the combined forms of contact cold give a greater proportion of long intervals than do the combined heat contact stimuli—a comparison which agrees with the proportion of long after-sensations of these two; and (4) that areal heat gives a greater proportion of both short latent intervals and brief after-sensations than does punctiform heat.

C. Combined Qualitative Results.

These results are by far the most difficult to interpret involving as they do peculiarities both of individual expression and response. Some subjects, for example, might call a sensation "prickling" which another would designate "tingling", while the variations in skin thickness, etc., of different subjects may cause an actual difference in sensation with the more delicate stimuli.

TABLE XII.

PERCENTAGE OF THE QUALITIES OF SECONDARY AFTER-SENSATIONS.

AREAL PRESSURE.

Dull pressure 44.6%; prickly 5.9%; throbbing 5.9%; tingling 13.1%; tickling 11.9%; deep tendinous feeling 1.2%; contact + pressure 1.2%;

strain 1.2%; soft elastic feeling 2.4%; stinging 1.8%; sharpness 3.6%; callous spot feeling 1.2%; cold .6%; cool .6%; cool tickling 2.4%; warmth 1.8%.

PUNCTIFORM PRESSURE.

Pressure 44%; cold and pressure 8%; prickinb 12%; pain prickle 8%; sharpness 8%; painful itching 8%; pressure and soreness 4%; throbbing 4%; pressure and pain 4%.

RADIANT HEAT.

Warm 25%; hot 18.7%; neutral indescribable sensation 12.5%; indefinite tingling 6.2%; slight warmth and smarting 12.5%; peculiar pain and throbbing 12.5%; cool 12.5%.

AREAL HEAT.

Pure warmth 34.6%; smarting 16.3%; tingle 6.1%; prickling 4.1%; cool menthol feeling 6.1%; hot, burning 8.2%; heat and touch 8.2%; pressure and smarting warmth 10.2%; cold 4%; cool 2%.

PUNCTIFORM HEAT.

Clear distinct warmth 28.5%; faint warmth 17.1%; almost a burn 14.3%; painfully warm, burning 11.5%; burning feeling of menthol 2.9%; warm pressure 11.4%; warm prickling 5.7%; large diffuse pain 2.9%; tingling 2.9%; prickling 2.9%.

ELECTRIC HEAT.

Warm 33.3%; hot 11.1%; sort of burning sensation 33.3%; smarting, biting 11.1%; cold 11.1%.

RADIANT COLD.

Clear cold 16.7%; cool 70.8%; rheumatic pain 8.3%; warm 4.2%.

AREAL COLD.

Vivid cold identical with stimulus 52.9%; cool subcutaneous vapor 1.5%; cool 4.4%; burning cold 4.4%; cold and pressure 7.3%; cold and wet 5.8%; cold and contact 10.3%; pressure 1.5%; tingle and throb with pressure 1.5%; tickle 4.4%; wet and heavy 1.5%; moist, no pressure 1.5%; tingling 1.5%; warm 1.5%.

PUNCTIFORM COLD.

Pure cold 60.9%; burning cold 2.2%; cold and pressure 2.2%; cold and touch 6.5%; cold and wet 6.5%; cold tingle 2.2%; cool wave 2.2%; cool itching pain 2.2%; faint rheumatic pain 2.2%; pricking 2.2%; stinging 4.3%; tingle 6.5%.

ELECTRIC COLD.

Cold 81.8%; cool tingle 9.1%; pricking pain 9.1%.

PUNCTIFORM PAIN.

Pure, clear pain 51.1%; somewhat painful 2.2%; pain and pressure 8.9%; sharp contact 4.4%; sharp beating 4.4%; perhaps painful pressure 4.4%; pricking and throbbing 8.9%; general ache 11.1%; pressure with tingle 2.2%; pressure with ache 2.2%.

Such a table clearly indicates, that every form of stimulus used gives a much greater proportion of secondary after-sensations *qualitatively similar* to the stimulus than differing from it. It can be seen too, that this is more evident with punctiform than with

areal forms of the same stimulus, punctiform heat being especially noticeable. The electric forms of stimuli as well as radiant cold seem to be especially favorable to this identical reproduction. Pressure stimuli produce a qualitatively different after-sensation more frequently than do temperature.

TABLE XIII.

PERCENTAGE OF CHANGES IN THE QUALITY OF SECONDARY AFTER-SENSATIONS.

AREAL PRESSURE.

Pressure ends in tickling 2.4%; cutaneous feeling changes to tendinous strain .6%; pressure changes to tingling and beating .6%; pressure changes to indescribable quality 1.2%; delicate pressure changes to pressure + sting .6%; pressure changes to warmth 1.2%; pressure ends in tickling .6%; pressure changes to cool .6%; alternate pressure and contact .6%; dull pressure, to cool, to pressure .6%.

PUNCTIFORM PRESSURE.

Pressure changes to sharpness 4%; pressure changes to pain 4%; cold and pressure, cold goes leaving pressure 4%; cold and pressure, pressure goes then a return like the original 4%.

RADIANT HEAT.

Returned cold 12.5%.

AREAL HEAT.

First return pressure then warm then cold 2%; cold returns 8.2%; cool returns 4.1%; pressure then warm then cold 2%; warm changes to throbbing 2%; pressure and heat then only heat 2%; returns cold then warm then cool 2%; neutral primary sensation is burning in secondary 2%.

PUNCTIFORM HEAT.

Prickly feeling to menthol feeling 2.9%; menthol feeling to warmth 2.9%; pain to warm pricking 2.9%.

ELECTRIC HEAT.

Cold returns 11.1%.

RADIANT COLD.

Returns warm 4.2%.

AREAL COLD.

Cold and touch, touch goes cold remains 1.5%; first return cold and contact, recurrences are pure cold 1.5%; stimulus pressure and cold only cold in after-sensation 5.8%; first recall pressure, second cold, third pressure 1.5%; returns warm 1.5%.

PUNCTIFORM COLD.

Cold tingle changes to pure cold 2.2%.

ELECTRIC COLD.

Returns warm, then cold then warm 9%; cold, then a pulse of pain 9%.

PUNCTIFORM PAIN.

Pain and pressure changes to pressure alone then pain alone 2.2%; pain to contact 2.2%; pain to pressure 2.2%; sharp pressure to sharp pain 2.2%; pain settles into ache 4.4%; pain and pressure, pain fluctuates

while pressure stays constant 2.2%; ache, with periods of prickling 2.2%; throbbing and pressure alternate 2.2%; two pressure returns then pressure + tingle 2.2%; first return pain, second an ache 2.2%; primary after-sensation is coldish, secondary only pain 2.2%; stimulus only touch stinging pain in the after-sensation 2.2%; touch and pain alternate 6.7% return pressure and pain 2.2%; primary is pain and pressure, secondary only pain 2.2%; first return sharp pain, second, pressure 2.2%.

It is evident that secondary sensations *may make their appearance* changed in quality, i. e. different from the primary, or the change may come in some one of the succeeding recurrences or again, they may change qualitatively during their continuance. The so-called "contrary after-sensations", i. e. heat to cold and vice versa, never made their appearance in this third manner, although there were cases where pressure changed gradually to warm and to cold, and where heat changed into contact, and cold into pain. The relative proportion of quality changes which took place in this manner, i. e. by a gradual shading of one sensation into another, stand in the following order: punctiform pressure 12%, punctiform heat 11.6%, punctiform pain 11%, areal pressure 8.4%, punctiform cold 2.2%, areal heat 2%, and areal cold 1.5%. From which it appears, that punctiform stimuli are more suitable than areal and that the order is pressure, heat, cold for both areal and punctiform stimuli. Electric and radiate stimuli show no changes of this type. This table also shows that heat gives a greater percentage of contrary after-sensations than cold —30.8% as against 14.7%. No contrary after-sensations were obtained with either punctiform heat or punctiform cold.

TABLE XIV.

PERCENTAGE OF THE INTENSITIES OF SECONDARY AFTER-SENSATIONS.

AREAL PRESSURE

Faint 42.3%; moderate 16.1%; hard and vivid 30.2%; stronger than stimulus 12.5%

PUNCTIFORM PRESSURE

Mild 24%, distinct 12%; strong, intense 44%, equal to stimulus 20%

RADIANT HEAT

Mild 50%; not intense 31.2%, intense and definite 18.7%

AREAL HEAT.

Faint, mild 37%; moderately intense 22.4%, strong, intense 18.4%; very distinct 18.4%, stronger than stimulus 4%

PUNCTIFORM HEAT.

Faint, mild 34.3%; moderately strong 25.7%; strong 25.7%; very intense 5.7%; painfully warm 5.7%; strong as stimulus 2.9%.

ELECTRIC HEAT.

