THE PSYCHOLOGICAL LABORATORY AT LEIPSIC.
James McKeen Cattell (1888)

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University laboratories have the same ends as the University itself, the education of students and the advancement of knowledge. For both of these purposes psychological laboratories are urgently needed. The student of philosophy, subject to special temptation and danger, requires even more than others the training coming from natural science and the immediate contact with facts. The extent to which original research can be carried on and knowledge advanced in a psychological laboratory can best be tested by experience. It may be that the problems opened by experiment to the: student of psychology are not less interesting or important than such as can be solved in chemical, physical or physiological laboratories.

Experimental psychology undertakes as its task the analysis and measurement of mental phenomena. It may be thought that the difficulty in psychology is the plethora rather than the lack of facts, but the facts with which psychology has mostly dealt are like the facts of the external world gained from everyday experience. In the face of a great mass of such facts astrology and alchemy were developed, and it was fancied that useless hypotheses explained phenomena such as the fall of heavy bodies, the rising of water in the pump, and the movements of the planets. It was only after exact methods of analysis and measurement had been introduced that astronomy and chemistry became possible, and apparently isolated facts were brought together under the law of gravitation. So long as the phenomena with which a science has to deal cannot be repeated for accurate study, there is but little hope of attaining exact knowledge. The progress of pathology, for example, has been slow, and it has only become a science since laboratories have been established and hospitals and medical journals have made it possible to study repetitions of the same symptoms. Again, the phenomena with which the Society for Psychical Research deals, in so far as they are inaccessible to experiment, are not apt to give accordant or scientific results. But whenever experiment has been introduced into [p. 38] science, a rapid and almost sudden advance has followed, and there are good grounds for hope that methods which have been so fruitful in physics will prove barren for psychology.

The relation in which experimental psychology stands to introspection has been much misunderstood, and this is not to be wondered at, seeing that certain physiologists seem almost to claim that psychology would be better off if there were no such thing as consciousness. Experiment is not meant to take the place of introspection, but is, meant to make scientific introspection possible. The study of consciousness is, as we all know, fraught with peculiar difficulties: it is not easy to be at once the observer and observed; "the eye sees not itself," and the phenomena are both complex and transient. The best results have been obtained when introspection has been combined with the study of the objective manifestations of the contents of other minds, more especially when these have on the one hand become fossilised as in language, customs, are, &c., or on the other hand are relatively simple, as in children, in savages and in disease. But, under circumstances the most favourable to scientific observation, there are serious difficulties in the way of exact analysis and measurement, and it will be found that in psychology, as elsewhere in science, experiment gives the most trustworthy and accurate results. Experiment calls up the phenomena to

be studied when wanted and, by keeping certain conditions constant and by altering others, gives the best chance for analysis; above ail it enables us to photograph the transient phenomena and subject them to objective examination and measurement.

Professor Wundt, by the publication of his Physiologische Psychologie in 1874 and the establishment of a psychological laboratory at Leipsic in 1879, has made himself the representative of the effort to introduce experimental methods into psychology. Weber, Lotze, Fechner and Helmholtz, in Germany, and Bain, in England, had cleared the way, but their books and researches remained to a certain extent isolated attempts, until Wundt directed toward one centre the divergent lines, and persuaded men of science on the one and hand [sic] students of philosophy on the other to accept the new science.

Wundt was called from Zurich to Leipsic in 1876, and as soon as possible afterwards took measures toward the establishment of an university laboratory for psychological research. He was known as the author of important works on physiology and physics, as well as on psychology, and hope that methods which will not prove barren for [p. 39] this gave his recommendation the more weight. In 1879 rooms for the laboratory were set apart in the university buildings: the authorities also granted a, yearly appropriation for the purchase of apparatus, and more recently a demonstrator with a salary has been appointed. The laboratory is at present established in four rooms, and two more are about to be added. The rooms are conveniently situated in what is known as the Convict building, looking out on quiet courts with both northern and southern exposure. The number of students has gradually increased: last semester there were nineteen carrying on original research and others attending demonstrations. The students come from all quarters (it should be added, except from England); there are nearly always Americans and Russians, and often Scandinavians, Czechs, Greeks and Frenchmen. The men work in groups; at least two are needed to carry on most psychological experiments, the one acting as subject, the other taking charge of the apparatus and registering the results. The students must, therefore, mutually help each other; one is responsible for the research, and if it is successful he prints it, often using it for a doctor's dissertation.