Mild 11.1%; quite strong 33.3%; moderate 22.2%; intense 11.1%; very intense 22.2%.

RADIANT COLD.

Faint 62.5%; moderate 25%; definite 4.2%; strong 8.3%.

AREAL COLD.

Mild 7.3%; less distinct 2.9%; moderate 4.4%; intense 58.8%; strong as stimulus 7.3%; very intense 11.8%; stronger than stimulus 7.3%.

PUNCTIFORM COLD.

Faint, mild 28.3%; moderate 2.2%; strong, distinct 56.5%; strong as stimulus 4.3%; *very* intense 8.7%.

ELECTRIC COLD.

Mild 18.2%; moderate 27.3%; very clear 45.4%; intense 9%.

PUNCTIFORM PAIN.

Faint 31.1%; strong 33.3%; steady 4.4%; less intense, moderate 8.8%; strong as stimulus 6.7%; intense 15.6%.

Adopting a purely arbitrary method of gradation, i. e. counting the response "faint" as 1, "moderate" as 2 etc., and with the assistance of the introspective comparisons of our subjects we find the after-sensations taking the following order according to their respective intensities,—areal cold, punctiform cold, punctiform pressure, punctiform pain, areal pressure, areal heat, electric heat, punctiform heat, electric cold, radiate heat and radiate cold. It therefore appears that areal and punctiform cold after-sensations are more intense than warm, and that areal stimuli give stronger after-sensations than punctiform except in the case of pressure.

TABLE XV.

PERCENTAGE OF THE LOCALIZATIONS OF SECONDARY AFTER-SENSATIONS.

AREAL PRESSURE.

Diffuse or spread 50.6%; massive and unlocalized 3.6%; sharply localized 31.1%; limited to a definite area 3.6%; localized as ½ size of the stimulus 1.2%; hole with pressure around it .6%; diffuse and comes to a point 2.4%; seems to go *in* 2.4%; moves 2.4%; moves then jumps back to stimulated spot .6%; goes to spots previously stimulated .6%.

PUNCTIFORM PRESSURE.

Diffuse, unlocalized, spread 36%; areal 16%; localized 48%.

RADIANT HEAT.

Unlocalized, diffuse, spread 56.2%; wrongly localized 12.5%; well localized 25%; localized subcutaneously 6.2%.

AREAL HEAT.

Diffuse, spread 55.1%; spread but generally localized 18.4%; distinctly localized 18.4%; ¼ in. circle 2%; dot-like area 4%; changes position 4%.

PUNCTIFORM HEAT.

Diffuse and spread 31.4%; areal 20%; well localized and punctiform 40%; spread to other areas 2.9%; goes in deep 5.7%.

ELECTRIC HEAT.

Unlocalized, spread 44.4%; whole arm warm 11.1%; heat radiates off from stimulated spots 11.1%; areal 11.1%; localized 33.3%.

RADIANT COLD.

Diffuse, unlocalized 87.5%; cool breeze over that region 4.2%; spread to elbow joint 4.2%; localized 4.2%.

AREAL COLD.

Diffuse, spread 38.4%; heat radiated from touch spot 1.5%; not as localized as pressure 2.0%; spread following artery 1.5%; moves 2.0%; goes down like a cone with its base on skin 1.5%; not as deep as pressure but not on the skin 1.5%; clearly localized 50%.

PUNCTIFORM COLD.

Diffuse, spread 28.2%; wrongly localized 6.5%; becomes two points 2.2%; goes in deep 4.3%; whole arm cold 2.2%; area 6.5%; areal coming to a point 2.2%; punctiformly localized 45.6%.

ELECTRIC COLD.

Diffuse 27.2%; cold radiating off from a spot 0%; sharply localized 54.5%; can't tell 9%.

PUNCTIFORM PAIN.

Diffuse, spread 33.3%; areal 2.2%; clearly localized 64.4%.

From this table it is seen that punctiform pain gives the greatest per cent of clearly localized after-sensations, and, that the percentage of clear localization decreases and that of diffuseness and spreading increases in the following order: electric cold, punctiform cold, punctiform pressure and areal cold (almost identical), punctiform heat, electric heat, areal pressure, areal heat, radiant heat and radiant cold. It is therefore evident that punctiform stimuli give more clearly localized after-sensations than areal and that with the exception of the radiant form, cold is more easily located than heat.

TABLE XVI.

PERCENTAGE OF THE MANNER OF APPEARANCE OF SECONDARY AFTER-SENSATIONS.

AREAL PRESSURE.

"Wells up" 8.4% (suddenly 3.6%); increases gradually 22.1%; comes crescendo as a pulsation from within 3%; comes suddenly 25.1%; comes gradually tingling and beating 3.6%; comes from within, i. e. no contact

6%; comes like a twinge 3.6%; in waves 6%; waves from within 1.8%; comes up more quickly than dies down 1.2%; diffuse and coming to a point 2.4%; returns on a full pulsation 3%; can't be sure 10.8%; comes from within in connection with the pulsation 3%.

PUNCTIFORM PRESSURE.

Suddenly 32%; quite sudden 4%; gradually 44%; came from below in a quick throb 4%; impossible to tell 16%.

RADIANT HEAT.

Comes suddenly 6.2%; "wells up" slowly 31.2%; gradual return 25%; comes in waves 25%; impossible to tell 12.5%.

AREAL HEAT.

Suddenly 14.3%; slowly, gradually 57.1%; comes in waves 18.4%; comes in streaks 8.2%; moderately gradual 2%.

PUNCTIFORM HEAT.

Suddenly, quickly 31.4%; quite suddenly 2.8%; "wells up" 5.7%; gradually, slowly 60%.

ELECTRIC HEAT.

Comes suddenly 55.5%; gradually 44.4%.

RADIANT COLD.

In markedly recurrent waves 75%; gradually 20.8%; a cool breeze coming to a point from all directions 4.2%.

AREAL COLD.

Suddenly 38.2%; slowly, gradually 44.1%; in gradual waves 7.3%; comes from below 4.4%; primary sensation spread and came to a head at the stimulated point 2.9%; in waves 2.9%.

PUNCTIFORM COLD.

Suddenly 34.8%; slowly, gradually 30.4%; areal coming to a point 4.3%; in waves or pulses 15.2%; pulsates with the breathing 4.3%; comes in throbs 6.5%; impossible to tell 4.3%.

ELECTRIC COLD.

Gradually 45.4%; suddenly 54.5%.

PUNCTIFORM PAIN.

Slowly, gradually 42.2%; suddenly, quickly 42.2%; in quick beats 2.2%; in irregular short jabs 6.7%; throbs with the pulse 4.4%; uncertain 2.2%.

The only basis for a comparison of the different stimuli here is with regard to the abruptness of appearance of the returning sensation. Grading them in this respect they take the following order: electric heat, electric cold, punctiform pain, punctiform pressure, areal cold, punctiform cold, punctiform heat, areal pressure, areal heat, and radiant heat.

It is to be seen therefore that, with the exception of cold, punctiform stimuli give more sudden returns than areal, that cold, except electric cold, reappears more abruptly than heat, and that pain and electric stimuli give especially sudden returns.

TABLE XVII.

PERCENTAGE OF THE MANNER OF DISAPPEARANCE OF PRIMARY AFTER-SENSATIONS.

AREAL PRESSURE.

Spread and disappear 11.7%; end in tingling 10.1%; go slowly 7.4%; quickly, abruptly 21.8%; scatter 5.1%; pass off in two lines converging toward the wrist .4%; move toward the fingers 1.1%; go to a point and disappear 3.1%; go almost instantly 3.5%; moderately slow disappearance 4.7%; fading gradually 11.3%; ends in tickling .8%; ends in a consciousness of the place .8%; spread gradually and disappear 3.5%; uncertain 14.8%.

PUNCTIFORM PRESSURE.

Disappear gradually 55.3%; go abruptly 42.1%; spread away 2.6%.

RADIANT HEAT.

Rather abruptly 14.3%; disappear slowly and gradually 48.5%; diffuse away 37.1%.

AREAL HEAT.

Go gradually 61.9%; abruptly 6.3%; fairly suddenly 3.2%; persistent, i. e. slow in disappearing, 7.9%; very persistent 7.9%; diffuse away gradually 12.7%.

PUNCTIFORM HEAT.

Shades off into a kind of menthol feeling 4.6%; go suddenly 44.2%; go gradually 51.2%.

ELECTRIC HEAT.

Go suddenly 28.6%; go more gradually 28.6%; quite persistent 14.3%; fade out 28.6%;

RADIANT COLD.

Quick but gradual 11.1%; sudden 2.8%; very sudden 8.3%; fade away gradually 63.9%; impossible to tell 13.9%.

AREAL COLD.

Fading slowly and gradually 62.9%; fade out 11.2%; spread away 5.7%; gradually diffusing 19.1%; suddenly 1.1%.