Wundt himself visits the laboratory every day, and is glad to answer questions and give help; he, however, tries to encourage the men to think for themselves, and to he responsible for their own experiments. He suggests subjects for research at the beginning of the semester, but he lets the students choose the direction in which they prefer to work, and encourages them to find independently problems and the methods of solving them.

It is interesting to note that the example set by Wundt at Leipsic is being followed in other universities. Psychological laboratories have been established or are being planned at Berlin, Bonn, Göttingen; in America, at Johns Hopkins, Harvard, Pennsylvania and Princeton; in England at Cambridge; also at Copenhagen and elsewhere.

Wundt established not only the laboratory, but also a journal or " Archiv," the Philosophische Studien, for the publication of the methods and results of psychological research, and for the scientific discussion of questions in psychology, logic aid theory of knowledge. This serial, published by Engelmann at Leipsic, appears whenever material making up about 150 pages has been collected. Since 1882 fifteen such parts have been issued; the table of contents of each number, as it appears, being given in MIND.

I shall now try to give a systematic account of the researches which have been completed or are now being [p. 40] carried on in the Leipsic laboratory. The limits of a single article confine my notice to the briefest summary; I can, however, refer the reader who is interested in any special line of research to the detailed accounts in the Philosophische Studien. It may also be worth while to call attention to Ladd's Physiological Psychology, noticed in the last number of MIND, and to the fact that Wundt is about to publish a new and rewritten edition of his Physiologische Psychologie. We can classify the work done at Leipsic under four heads: (1) The Analysis and Measurement of Sensation; (2) The Duration of Mental Processes; (3) The Time-sense; (4) Attention, Memory and the Association of Ideas. Such a classification is, of course, merely a, matter of convenience. Experiments made in different directions throw light one upon another and at their boundaries overlap, so that many of the researches put under one heading reach beyond its limits and into others. All science is, indeed, an organism no member of which call be thought of apart from the rest. As Aristotle has said, a hand cut off from the rest of the body is not even a hand.

1. The Analysis and Measurement of Sensation.

In physics force is usually measured by its effects, and in psychology we may some day be able to measure sensation by determining the movement accompanying a given sensation. But the cause is no less constant than the effect, and we may with scientific accuracy specify and measure sensation by the physical stimulus causing the corresponding cerebral commotion. The relation subsisting between the sensation and the physical stimulus has, therefore, been the subject of much experiment and discussion. An especially large share of attention has been given to studying the way in which the intensity of the sensation varies with the intensity of the corresponding stimulus. It is impossible to give much account of this here; the reader must be referred to the books by Fechner, Müller, Delboeuf and others, and to the many papers which have been published in the Philosophische Studien[1] and elsewhere. [p. 41]

Weber first called attention to the fact that, when weights are laid on the supported hand, each must be increased by about 1/3 of its original weight before any change is noticed. Since then many experiments have been made on the several senses, and it has been found approximately to hold that the least noticeable change in the intensity of a sensation is occasioned by a chnnge in the stimulus directly proportional to the amount of the stimulus. Thus if there are 100 candles in a room we can just notice the change in the illumination caused by taking away or adding one candle; if there are 1000 candles, 10 must be taken away or added before a change is noticed. This relation holds most nearly for moderate intensities of the stimulus, and for the more mechanical senses, as sound. Weber's generalisation admits of several interpretations. It has been looked upon as a purely physiological fact, it being argued[2] that the sensation must increase more slowly than the stimulus, owing to the inertia of the sense-organ and more especially to irradiation in the brain. The view supported by Fechner is that we have to do with a psychophysical fact, which expresses an ultimate relation between physiological and mental change. Wundt points out that it may be given a, psychological interpretation, and referred to the apperception of the sensation, thus being brought under "the law of relativity".