PUNCTIFORM COLD.

Go gradually 39.6%; go very gradually 31%; spread out and disappear 10.3%; go more suddenly 10.3%; go suddenly 3.4%; can't be sure 5.2%.

ELECTRIC COLD.

Go gradually 42.1%; quite persistent 21%; rather suddenly 36.8%.

PUNCTIFORM PAIN.

Go suddenly 51.9%; disappear slowly and gradually 48.1%.

Such a table indicates that: punctiform pain is the only stimulus which gives a greater percentage of sudden than of gradual disappearances; that heat sensations disappear more abruptly than cold and, that areal forms disappear more slowly than punctiform or electric.

TABLE XVIII.

PERCENTAGE OF THE MANNER OF DISAPPEARANCE OF SECONDARY AFTER-SENSATIONS.

AREAL PRESSURE.

Goes very slowly 17.3%; goes suddenly 14.3%; moderately abrupt 3%; fading gradually 10.7%; spreads and disappears 14.3%; ends in a vague tingle throughout the entire region 2.4%; disappears in a point 3.6%; moves up arm and disappears 2.4%; spreads and dies out in a scattered tingling 12.5%; uncertain 19.6%.

PUNCTIFORM PRESSURE.

Very gradual disappearance 28%; more sudden 16%; gradual 32%; abruptly 8%; uncertain 16%.

RADIANT HEAT.

Suddenly 6.2%; quickly but gradually 18.7%; moderately gradual 56.2%; uncertain 18.7%.

AREAL HEAT.

Fade suddenly 14.3%; go gradually 65.3%; die away in throbbing 6.1%; spread and rapidly disappear 2%; impossible to say 12.2%.

PUNCTIFORM HEAT.

Suddenly 22.9%; apparently suddenly 20%; less suddenly 11.4%; slowly and gradually 25.7%; very persistent 11.4%; radiate off 5.7%; spread 2.9%.

ELECTRIC HEAT.

Suddenly 22.2%; gradual 11.1%; slow disappearing 11.1%; spread and radiate off 55.5%.

RADIANT COLD.

Wave-like decrease 54.2%; gradual 8.3%; quick but gradual 8.3%; impossible to tell 29.2%.

AREAL COLD.

Persistent, fading gradually 69.1%; fade out in indefinite feeling 14.7%; spread 8.8%; go suddenly 7.3%.

PUNCTIFORM COLD.

Go suddenly 13%; go slowly, persistent, 52.2%; spread away 10.9%; fade out 21.7%; go in deep and disappear 2.2%.

ELECTRIC COLD.

Suddenly 36.3%; quite suddenly 36.3%; gradually 27.2%.

PUNCTIFORM PAIN.

Suddenly 31.1%; quite suddenly 15.5%; slowly 35.6%; turned into an ache 8.9%; left a soreness 4.4%; uncertain 4.4%.

This would seem to indicate that punctiform pain and electric cold show the largest percentage of sudden disappearances; that punctiform sensations disappear more abruptly than areal and, that with the exception of electric heat, the heat stimuli disappear more suddenly than the cold.

D. Summary of Combined Numerical, Quantitative, and Qualitative Tables.

If now, all these tables, numerical, qualitative, and quantitative

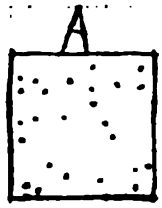
are considered together and the combined data subsummed under the different stimulus headings the following results are shown.

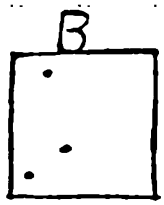
Areal pressure stimuli are quite favorable for primary after-sensations but relatively less so for secondary. More than a third of their primary after-sensations appeared alone, and this is the greatest proportion obtained by any form of stimulus except radiant and electric heat. The quantitative measurements show that the greater part of these primary after-sensations were of "moderate" duration, and that equal proportions of the remainder were "very brief" and long". As to their manner of disappearance, it is seen that 25% disappeared abruptly,—"rang off" without a process of gradual fading, while most of the remainder faded slowly, or spread away still keeping the character of the original stimulus, or perhaps, ended in a tickling, tingling sensation. 38% of these stimuli gave clear latent intervals (a greater proportion than is given by any other type of stimulus), 54% of which endured less than 1" and only 16% lasted beyond 30". A small proportion (5.2%) of secondary sensations made their appearance unpreceded by primary,—a greater percentage, however, than was obtained by punctiform pressure or by the other forms of areal stimulation. Of those secondary sensations which it was possible to measure, about 25% were under 15" in duration and more than half the remainder were "moderate". About 45% (44.4) reproduced the original quality of the stimulus, the remainder taking the qualities of pricking, throbbing, tingling, tickling, stinging, etc., with a few instances of coolness. In less than 10% of the cases did the quality change. In the matter of intensity, areal pressure gave about equal proportions of mild and intense recalls. About a third of the secondary sensations were clearly localized, the rest being diffuse or spread. About a third, likewise, made their appearance abruptly and a considerable number were said to "come from within". The great majority disappeared by a process of slow fading or scattered tingling. The percentage of recurrences was, with this stimulus, 7.5,—a figure almost identical with the percentage of recurrences of areal cold and much in excess of that of areal heat.

h

Winifred M Corcoran.

To prove Temperature Sensations.





area 1cm. x 1cm. showing cold spots.
area 2cm. x 2cm. showing Warm spots.

from any stimulus. Quantitatively only 4.3% of the primary sensations were found to be of less than 2″ duration and only 21.7% exceeded 60″, the great majority lying therefore between these limits. A very small part of these (14%) disappeared suddenly and the rest diffused slowly. The number of latent intervals was also very small (8%), and these were over 30″ in duration. The percentage of secondary sensations was also small (only 34% as contrasted with 65% for areal heat) and no secondary sensations were obtained without primary. The few secondary sensations that were measurable were of moderate duration. The percentage of qualitative similarity to the stimulus is here considerably reduced, especially if the responses "warm" and "hot" are to be considered qualitatively different. Contrary after-sensations were obtained in 12% of the cases. Only 19% were intense and only 25% clearly localized. A very small number (6.2%) came suddenly, (25% were said to "come in waves", and 31% to "well up"). The same amount, 6%, disappeared abruptly. There were 8.5% of recurrences.

Areal heat gave a percentage of 86.7% of primary after-sensations. The greatest part of these were of more than 15″ duration,—a full 50% (51.6) lasting beyond 60″, and only 3.7% less than 2″. As to their manner of disappearance less than 10% vanished abruptly. In 22.7% of the cases the primary sensations appeared alone (a percentage less than that of areal pressure but greater than cold). The preponderance of primary over secondary sensations is smaller for this stimulus than for any other areal stimulus; the percentage of secondary sensations being in this case 65.3%. Of these secondary sensations 2.7% appeared alone. The percentage of clear latent intervals is 16; two-thirds of these were short and none were long. The quantitative measurements show the secondary sensations considered, to have 18.2% which lasted between 5-15″ and the remainder to be divided between the durations "moderate" and "long" with the greater part "long". Qualitatively these sensations show 35% pure warmth and 8% burning, the rest being reported as smarting, tingling, prickling, with 18% of pressure or touch, and 12% of the opposite temperature. In 22% of the cases the quality

changed, 16% being a change to the opposite temperature, and the remainder being an alternation between pressure and heat and heat and throbbing. About 40% of these sensations were intense as against 37% mild, 4% were judged "stronger than the stimulus". More than 50% are recorded as diffuse or spread, as against 18% distinctly localized. Only 14.2% are said to return suddenly, the rest coming back gradually or "in waves" or "streaks". About the same proportion (14%) faded out suddenly, while 65% died out gradually,—6% are said to "go out in throbbing". The number of recurrences was less with areal heat than with any other stimulus, being only 4%.

Punctiform heat gives 74% of primary after-sensations, of which 19% appear alone. A small percentage of the primary sensations (4.2%) are of "very brief" duration, 20.8% last from 2-15" and the remainder is equally divided between the other two headings. 51% disappear gradually as against 41% which "ring off" suddenly, while 5% is said to "shade off into a menthol feeling". Secondary after-sensations appear for 60.3% of the stimulations; 27.6% being preceded by a clear latent interval, and 5.2% coming unattended by a primary sensation. The durations of the latent intervals are equally divided between short and long; and the durations of the secondary sensations are all over 15", 36.4% being over 60". Qualitatively more than 50% reproduce the original stimulus (if heat and warmth are to be ranked as the same), the rest are reported as "diffuse pain", "menthol feeling", "tingling", "warm pressure" and "prickling". About 12% change their quality, alternating heat with touch or with the menthol feeling. 34% are called mild as against 40% intense, 3% were spoken of as "stronger than the stimulus" and 6% as "painfully warm". 40% were localized punctiformly while 31% seemed diffuse or spread out, 6% were localized "deep", i. e. subcutaneously. 34% made their appearance suddenly while 60% came gradually, (5.7% are said to "well up"). These sensations show a rather large percentage of abrupt disappearances,—43% going in this way as against 37% of the more gradual type. 13.8% of these sensations show recurrences.

Electric heat gave the smallest percentage of primary sensa-

tions obtained by any stimulus and very nearly the smallest percentage of secondary,—58.3% in one case and 37.5% in the other. 20.8% of the primary after-sensations appeared alone but no secondary sensations made their appearance unaccompanied by primary. The quantitative measurements show 42.8% of brief, i. e. 2-15″, primary sensations and 57.1% over 60″. 29% of these die out suddenly as against 43% which fade away gradually. The percentage of latent intervals was about the same as that obtained from radiant heat,—8.3%, and quantitatively they were all long. The secondary sensations gave 31.2% "moderate" and the remainder over 60″. In quality 44% were warm or hot and the remainder gave "smarting", "biting", "sort of burning" sensations with 11% of contrary after-sensations. 33% were said to be intense as against 11% mild; and 33% were clearly localized. The manner of appearance was abrupt for 55.5% and gradual for 44.4%. 22% disappeared suddenly and the rest disappeared gradually or spread or radiated off. Recurrences occurred in 8.3% of the cases.

Radiant cold gives a considerably smaller percentage of primary after-sensations (67.9%) than radiant heat but a noticeably greater one of secondary (45.3%). Necessarily then, the percentage of primary sensations alone is much less than that obtained by cold, being only 18.9%. The quantitative measurements show an identical percentage, for the primary sensations, of "brief" and "moderate" durations (40%) and the remainder were "long". 11% of these disappear suddenly while 75% fade out gradually. As with radiant heat, no secondary sensations appeared unattended by primary and in no case was a clear latent interval reported. No secondary sensations appeared which could be measured. In 17% of the sensations clear cold was reported in 71%, cool; the other responses were "warm" and "rheumatic pain". The percentage of warm returns was 4.2%. Only 12% were spoken of as "strong and definite" and only 4.2% as localized while 62% were reported "faint" and 87% diffuse. 75% of these sensations were said to come "in markedly recurrent waves", 21% came gradually and 4% "like a cool breeze", so that none seemed to show that abruptness of appear-

ance characteristic of some forms. 54% showed also a wave-like *decrease*. The percentage of recurrent sensations was 7.5 as against 8.5 obtained by radiant heat.

Areal cold showed the highest percentage of primary after-sensations (92.7%) and next to the highest percentage of secondary (70.8%). Comparatively few primary sensations therefore appeared alone (21.8%). This stimulus gave also, the highest percentage, with the exception of electric heat, of primary sensations with long duration (52.1%), while, like areal heat, the percentage under 15″ was very small (6.2% "very brief" and 8.3% "brief"). Practically all of these fade out or spread away gradually (1.1% going suddenly out). The percentage of latent intervals was 11.5%, half of which were of long duration and the other half equally divided between short and moderate. A small percentage of secondary sensations were unpreceded by primary (2.1%). 73.1% of the secondary sensations lasted beyond 60″ and none of the remainder endured less than 15″. Qualitatively 40% were described as identical with the stimulus, 10% gave cold plus contact and the rest were variously described as tingling, moist, wet and heavy, tickle, cool, cold and wet, and throbbing. In about 11% of the cases the quality changed, 1.5% giving the contrary sensation, and the others mainly alternating cold and pressure. This stimulus gave also the strongest after-sensations, 85% being intense with only 7% mild. 50% were clearly localized as against 38% which were not. 38% came suddenly while 51% made their appearance gradually. Only 7.3% disappeared suddenly. The percentage of recurrences was 7.3.

With punctiform cold the percentage of primary after-sensations was 80.6,—the highest obtained for any punctiform stimulus except pain. In duration the percentage over 60″ was less than that found for punctiform heat (40.5%) but the percentage of moderate durations is larger (40.5%); 18.1% lasted less than 2″, a percentage nearly twice that obtained for punctiform heat under this heading. Only 14% of these sensations disappeared abruptly. 20.8% of the primary sensations appeared alone. The percentage of secondary sensations was 63.9, of which 4.2% appeared alone,

and 25% were preceded by latent intervals (20% of these being "brief" and the remainder equally divided between "moderate and long"). Quantitatively, the secondary sensations gave percentages very similar to those of areal cold (31.2% moderate and 68.7% long). 61% reproduced the original quality of the stimulus while 2.2% gave "burning cold"; the remainder were spoken of as "cool itching", "cool wave", "cold and pressure", "faint rheumatic pain", "cold tingle", "pricking", "stinging", "cold and touch", "cold and wet", "tingling". The only change in quality was where cool tingle changed to pure cold (2.2.%). 69% of these sensations were intense and 28% mild. 45% were clearly localized as punctiform spots, 28% were diffuse and 6% areal. 34.8% came quickly; while in their manner of disappearance 13% went suddenly while 85% faded out or spread away. The percentage of recurrences was enormously in excess of anything obtained by the other stimuli, being 26.4.

Electric cold gave a percentage of 59.3 primary after-sensations of which 18.5 appeared alone. In duration, the primary sensations all exceeded 2″, the greatest number lasting between 5-60" (33.3% "brief", 41.7% "moderate", 25% "long"). Their manner of disappearance was rather sudden in 37% of the cases. The percentage of secondary sensations was 40.7, of which 7.4 were preceded by a latent interval, although this interval was not measurable. Secondary sensations never appeared unattended by a primary. Half of the secondary sensations were of moderate duration and the remainder divided between brief and long with more long than brief. In quality, electric cold reinstated the original experience in 82% of the cases, while the remainder was divided between sensations of pricking pain and cool tingle. 18% of changes in quality was shown, 9% being a change to the contrary sensation and 9% a change from cold to pain. 54% were strong as against 18% mild; and 54% were localized while 27% were called diffuse. 54.5% appeared suddenly, and 73% disappeared in the same manner, while the remaining 45.4% and 27% were gradual. The percentage of recurrences was 7.4%.

With punctiform pain, the percentage of primary sensations is

exceeded only by areal cold, being 85.2. A relatively small percentage (19.7%) appeared alone. In duration, 50% were longer than 60″ and none were less than 2″ (19.4% brief and 30.5% moderate). This stimulus gave the greatest percentage of secondary sensations (73.8%), as well as the greatest percentage of secondary sensations alone (8.2%). The percentage of clear latent intervals was 29.5 and the quantitative measurement of these showed 58.3 to be over 30″ and 33.3 to be brief. The quantitative measurements of the *secondary* sensations showed none to exist under 2″, the entire amount being almost equally divided among the other three headings. In quality 49% reproduced the stimulus, the remainder giving pain and pressure, sharp contact, sharp beating, prickling and throbbing, general ache, pressure and ache, and pressure and tingle. This stimulus showed the greatest percentage of change in quality (usually pressure or touch alternating with pain or else pain changed to prickling or throbbing). About 60% gave strong, steady pain while only 31% were called faint; and 64% were localized clearly as against 33% diffuse or spread out—and this is the largest percentage of exact localization obtained by any stimulus. With regard to the manner of appearance the reports of "gradual" and "sudden" gave relatively close percentages (42.2% and 51%); while 47% disappeared quickly and 36% were persistent. The percentage of recurrences was 13.1.

It is therefore to be seen that with regard to [I] areal and punctiform stimuli of the same type: (1) areal stimuli are more favorable for the production of primary sensations as shown by, (a) the relative number obtained (with the exception of pressure), (b) the number of primary sensations unattended by secondary, (c) their greater duration and (d) their more gradual disappearance; (2) areal stimuli give also the greatest proportion of secondary after-sensations but; (3) punctiform stimuli give a greater percentage of latent intervals and; (4) secondary after-sensations alone (with the exception of pressure, in both cases). (5) Punctiform stimuli give a greater proportion of recurrences. (6) There is no striking difference between areal and punctiform stimuli in the duration of either the secondary sensation or the

latent interval. But qualitatively, it is seen that punctiform stimuli (7) more frequently reproduce the identical quality of the stimulus, (8) give no contrary temperature sensations, (9) are less intense (with the exception of pressure) but, (10) are more clearly localized and, (11) make their appearance and disappearance more abruptly than areal.