Weber's generalisation is of considerable interest both to physiologists and psychologists; inferences have, however, been drawn from it which I do not consider justifiable. The generalisation may be expressed in the equation

$$a = c\,DS/S$$

in which c is a constant, S the stimulus, DS the change in the stimulus which call just be noticed, and a the least noticeable, change in sensation. This equation, however, need only be true if a different value be given to a for every value of S, and only holds approximately and for certain values of S. It evidently is not true when S is very small, for then there is no sensation whatever. Fechner in order to get his equation

$$E = c \log S$$

in which E is the sensation and S the stimulus, the sensation [p. 42] being thus measured in terms of the stimulus, must assume the least noticeable change in sensation to be an equal increase or decrease in the intensity of sensation, and must, further, introduce in a questionable way the "fact of the threshold". We have, however, more especially to do with the experiments made in the Leipsic laboratory. Sound and light have been used to investigate the relation between stimulus and sensation. The loudness of sound has not been satisfactorily measured objectively; so it was found necessary at Leipsic to set up some standard of sound before its intensity could be brought into relation to the sensation. Tischer[3] was the first to attempt to make such determinations; he found that the noise made by a falling ball was not proportional to the weight of the ball multiplied by the height from which it falls, but increases more slowly. Later experiments made by Starke[4] and by Merkel[5] seem, however, to show that

$$i = cwh.$$

in which i is the intensity of the sound, w and h respectively the weight of the ball and the height from which it falls, and c a constant depending on the material of the ball and sounding-board. The results of Starke's experiments, especially, correspond more exactly with the law than could have

been foreseen, as there were several sources of variation; c, for example, was not always the same. The balls were at first lead and polyhedrons, and afterwards steel and ellipsoids, and the different points in the sounding-board had different elasticities, &c. The experiments by Tischer,[6] Lorenz,[7] Starke,[8] and Merkel,[9] all show the validity of Weber's generalisation, and give more exact results for sound than have been obtained in connexion with the other senses. Whatever the loudness of a, sound may be, it must be increased by about 1/3 before a difference is noticed. It should, however, be stated that the value of Lorenz's research has, not without cause, been questioned by Fechner, [10] and that experiments made by Merkel in another direction[11] do not seem to [p. 43] be trustworthy. Researches on the loudness of sound are still being carried on at Leipsic; so we may hope for further light on the subject.

Ever since- Helmholtz published, in 1862, his classical researches on sound, much attention has been given to the perception of musical notes, investigations having been undertaken by Mach, Preyer, Hensen, Stumpf and others. Careful experiments, not yet published, have also been carried on for several years past in the Leipsic laboratory. Luft with tuning-forks and Lorenz with an apparatus on the principle of the harmonium have been investigating the least noticeable difference in pitch in the same manner as the loudness of sound has been studied. We have seen that the ear does not readily distinguish differences in loudness; in pitch, on the contrary, small changes can be noticed with marvellous[sic] accuracy, and this whether the observer be 'musical' or not. In the range most easily covered by the human voice (from about c' to c'", 256 to 1024 vibrations per second) successive notes call be distinguished when the difference between the physical stimuli is 1/4 to 1/5 of a vibration per sec. Where the pianoforte machine gives 24 notes the ear can distinguish over 3000. Outside the limits of the human voice the least noticeable difference in the stimulus becomes a smaller fraction of a vibration as the note is taken lower, but not in direct proportion to the rate of vibration; so Weber's law in no case holds for pitch. Experiments are being now carried on at Leipsic to determine the accuracy with which the ear can distinguish musical intervals, the notes being given in succession.