[II] The relations of heat and cold show that: (1) cold (with the exception of radiate) gives a greater percentage of primary sensations than heat, and that: (2), also with the exception of radiate cold, these sensations have a greater duration. (3) Heat, on the contrary, gives the greater percentage of primary after-sensations alone. (4) The percentage of secondary sensations is greater for cold, (5) which also gives a greater percentage of latent intervals, and (6) secondary after-sensations alone. (7) Quantitatively, the cold sensations show a greater duration. (8) Cold more frequently reproduces the quality of the stimulus, and (9) shows less qualitative changes, including contrary after-sensations. (10) Cold is, with the contact stimuli, more intense, and (11) with the exception of radiate cold, is more clearly localized. (12) Again with the exception of radiate cold, the returns are more abrupt, and (13), this time excepting electric cold, the manner of disappearance is more gradual.

[III] Punctiform pain is more nearly akin to the areal stimulations in: (1) its percentage of primary after-sensations, and (2) the length of their duration as well as (3) in the proportion of secondary sensations obtained. But, it follows the laws of punctiform stimuli in: (4) the number of primary sensations appearing alone, (5) the abrupt disappearance of primary sensations, as well as, (6) the percentage of latent intervals, and (7) of secondary sensations appearing alone. Like the punctiform stimuli, also, it gives (8) a large percentage of qualitative similarity of recall, although it shows a greater proportion of qualitative change than is found with the punctiform temperature sensations. (9) In intensity its percentage is more nearly like that obtained by areal stimuli, but, it follows punctiform rules in its (10) clear localization, and (11) its abruptness of appearance and departure.

E. *Corneal Pain.*

A limited number of experiments were made on the after-sensations of corneal pain; the author serving as the only subject.

For these experiments, a camel's-hair brush, carefully sterilized, was applied to the surface of the cornea with sufficient force to cause a clear sensation of pain.

The results are given below.

A. NUMERICAL TABLE.

1. Stimulations	25
2. Prim. Aft. Sens.	24
3. Secd. Aft. Sens.	22
4. Prim. Aft. Sens. Alone	2
5. Secd. Aft. Sens. Alone	0
6. Latent Intervals	19
7. Recurrences	10
8. No. Aft. Sens.	1
9. Percentage Prim. Aft. Sens.	96%
10. Percentage Secd. Aft. Sens.	88%

B. QUANTITATIVE TABLE.

Duration Prim. Aft. Sens.	
Very Brief	9—42.8%
Brief	10—47.6%
Moderate	2— 9.5%
Long	0
Duration Latent Interval.	
Short	4—21 %
Moderate	11—57.9%
Long	4—21 %
Duration Secd. Aft. Sens.	
Very Brief	2—10.5%
Brief	11—57.9%
Moderate	6—31.6%
Long	0

C. QUALITATIVE TABLE.

1. Quality. 12 fine pricking, no contact, 8 sharp prick, 2 fine sting.
2. Change of Quality. 5 end in contact sens.
3. Intensity. 10 intense, 2 mild, 2 strong, 8 stronger than stimulus.
4. Localization. all well localized, 12 finer than stim.
5. Manner of Appearance. 19 sudden, 3 gradual.
6. Manner of Disappearance.
   (a) Prim. 13 sudden, 9 quite sudden, 2 gradually.
   (b) Secd. 13 sudden, 2 quite sudden, 2 gradual, 5 end in a contact sensation.

These figures seem to give results remarkably definite and unequivocal, but as they represent an individual report it is not fair to compare them with the *average* percentages obtained from other stimuli.

It appears, however (1) that the percentage of primary and secondary sensations, as well as that of latent intervals and recurrences, is very large; (2) that the primary sensations are all under 60″ in duration, (3) that over 50% of the latent intervals are of "moderate" duration, with the remainder equally divided

between "short" and "long"; and (4) that more than half the secondary sensations are "brief", with 30% "moderate", and the small remainder under 60″. (5) In quality, they are described as fine pricking, sharpness or a fine sting: (6) About 25% end in a contact sensation, but, that is the only change of quality reported. (7) In intensity, all but 9% are strong, and 37% are called stronger than the stimulus. (8) They are all well localized, 64% being said to be finer or more punctiform than the stimulus. (9) 86% come suddenly, while (10) 91% of the primary sensations go abruptly, and (11) 68% of the secondary.

It can now be seen that corneal pain follows the laws of the numerical percentages obtained from pricking pain. Quantitatively, the primary and secondary sensations (as well as the latent intervals although in a lesser degree), are shorter than those of pricking pain. In quality, corneal pain more frequently reproduces the original stimulus, and the intensity seems somewhat greater than with pricking pain, but the two are closely similar in the remarkable accuracy of localization, and the abruptness of appearance and departure.

IV. COMPARATIVE REVIEW.

We have found that in some of the more incidental descriptions, of the relevant literature, it is hard to say whether a reference to the primary or secondary phenomena is intended. It seems clear, however, that the primary after-sensation of pressure is indicated by Kottenkamp and Ullrich, Funke, Blix, Clark, Krohn, Pillsbury, Henri, Parrish, and by von Frey and Kiesow in their mention of the persistence of sensation after a skin deformation, and, that Donaldson's reference is to the primary temperature sensations.

The descriptions given by Goldscheider, Urbantschitsch, etc., of the primary and secondary sensations and of the latent interval apply perfectly to the phenomena obtained by us. These authors found, as did we, that both sensations may appear or either alone.

REGIONS BEST SUITED TO THE PRODUCTION OF AFTER-SENSATIONS.

It seems to be generally recognized that the strength and clarity of the after-sensations vary with the region stimulated. We accordingly made a topographical survey of the entire body, with two subjects, to find out if the regions most favorable for the production of after-sensations would show any correspondence with the recognized areas of greatest sensitivity. The results obtained by pressure, temperature, and pain stimulations are given below and while admittedly inexact and unsatisfactory would seem to indicate some such general correspondence.

Pressure.

Subject X.

Forehead, breast and palm were the most favorable, giving strong and persistent primary and secondary sensations, and distinct latent intervals. Lips, cheek and finger-tips also produced after-sensations that were very clear and strong and had definite latent periods.

There appeared to be after-sensations from stimulations on the abdomen, but the subject believed them confused with sensations from the viscera.

There were moderately intense returns from stimulations on the back.

The ball of the thumb, upper and lower arms, thighs, and the dorsal surface of the lower legs were about equally sensitive.

The volar lower leg seemed to be the region least sensitive to after-sensations, giving no clear latent period and being of faint intensity.

Subject VII.

Face by far the most sensitive.

Palm gave very vivid after-sensations.

Arm and leg about the same and fairly sensitive.

Chest moderately sensitive.

Very few after-sensations obtained on the back.

Six subjects tested on face, hands, and forearm.

Face generally the most sensitive. Palm gave intense and very persistent after-sensations.

Volar side of forearm rather more favorable than dorsal.

Krohn's figures are based on the persistence of pressure sensations; and we would agree with them in that we find pressure sensations to endure longer on muscular surfaces, like the calf of the leg, than on those regions like the shins and ankles where the bones more nearly approach the surface.

Heat.

Subject X.

Forehead and palm gave very clear recalls.

Back of shoulder quite favorable.

Arm, dorsal and volar, moderately favorable.

Practically no after-sensations obtained from stimulation on the thighs.

Subject VII.

Lips and elbow gave very clear after-sensations.

Forehead, cheeks, and palm moderately favorable.

Foot and chest quite sensitive to after-sensations.

Leg, volar and dorsal, poor in after-sensations.

Six subjects tested on face, hands, and forearm.
Forehead and lips favorable.
Volar forearm rather better than dorsal.

Cold.

Subject X.
Forehead and back of neck gave especially clear recalls.
Back of hand better than palm.
Cheeks only moderately favorable.
Legs and arms quite sensitive and about equally so.

Subject VII.
Forehead and chest favorable.
Forearm, foot, palm, and back of hand fairly good and about equal.
Volar surface of elbow very good.
Back fairly sensitive.

Six subjects tested on face, hands, and forearm.
Forehead very favorable.
Palm fairly good.
Volar and dorsal surface of forearm moderately sensitive.

Pain.

Subject X.
Face and breast favorable for the production of after-sensations.
Arm and back of shoulder gave quite clear after-sensations and were about equally favorable.
Legs gave very few and indistinct after-sensations.

Subject VII.
Cheek and lips gave very strong after-sensations.
Back quite favorable.
Upper and forearm moderately favorable and about equal.
Palm poor in after-sensations.

Six subjects tested on face, hands, and forearm.
Face most sensitive.
Volar and dorsal surface of forearm quite good and about equally favorable.

CONDITIONS BEST SUITED TO THE PRODUCTION OF AFTER-SENSATIONS.

No attempt has been made in this study to measure with exactness the relative value of different conditions of stimulation—such as intensity duration etc.—for the production of after-sensations, so we have no basis for a satisfactory comparison with the results of Goldscheider, Thunberg, etc. Assembling, however, what data we have, *it can be said that there seems to be a middle ground, both of duration and intensity, within which the after-sensations make their appearance most readily and most clearly.*

With pressure stimuli, it was found that (1) with slow impact, faint intensity, and long duration all sensation tended to be lost during the stimulation, probably as a result of adaptation, so that the removal of the stimulus, if it was effected smoothly, could pass unnoticed. (2) With strong pressure and long duration, the stimulus could likewise be removed unnoticed at the moment, leaving a sensation similar to the stimulus-sensation. There was left, in such cases, however, a clear skin depression and von Frey's contention that the consequent pressure image is dependent on the rapidity with which the skin recovers from this depression is here, perhaps, the best explanation. Such cases are on a par with the common illusions of pressure from a hat-band or from a coin pressed on the forehead, and, might, in a sense, be said to be no after-sensation at all in as much as the resulting skin depression is actually causing a continuous pressure on the subcutaneous tissues. Von Frey's further assertion that the "after-enduring pressure sensations" did not make their appearance with weights of minimal intensity, i.e. those too light to cause a skin depression, would, perhaps, since these stimuli were of "not too brief duration", be explained under (1), i.e. as the result of adaptation. (2) With a less intense stimulus, but with a very long duration the sensation shows a tendency to die out during the stimulus, supposedly as a result of adaptation, and to remain absent for a time after the removal of the stimulating object then to reappear after the manner of a secondary sensation. This seems to be the order of phenomena described by Spindler, who left his weights on the skin 5″-10′. (3) Goldscheider found that

primary and secondary sensations separated by a latent interval made their appearance even with stimuli close to the threshold. We, have found this to happen occasionally with weak stimuli and brief duration, but these conditions were always attended by two objections, first, that these stimuli were so near the perceptual limen that their appearance and disappearance were liable to be confused by oscillations of attention, and second, that such light touches often aroused the tickle sensations which quite changed the character of the experiment. (4) Too strong a stimulus, however brief, would apparently cause a bruise the aching quality of which obscured the pressure sensation. (5) Rate of impact is of course closely bound up with intensity but it was found that rapid impact gave better results than slow, apparently because of the fact, that the skin was more apt to adapt itself to the stimulus if it was applied gradually, and the full value was, accordingly, not appreciated. It seems, therefore, that quite strong, relatively brief, and rapidly applied stimuli are best suited to produce the after-sensations of pressure. This would in a general way agree with the results of Goldscheider and Thunberg, who found that there were certain optimal conditions within which the after-sensations made their appearance most definitely, and that these optimal conditions occupied a middle range both of intensity and duration.

Dresslar found that by tickling the region about to be stimulated, so as to bring more blood to the surface, the subsequent after-sensations of pressure were stronger and more definite. We experimented with this method on two subjects and found that the strength and persistence of the *primary* after-sensation would seem to be somewhat increased by this means, but that it had no apparent effect on the *secondary* sensation. This method was discarded, however, on account of the difficulty in getting rid of the tickle sensations aroused, or of the itching which was frequently set up thereby. We tried also the effect of increasing the blood supply in a given region by binding the arm about 5 cm. above the point of stimulation. (2 subjects were used.) The after-sensations resulting from pressure stimuli under these conditions were described as "duller" and somewhat more diffuse

than those normally obtained, but the stricture of the bandage and the unpleasant effect of the increased blood pressure made it difficult to attend closely to the pressure sensations *per se*. Rubbing the skin was found the best method of increasing the capillary blood supply without the introduction of distracting sensations; and by this method it was found that the after-sensations of pressure were slightly facilitated, especially if the temperature of the room was such that the arm was slightly cold-adapted. Warming or cooling the skin by immersion in water of 10 C. and 46 C. seemed to detract from the clear definition of the after-sensation, rendering it duller and more diffuse.

Donaldson and Hall speak of the vivid persistence of the after-sensation (primary) of a moving point. We tested each of our 6 subjects by this method and all reported the astonishing clearness of the subsequent sensation. This seemed to fluctuate in parts throughout its length—the first third sometimes standing out most clearly, and sometimes the last quarter being most insistent, and this arrangement made it difficult to say whether the sensation on any part dropped out entirely and again returned, or whether it was simply a decrease in intensity enhanced by the contrast of an increase in intensity on another part. It was very hard to prevent a skin-irritation by this method, too strong a stimulus causing a welt to arise.

Later a more detailed series of experiments was made on three subjects, to test the relative persistence of the sensations of a point moving over a given distance as compared with the after-sensation resulting from a linear stimulus of the same length. Strips of hard rubber 1 mm. in width and varying in length 2-10 cm. were used for the pressure experiments. These were provided with a handle in the center which allowed them to be applied with an even pressure upon the surface of the forearm. The second stimulus was given with a wooden point, 1 mm. in diameter, which was drawn for an equivalent distance along a neighboring surface. The method of thermal stimulation was the same, except that here the strips and point were of brass and warmed or cooled as in previous experiments. Space does not permit a detailed account of these tests, but summarized briefly

they resulted as follows: With pressure as the stimulus, it was found that with all three subjects tested the after-sensations of the moving point produced a clearer and more persistent after-sensation, both primary and secondary, than could be obtained by a linear stimulus. With heat as the stimulus the results were quite opposite, the linear stimulus seeming to call out more consistent after-sensations than the other, except in the case of the two smallest lines—i.e. 2 and 4 cm.—where no perceptible difference was noted. With cold one subject obtained her best after-sensations from the moving point, a second distinctly favored the linear stimuli while the results of the third were more or less equivocal, but appeared rather more in favor of the linear form.

With temperature stimuli in general, it was found that the best results were obtained where the stimuli were of such an intensity and endured for so long a time as to give a clear temperature sensation. With too intense stimuli, however brief, a painful or unpleasant quality made its appearance and complicated the results; and the same thing happened if a less intense but still strong stimulus was left too long in contact with the skin. If the intensity were moderate but the duration long both the phenomenon of adapation and the objective change in temperature of the stimulus itself entered in. If the stimulus was strong without being painful (a condition easy to be obtained with cold) the primary sensation tended to show itself clear but so persistent as to obscure any possible secondary sensation. This is in accordance with Dessoir's findings. The best results were, therefore, obtained by stimuli which were of sufficient intensity to give a clear temperature sensation without a painful or unpleasant tone, and which endured only a sufficient length of time for the sensation to be clearly perceived, this apperception-time varying, of course, with the stimulus and the area stimulated.

Binding and tickling the skin were subject to the same difficulties with temperature stimuli as with pressure (although to a somewhat less degree) and the resulting after-sensations showed the same traits.

Warming and cooling the skin, while it decreased the strength of the primary after-sensations of the same stimulus and increased

that of the opposite, after the manner of sensation contrast, still gave both primary and secondary sensations which seemed to be duller and less evident.

Rubbing the skin appeared, as with pressure, slightly to "brighten up" the after-sensations.

Dessoir states that the primary after-sensations were stopped by the opposite, and reinforced by the same stimulus, and these facts we easily verified.

We never succeeded in arousing after-sensations on temperature spots by tapping—a rare phenomenon which Goldscheider describes as occasionally taking place; although it must be admitted the number of cases where the temperature sensations themselves were thus mechanically called out was very small.

With pain, those stimuli had to be avoided that were intense enough to bring blood or to cause a definite puncture, for here, the soreness of the actual wound entered into the subsequent sensation. Too long a duration also tended to bring out this objective soreness. A relatively slow impact was found more satisfactory than one faster, in that it gave the subject time to discriminate the moment of actual pain from "the feeling of sharpness" and thus permit a stimulus of the proper intensity to be given.

Binding, warming and cooling, and, in this case, rubbing the skin detracted from the vividness of the recall. It was noticed that in some cases where the skin had been cooled and then stimulated by a prick, a recurrence of the pain sensation occurred after the skin had returned to the normal - or approximately normal—temperature.

Skin Anæsthetised

We have tested the after-sensations of different stimuli on the anæsthetised skin with 8 subjects (3 being instructors and 5 graduate students in the department of Psychology).

The method was as follows. A normal unshaved skin area was selected on the volar forearm and marked out with analine dye, and this area was then sprayed with ethyl chloride until it was anæsthetic to the prick of a needle. When the white frost

had evaporated the stimuli were applied as in the preceding experiments, care being taken here not to let them overlap the normal region.

The results are given below.

Pressure.

Subject I.

Sensitivity is lost for superficial prick, contact and light pressure, as well as for the mild degrees of temperature. It is retained for cotton-wool, and the deep sensibility seems to be unaltered. In many cases, the primary sensation drops out with or before the removal of the stimulus. The latent intervals vary from 5-20″. All sensations are described as deep or tendinous and dull in quality. With intense stimulations a severe, deep-seated pain made its appearance, it came suddenly and usually after a latent interval. Accuracy of localization somewhat better than normal; direction of error the same.