Light-sensations have been investigated at Leipsic by Kraepelin[12] who found that with moderate intensities a difference in the illumination of 1/120 could be noticed, and that the difference must be increased to 1/100 when the light was taken very faint. It is natural that the fraction should become larger as we approach the threshold of sensation, owing to the chemical process supposed to take place in the retina, and to the eye's "own light". Lehmann[13] and Neiglick[14] applied to light the so-called "method of mean graduation," a method of considerable interest to the psychologist. The observer tries to give the shade of gray [p. 44] which seems to him equidistant from a lighter and a darker shade, or from white and black. If it were possible to find a sensation y as much weaker than x as it is stronger than z we could take a unit of measure and speak of one sensation as three times as strong as another, &c· The application might, further, be extended beyond the intensity of sensation, so that, for example, the hedonistic calculus could really be put in practice, and it would not be absurd to calculate, as Plato does, that a just king lives 729 times as happily as a tyrant. The fact, however, is that we are not dealing directly with sensation but with our estimates, and even these seem to me, to a certain extent, conventional. I can say that a very dark gray seems to me more like black than like white, but when I come to pick out a shade which seems equidistant from the two, I am in doubt within rather large limits, and only come to any decision by thinking of the number of differences of shade I could distinguish in each direction. If this view be correct the method is reduced to a less accurate version of that of the "least observable difference" Neiglick found that his estimate remained constant, and that other observers, varying considerably at first, finally agreed with him. He naively concludes that some person naturally judge differences in light with accuracy others only after practice. The fact probably is, that Neiglick, knowing the objective measure of the light, was unconsciously aided by association, and, perhaps, to an extent which invalidates his results. The other observers, comparing their results with his after the series had been completed, naturally tended next time to approximate to his judgment. It is difficult to decide that one shade of gray is equidistant from two others, but after the decision has once been made it seems quite evident and the point is easily held in mind. Lehmann's results were disturbed by contrast, and he was led to study its influence. He found that, whatever the illuminations of two contrasted surfaces might be, the contrast was the greatest when there was a constant ratio (1:4.76) between them. Neiglick found Weber's law to hold the more accurately the more nearly the contrast between the compared surfaces was a maximum. Schmerler[15] had previously made careful experiments, determining quantitatively the saturation of a colour the most favourable to contrast. The fact which however, was already known, that contrast is not the greatest when there [p. 45] is the greatest illumination of the surface or saturation of the colour is interesting, and not readily

explained by either of the current theories of light-sensation.

Before leaving this subject a second paper by Lehmann[16] must be noticed, in which he advocates the revolving wheel with black and white sectors for photometric purposes and a paper by Fischer [17] on the interesting phenomena of the stroboscope or 'wheel of life'.

2. The Duration of Mental Processes.

The department of research which we have just been considering, that concerned with the relation between the psychical state and the physical stimulus, has been aptly called psychophysics, and it might be well to limit the term to this subject, and not use it as synonymous with physiological and experimental psychology The term psychometry can, in like manner, be confined to the subject which we are about to take up, the measurement of the duration of mental processes. Psychometry has received abundant attention front astronomers, physicists, physiologists and psychologists; nearly half the researches undertaken in the Leipsic laboratory are concerned with this subject. We are naturally glad to find it possible to apply methods of measurement directly to consciousness; there is no doubt but that mental processes take up time, and that this time can be determined. The measurements thus obtained are not psycho-physical as those which we have been recently considering, but purely psychological. It may be true that we are in some sort measuring the 'outside' of the mind, but the facts obtained, when we learn how long it takes to perceive, to will, to remember, &c, are in themselves of the same interest to the psychologist, as the distances of the stars to the astronomer or atomic weights to the chemist. But, besides the general interest of psychometrical facts as a part of a complete description of the mind, these times are of further and great use to the psychologist, as they help him in analysing complex mental phenomena, and in studying the nature of attention, volition, &c. It should also be noticed that psychometrical experiment has brought, perhaps, the strongest testimony we have to the complete parallelism of physical and mental phenomena; there is scarcely any doubt but [p. 46] that our determinations measure at once the rate of change in the brain and of change in consciousness.

While the importance of psychometrical research for the special student of mind would be admitted, it seems to me that its general interest has been overlooked. Time, like size, is relative. If all things should suddenly move more slowly or more quickly than at present, there would be no change for us. If, however, our physiological movements and mental processes should take place at the same rate as now, while our objective measures of time should move twice as fast, the days of our years would become seven score years, instead of three score years and ten, but we should not for this reason live any the longer or be any the older. If, on the other hand, we should live as many years as at present, but the rate of our physiological and mental motions be doubled, we should live twice as long and become twice as old as now. It would, consequently, be of immense theoretical and, perhaps, practical importance to learn whether in the course of evolution the molecular arrangement of the nervous system becomes more delicately balanced, so that the physical changes corresponding to our thinking pass more quickly-whether as thoughts become broader, feelings more intense and will stronger, the time they take up becomes less. It is thus an interesting branch of research to determine the time required for the simpler and more complex mental processes, and to study the variation in persons of different race, sex, age, education, occupation, &c.