Subject VII.

Surface sensibility lost for everything but cotton-wool. Deep sensibility unaltered. Pressure after-sensations obtained but much less clear and vivid than on normal skin. Severe pain from intense stimulation not found, but this was not expressly tested for. Accuracy of localization very nearly normal.

Subjects VIII, IX, X, XI, XII, VI.

All experienced the loss of all forms of touch, etc., except with cotton-wool, but were unable to be sure of any secondary after-sensations.

Cold.

Subject I.

Insensitive to faint and moderate cold. Two cases of secondary after-sensations. Relatively long intervals, 20-60″. In quality, cold sometimes mixed with slight pain; well localized. With intense stimuli frequent appearance of a very distinct and intense pain, sometimes with and sometimes without slight cold, located

deep down below the point stimulated. This pain is occasionally projected.

Subject VIII.

Insensitive to mild and moderate cold. With strong stimulations a period of no sensation intervened and then a stinging pain, like the pain of the anæsthetic.

Subject VII.

Insensitive to mild temperatures. Apperception time for cold very long,—intensity of the cold less vivid than on normal areas. With intense stimulations there results a *very* strong deep pain with no temperature in it.

Subject IX.

Insensitive to weak stimuli. With strong stimuli gets very vivid, intense pain which is projected from the middle forearm to the wrist.

Subject X.

Insensitive to weak stimuli. Thinks can obtain recurrent after-sensation of faint intensity. No pain from intense stimulation.

Subject XI.

Insensitive to weak stimuli. Strong stimulation gave little heat then a warm stinging pain, very intense.

Subject XII.

Insensitive to weak stimuli. Gets pressure after-sensations without temperature, these are frequently projected. With strong stimuli gets cold with a slight superficial pain.

Subject VI.

Insensitive to weak stimuli. With strong stimuli gets strong, deep pain without temperature.

Heat.

Subject I.

Insensitive to weak stimuli. A noticeable delay in perceiving warmth with stronger temperatures. With intense stimuli, a strong deep pain usually projected medianly and distally, with or without warmth. The phenomenon is not as marked as cold.

Subject VIII.

Insensitive to weak stimuli. With strong stimuli, a latent period and then a slight heat with a sting that may be either deep or superficial.

Subject VII.

Insensitive to weak stimuli. With strong stimuli got an intense pain but usually some warmth with it.

Subject IX.

Insensitive to weak stimuli but felt something that was either contact or slight pressure. With strong stimuli, got contact (or pressure) and a slight pain below the surface, maybe a little warmth with it.

Subject X.

Insensitive to weak stimuli. With strong stimuli slight burning but no real pain.

Subject XI.

Insensitive to weak stimuli. With strong stimuli, a little heat felt and strong pain.

Subject XII.

Insensitive to weak stimuli. With strong stimuli got a sensation of blunt pressure with a stinging pain in the center of it, and sometimes a dull warm sensation with a pain that is both superficial and deep.

Subject VI.

Insensitive to weak stimuli. With strong stimuli, gets nothing but pressure and slight diffuse warmth.

Pain.

Subject I.

Prick gave a mild pain with a mildly painful after-sensation. Hair pulled gave a slow developing but very persistent pain.

Subject VII.

Prick gave a relatively quite painful sensation, having a long apperception time. Hair pulled gave dull but persistent pain.

Summary.

It would seem that by this process of skin anæsthetisation we have for a short time, largely destroyed the "epicritic" sensibility and put the affected area in a "protopathic" condition more or less complete. Deep sensibility appears to remain intact, under these conditions,—moderate and strong pressure are perceived and can be localized. Many of the characteristics of protopathic sensibility are quite marked,—the intense pain from temperature stimuli, the slow development of these sensations and their diffuseness and tendency to be projected. The perception of superficial touch and prick as well as the mild degrees of temperature—the distinguishing marks of epicritic sensibility—are, quite absent.[1]

When after sensations were obtained they were less vivid and definite than those obtained on the normal skin.

These results are mainly interesting as showing that a protopathic condition more or less complete, can be set up by the use of a local anæsthetic.[2]

NUMERICAL COMPARISON.

No numerical comparison of the after-sensations from different stimuli is given in the literature so there is no basis here for a comparison with our results.

[1] The three phases of sensibility observed by Head, Rivers and Sherren to condition the regeneration of a sectioned cutaneous nerve. (1) Deep sensibility, unaltered after such sectioning, provides sensations of deep pressure and admits of localization by this means although the perception of two points as two, is lacking. (2) Protopathic sensibility, first stage of recovery, attends the perception of prick and temperature (spots) although the threshold for both is higher and the response more intense than normal and strongly subject to "radiation" and "reference." Pain is not appreciated below 30-40 on the algesimeter and the hot and cold spots do not respond to stimuli between 36° 37° C. (3) Epicritic sensibility involves the perception of light touch (cotton wool and no. 5 von Frey hairs on shaved areas) and the intermediate degrees of temperature, these being perceived other than in response to the stimulation of hot and cold spots. The tendency to radiation and reference fades out, and the discrimination of the size and shape of the stimulus, as well as the perception of two points as such, is regained.

[2] Since the writing of this thesis a brief paper has come to our notice by Franz and Ruediger[3] on the sensory changes in the skin following anæsthetization by ethyl chloride. The interest of their research and in consequence the points emphasized differed from ours, but their results do not seem to show anything noticeably at variance with what we have found.

Urbantschitsch found that touch (pressure) stimuli gave more recurrences than areal temperature sensations and from table IV it is seen that this is the case in our experiments.

QUANTITATIVE COMPARISON.

Funke speaks of the great persistence of pain (primary after-sensation) and our tables show 51% over 60″.

Goldscheider found that some temperature points, especially cold, give very long primary sensations and Donaldson found after-sensations from cold spots lasting "several minutes". We have found a large percentage of primary after-sensations from punctiform cold to exceed 60″.

The length of the latent interval is given as 9/10 of a second by Goldscheider, by Thunberg .88-.96″ for pressure and .85″ for thermal stimuli, while Dessoir speaks of it as "about a second" for temperature stimuli and Külpe says the same for heat. With areal heat stimuli we found that 66% were brief, i.e. under 1″, but the average duration of the latent interval for cold and pressure was found to be greater,—approaching more nearly the figures of Urbantschitsch for whom the latent interval varied from 12-25″.

The length of the secondary sensation of pressure is measured by Spindler but his conditions of stimulation are so different from ours that comparison seems useless. Thunberg speaks of his sensations as "brief enduring"; and Urbantschitsch found the after-sensations of warm varying between 4-45″ and cold between 18-60″; and our figures would come between these limits.

QUALITATIVE COMPARISON.

We find most of Goldscheider's sensations described as identical with the stimulus, with a painful tone if the stimulus was too intense. The quality with both electric and mechanical stimulation is described as "stechende", and Thunberg described his sensations by the same adjective, but notes two types of response—one a "stechende" sensation followed by a second similar to it, and the other where there is only contact in the first sensation but the second is "stechende" in quality. The sensation of pressure

or contact followed by pain, which is identified by Goldscheider with his later phenomena, is shown by von Frey to be nothing other than delayed pain. Dresslar variously describes the sensations as sticking, contact, or tickling and notes the slightly painful tone of some recalls. In our experiments the areal pressure stimuli generally gave the quality of "dull pressure" but the punctiform stimuli, which is the form used by Goldscheider and Thunberg, were often described as "sharpness", "prickly", "stinging", "a pain prickle" or "unpleasant sharpness". Preyer speaks of sensations of opposite temperature following after one of the same temperature as the stimulus, and Urbantschitsch reports many cases of these contrary after-sensations. We have obtained such sensations from areal stimuli, which was the form used by Urbantschitsch.

In intensity, Goldscheider, Thunberg and Urbantschitsch speak of "faint" recalls "strong and definite" and those which are described as—"as strong and stronger than the stimulus";—grades of intensity which we have frequently encountered. Goldscheider found that nearly painful pressure stimuli gave painful recalls, while with actually painful stimuli the after-sensations were less so. In our experiments it was found that intense pressure stimuli usually gave after-sensations which were more or less painful, but, it was not noticed that those stimuli which were strong enough to cause pain gave, as a rule, a non-painful recall.

The after-sensations of Goldscheider and Thunberg are said to be well localized, and, we have found a large percentage of exact localizations for punctiform pressure. Dresslar, using more areal stimuli, describes more diffuse recalls, and Urbantschitsch reports many such for temperature, as well as those which spread and radiate. These characteristics have been noticed by us for areal pressure and temperature.

We have no data to compare with Urbantschitsch on the direction of spreading peculiar to the individual or the stimulus, or on the effect on that spreading of a second application of the stimulus. It may be remarked here that the introspections of our subjects show the phenomena of cutaneous after-sensations to be something less definite and exact and therefore more difficult to

trace through its various evolutions than was apparently the case with the subjects of Urbantschitsch; his stimuli were considerably larger and this may, perhaps, have had some effect.