It will not be necessary to describe at length the psychometrical researches undertaken at Leipsic, as the most recent of these have been printed in MIND.[18] Most of the earlier work[19] on this subject was then reviewed; attention should, however, be called to researches by Kraepelin and by Berger. Kraepelin[20] studied the effects of certain drugs on the duration of a reaction and of simple mental processes. These [p. 47] times seem to be at first lengthened and then shortened by ether and chloroform, and at first shortened and then lengthened by alcohol, a difference of action which, perhaps, has less to do with different effects of the drugs on the nervous system than with the method of taking them, ether and chloroform being inhaled and alcohol drunk. Berger,[21] in experimenting with light, sound and electric shock, found the reaction-time to become shorter as the stimulus was taken stronger. According to these experiments, the reaction-time for the several colours is the same.

It yet remains to notice some unpublished experiments made by L. Lange. He finds that the reaction-time is nearly twice as long when the attention is concentrated on the sense-organ as when it is concentrated on the hand. Wundt looks on these results as important, holding the "muscular" reaction to be reflex, while the "sensorial" includes apperception and volition. I have pointed out[22]

that the reaction is at first voluntary, but that with practice the process becomes reflex and the time shorter. We must wait for the publication of Lange's results, and, perhaps, for new experiments, before we know whether an unpractised observer could immediately make his reaction reflex and quicker by concentrating his attention on the movement to be made, or whether the reaction-time of a practised observer would become voluntary and lengthened if he concentrated his attention on the sense-organ.

3. The Time-Sense.

Under this head I shall notice experiments concerned with the time-relations of perceptions and our power of estimating intervals of time. Together with this subject corresponding researches on space might be grouped, but experiments on local signs, sensation-areas, binocular vision, massiveness of sensations, &c., have not as yet been undertaken at Leipsic.

Stimuli must be separated by a certain interval of time in order that they may be recognised as distinct. This is doubtless in many cases a physiological fact due to inertia in the sense-organ. Thus in sight a chemical process is supposed to take place, and this does not reach its maximum until the stimulus has worked some little time, 1/10 sec. perhaps, [p. 48] and continues after the stimulus has ceased. Light-stimuli following each other at intervals shorter than 1/40 sec. are fused together into one sensation. In the case of sound and of touch the transference from external motion into a nervous impulse seems to be of a more mechanical nature than in the case of sight, and stimuli separated by a shorter interval may be given in consciousness as distinct sensations. The problem becomes more truly psychological when different senses are affected. Exner[23] found that the interval between such stimuli must be 1/20 to 1/6 sec. before the correct order could be given. Wundt,[24] and afterwards v. Tchisch,[25] experimented with an apparatus made so that a pointer passed a scale and when it reached a given division a sound, touch, or electric shock was produced. The problem was to decide whet division of the scale the pointer seemed to have reached when the sound was heard or the touch felt. In this experiment there was usually what Wundt calls a "negative displacement," the added stimulus being associated with a position of the pointer earlier than that at which it had in reality been produced. The experiment was varied by altering the rate at which the pointer moved, and by making the added stimulus a complex affecting different senses. The results are perhaps explained by, and in return throw light on, the nature of attention.

Mach[26] and Vierordt[27] first undertook to determine how accurately intervals of time can be compared. This work has been continued in the Leipsic laboratory by four elaborate researches, which, however, do not seem to have given final or satisfactory results. The first three of these[28] need not detain us; we must, however, notice a, recent paper by Glass.[29] He finds that times shorter than 2 sec. are over-estimated, and those longer than 4 sec. underestimated. He concludes, further, that multiples of l 1/4 sec. are estimated more correctly than other times, and that the "psycho-physical [p. 49] law" holds for the time-sense. Glass's experiments have been carried out with the greatest case, but the fact that four researches on the same subject have all given discordant results, leads us to suppose that something must be wrong in the methods used. Such an error ion method is not hard to find. When the experimenter knows that a certain estimate will correspond with the law he has set up, he as a matter of course, though quite unconsciously, makes such estimate. Thus Glass made all his experiments on himself, and the same interval was estimated 100 times in succession He gives his results in three series; the first of these does not correspond at all with "the law," the second approximates to it, but with considerable irregularity; in the third series he took the intervals where he expected to find his relative maxima and minima, and found them most accurately. The experiments by Stevens[30] on the time-sense, contributed to MIND, seem more satisfactory than those from Leipsic.

4. Attention, Memory, and the Association of Ideas.

In the course of the experiments which we have been considering we have advanced from the outworks toward the citadel of the mind. We first examined sensation and its relation to the physical and physiological processes which accompany it. While the sensation is a fact of mind in no wise resembling the matter in motion with which it is associated, physical and mental processes have one important characteristic in common, an order in time. We found that the time taken up by mental processes call be measured in much the same way as physical change. We next considered experiments such as are meant to throw light on our space- and time-sense. We now, in considering

attention, memory and the association of ideas, find ourselves at the centre of the mind, and in so far as such subjects are open to experiment, the results are of special interest to the psychologist. As has already been pointed out, our classification of experimental research is a matter of convenience and to some extent artificial. Many of the experiments already noticed concern matters now to be considered; for example, the "least perceptible difference" is a fact of attention, and the reproduction of time-intervals a fact of memory.

There seems to be an upper and a lower limit to consciousness or attention. On the one hand we cannot attend to a presentation of more than a certain degree of complexity; on [p. 50] the other it must have a certain intensity and interest in order that we may be conscious of it at all. The upper limits of consciousness have been studied by Dietze and by myself. Dietze[31] used successive sound-impressions and found that when 16 beats of a metronome followed each other at intervals of .2 to .3 sec. the number could be correctly estimated. If the interval be taken longer or shorter than this, not so many can be grasped. If the beats are combined into groups as many as 40 can be at one time in consciousness. Even when 16 were used it is likely that they were combined into a rhythm with one accented and one unaccented beat. If this can be assumed, the results would agree with the limits of the rhythm used in music and poetry. It must, however, be difficult to be sure that the beats are not otherwise combined and perhaps unconsciously counted. With these results the experiments by Hall and Jastrow, contributed to MIND,[32] should be compared. I myself[33] determined the number of simple visual impressions, or complexity of an impression, which cut be simultaneously attended to. On the average five simple impressions, such as lines or letters, can be at one time apperceived. When the impressions are combined into familiar complexes, as letters into words and sentences, many more can be grasped. The extent of consciousness varies considerably with the individual. I also determined the minimum sensation by letting colours and other objects work on the retina for a very short time. The time was found to vary for the several colours, as also with different words, letters, &c. It was thus found possible to determine the relative legibility of the letters of the alphabet. In this case we are left in doubt as to how far the inertia is in the eye and how far in consciousness. Experiments by N. Lange,[34] however, seem to be concerned wholly with a fact of attention. Helmholtz experimenting with light and Urbantschitsch with sound had noticed that a faint stimulus is sometimes perceived, sometimes not. Thus the ticking of a watch is heard, then disappears, then is heard again, &c. Lange found the intervals between the [p. 51] maxima of intensity in sensation to be constant, and that a similar alteration in distinctness takes place in the case of images. This interval, two to three seconds, does not seem due to fatigue in the sense-organ or nerve, but apparently represents a natural rhythm in consciousness or attention. Wolfe[35] found a, like rhythm in the accuracy with which musical notes can be remembered. Apart from this rhythm the accuracy of memory seems, in a general way, to vary inversely as the square of the time. A similar result had been reached by Ebbinghaus experimenting with more complex impressions.[36]

Experiments on the association of ideas have been made at Leipsic by Trautscholdt[37] and by myself.[38] The former determined the time it takes for one idea to suggest another, and also in 400 cases the qualitative results, classifying them in accordance with the nature of the association.

Thus have been briefly noticed the results obtained by research in the Leipsic laboratory during the past seven years. They prove conclusively that it is possible to apply experimental methods to the study of mind. The positive results are, besides, not insignificant, and will compare favourably with what has been accomplished during the same period in many chemical, physical and physiological laboratories. An increased interest is everywhere being taken in experimental psychology, and we may hope that we shall some day have as accurate and complete knowledge of mind as of the physical world.