In their mode of appearance Goldscheider and Thunberg's phenomena seem to come relatively suddenly but, Urbantschitsch, on the contrary, seems to find more that make their appearance by a process of gradual increasing. Our data would confirm this, in that the punctiform stimuli, which is what Goldscheider and Thunberg used, make their appearance more abruptly than areal.

The manner of disappearance for primary sensations may be either instant or gradual according to Urbantschitsch, Goldscheider speaks of the primary sensations on temperature spots as ending in an indefinite sensation and the secondary sensations of pressure are spoken of by Dresslar as "going instantly". We have data regarding the manner of disappearance, in accordance with that of Urbantschitsch and Dresslar, but have never received exactly such an account of the ending of punctiform temperature stimuli as is described by Goldscheider.

SUMMARY.

Our findings in this study are of such a nature that we have found a brief review of them almost impossible. We have summarized in detail the results of our main experiments on pp. 55-65, and would refer the reader thereto.

We think we have shown that cutaneous after-sensations are real phenomena and not explainable by imagination, oscillating attention, or the presence of skin and muscle sensations ordinarily passing unnoticed.

We have found that these phenomena, with their various phases of primary and secondary after-sensation, latent interval, recurrences, etc., occur after the application of each of the forms of stimuli employed.

For a statement of the relative importance of these phases and their relation to the different forms of stimulation we refer to the above mentioned summary of pp. 55-65.

An attempt at an exact quantitative measurement of the dura-

tion of these different phases has seemed to us unwise, for the reasons given on pp. 37-39. But by grouping them under such headings as "long", "moderate", "brief", etc. (cf. p. 39) we have obtained some comparative data which are summarized on pp. 45-47 and 55-65.

We have found the after-sensations sometimes differing in quality from that of the stimulus (in a few cases even going to such extremes as the "contrary" temperature after-sensations of Urbantschitsch), but more frequently reproducing the same quality. The degree of definiteness with which the after-sensations can be localized likewise differs with the different stimuli, as does also the manner in which they make their appearance and disappear. A comparative summary of these points is given in detail on pp. 47-55 and 55-65.

(We would state that we place less weight on the data obtained from temperature stimuli radially and electrically given than on those secured from any of the other forms of stimulation, for the reason that the number of stimulations given was less, and because with subjects III, V, and VI we were unable to locate "heat spots" electrically, and with subjects V and VI to locate "cold spots" in this manner.)

Our data on the region of the body best suited to the production of after-sensations pretend to only a rough accuracy, but they seem to indicate that there is a general agreement between these and the regions of greatest sensitivity.

Regarding the conditions most favorable to the production of after-sensations we have found that there is a middle ground both in the intensity and in the duration of the stimulus which causes the after-sensations to appear most clearly, since stimuli above or below this introduce factors of adaptation, bruising, skin-deformation, etc. We also tried the effect of increasing the capillary circulation by rubbing, binding the arm, etc., of rendering the skin hot and cold adapted, and of anæsthetising it by ethyl chloride and found that none of these methods added materially to the clearness of the after-sensations.

PHYSIOLOGICAL EXPLANATIONS.

The most commonly accepted explanation of cutaneous after-sensations is that of Goldscheider who, it will be remembered, accounts for the delay of the secondary sensation by reason of its course through the grey matter of the cord,—the resistance to this path having to be overcome by an intense, i.e. a painful-stimulus or by a *summation* of more moderate stimuli.

Von Frey explained those early cases of Goldscheider's, where a pressure sensation was followed after an interval by pain, by his discovery of pain spots in the neighborhood of pressure spots and of the greater inertia of these pain spots which caused them to be sensed more slowly. This explanation does not however, as Thunberg suggests, account for those primary and secondary "stechende" sensations, qualitatively similar and neither being in the least painful.

Külpe quotes Goldscheider's theory but suggests the centrifugal fibers running in the sensory roots as affording a more simple explanation.

Thunberg thinks the early sensations are due to a direct nerve stimulation and the secondary are conditioned by a sort of intermediary "Zwischenprocess" set up thereby.

Goldscheider's summation theory as such, seems untenable since the discovery, under his own conditions, of secondary sensations from a single induction shock as was made by Thunberg, and Vintschgau and Durig. Goldscheider's further hypothesis of pressure being in itself a series of stimuli, while it is impossible to disprove, becomes even more difficult to understand if it is to be applied, as it apparently must be, to the thermal (especially the punctiform of moderate intensity) after-sensations since reported.

If the existence of centrifugal fibers in the posterior roots shall be proven and their areas of distribution be found to agree with those of the centripetal fibers, Külpe's suggestion will seem to afford an adequate explanation of the process.

Apart from such an hypothesis three types of theory seem possible. (1) An explanation in terms of spinal cord conduction, i.e. to suppose the nervous impulse arising from a given stimulation to be divided somewhere in its course and to make its way

to the conscious center by two or more pathways. The primary sensation is aroused at the moment of arrival of that portion coming by the shortest or most direct pathway and the difference in the length of, or preferably in the number of synapses involved in the two pathways accounts for the latent period. (2) To suppose the impulse to reach the cortex by a single channel giving rise on its arrival to the primary sensation. This impulse then to be taken up by associational neurones and carried on to neighboring regions of the somaesthetic cortex thereby arousing additional sensations, much in the manner that the association fibers between the temporal and occipital lobes are supposed to condition the phenomenon of visual-auditory synaesthesia. Both of these hypotheses are subject to the objection that, from what is known of the rate of nerve conduction and of the "Associationszeit" it would appear that the time necessary to traverse even the longest nerve course, or to effect connections between cortical areas is considerably less than the average duration of the latent interval. (3) Unless one can assume such a process as Külpe describes we are led to accept an explanation, like Thunberg's, in terms of the sensory end-organ. The duration of the latent period is here accounted for by the inertia of the sense organ to the kind of stimulus, presumably chemical, set up by the "Zwischenprocess". Such facts as a change in quality and localization (either by spreading or reference) of the secondary sensation could be accounted for by a diffusion of the "Zwischenprocess" about the surrounding region and its consequent action, in some cases, on sense organs of a different type.

It seems therefore, that, here, as in vision, the phenomena of after-sensations are best explained in peripheral terms; but it seems more safe to say that no satisfactory explanation of after-sensations, or for that matter, of any of the cutaneous phenomena, can be obtained until more is known of the anatomy and physiology of the skin.

Appendix.

After-Sensations from Electrical Stimulation.

For purposes of comparison with Goldscheider's work we attempted, but without success, to reproduce his conditions. We

were unable at the time the experiments were made to secure a circuit interrupter of satisfactory rate. The following is a brief summary of our results.

The electric stimulations were given by means of an induction coil supplied by a storage battery. The electrodes were of fine copper-wire and were imbedded in a wooden handle at a distance of 1 mm. from one another. The rate of oscillation was 50 complete vibrations per second, thus giving approximately 10σ intervals between stimuli, and, by weighting the oscillator, the intervals could be increased to 20σ. In order to limit the number of stimuli given, a Wundt Fall Hammer was introduced into the circuit of the primary coil in such a way that only with the fall of the hammer was the circuit closed and the current allowed to pass out through the secondary coil. The length of this period, and in consequence the number of stimuli given, was varied by adjusting the platforms and the counterpoise. In order to overcome the inertia of the oscillator,—which in the brief durations was very noticeable—it was kept constantly in motion by establishing a circuit through the electro-magnate of the coil, which did not include the primary induction coil. Into this circuit a small incandescent lamp was introduced, which offered a greater resistance than that of the Fall Hammer, although allowing the passage of sufficient current to run the oscillator. Accordingly, when the circuit was closed the current would run through the hammer, following the path of lesser resistance. Two subjects were used for these experiments.

Our results with these stimuli were manifestly unsatisfactory, since, in the first place, we were unable to give intervals greater than 20σ while Goldscheider's best results were obtained by intervals of from 30-70. The nearest approach we could obtain to his optimal conditions was by giving 4 stimuli with 20σ intervals and with this combination, and with one of 6 stimuli with 20σ intervals, we obtained our best results. The latent pauses were here quite clear, although of a duration considerably longer than Goldscheider's and, the secondary sensations were sudden, brief, and stinging or pricking in quality. The importance of the spot stimulated was very noticeable,—as many as 15-20 areas being tried, in some

cases, before a favorable one was found. When a considerable number of stimuli, i.e. 10-15+, were given a tingling, or the characteristic whirring, sensation was set up which was quite persistent. With less than 3 stimuli, no certain secondary sensations were obtained, but only a limited surface was tested.

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