Footnotes

[1] Papers in the Philosophische Studien giving a description of research will be noticed below (being cited by vol, and pp. only). The following are those concerned only with theoretical discussion:

W. Wundt, "Ueber die Methode der Minimaländerunng," i. 556-572.

W. Wundt, "Ueber das Weber'sche Gesetz," ii. 1-36.

G. Th. Fechner, "In Sachen des Zeitsinnes and der Methods der richtigen und falschen Fälle, gegen Estel und Lorenz," iii. 1-37.

Alfred Köhler, "Ueber die hauptsächlichsten Versuche einer mathematischen Forumlirung des psychophysischen Gesetzes von Weber," iii. 572-642.

G. Th. Fechner, "Ueber die psychischen Massprincipien und das Weber'sche Gesetz," iv. 161-230.

[2] See J. Ward, MIND i. 482.

[3] E. Tischer, "Bemerkungen über die Messung von Schallstärken mit Rücksicht auf psychophychische Versuche," i. 543-555.

[4] P. Starke, "Die Messung von Schallstärken," iii. 254-304.

[5] J. Merkel, "Das psychophysische Grundgesetz in Bezug auf Schallstärken," iv. 117-160, 251-291.

[6] Op. cit.

[7] G. Lorenz, "Die Methode der richtigen und falschen Fälle in ihrer Anwendung auf Schallempfindungen," ii. 394-474, 655-657.

[8] Op. cit.

[9] Op. cit.

[10] Op. cit.

[11] See Cattell, MIND xi. 229.

[12] E. Kraepelin, "Zur Frage der Gültigkeit der Weber'schen Gesetzes bei Lichtempfindungen," ii. 306-326, 651-654.

[13] A. Lehmann, "Ueber die Anwendung der Methode der mittlern Abstufungen auf den Lichtsinn," iii. 497-533.

[14] H. Neiglick, "Zur Psychophysik des Lichtsinns," iv. 28-111; cp. W. Wundt, "Bemerkungen zu vorstehendem Aufsatze," ib. 112-116.

[15] B. Schmerler, "Untersuchungen über den Farbencontrast vermittelst rotirender Scheiben," i. 379-416.

[16] A. Lehmann, "Ueber Photometrie mittelst rotirender Scheiben," iv. 231-240.·

[17] O. Fischer, "Psychologische Analyse der stroboskopischen Erscheinungen," iii. 128-156.·

[18] J. McK. Cattell, "The Time taken up by Cerebral Operations," MIND xi. 220-242, 376-392, 524-538; cp. xi. 63-5.

[19] M. Friedrich, "Ueber die Apperceptionsdauer bei einfachen und zusammengesetzten Vorstellungen," i. 39-77, ii. 66-72.

M. Trautscholdt, "Experimentelle Untersuchungen über die Association der Vorstellungen, i. 213-250.

E. Tischer, "Ueber die Unterscheidung von Schallstärken," i. 496-542.

W. Moldenhauer, "Ueber die einfache Reactionsdauer einer Geruchsempfindung," i. 606-614.

J. Merkel, "Die zeitlichen Vorhältnisse der Willensthätigkeit," ii. 73-127.

[20] E. Kraepelin, "Ueber die Einwirkung einiger medicamentöser Stoffe auf die Dauer einfacher psychischer Vorgänge," i. 417-462, 573-605.

[21] G. O. Berger, "Ueber den Einfluss der Reizstärke auf die Dauer einfacher psychischer Vorgnge mit besonderer Rücksicht auf Lichtreize," iii. 38-93; Also Cattell, Brain, vol. viii.

[22] MIND xi. 232.

[23] Pflüger's Archiv, xi.

[24] Physiologische Psychologie, 2te Auflage, ii. 264 ff.

[25] W. v. Tchisch, "Ueber die Zeitverhältnisse der Apperception einfacher und zusammengesetzter Vorstellungen, untersucht mit Hülfe der Complicationsmethode," ii. 603-634.

[26] Sitzungsberichte der Wiener Akad., 1865.

[27] Der Zeitsinn, Tübingen, 1868.

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[31]. G. Dietze, "Untersuchungen über den Umfang des Bewusstseins bei regelmässig aufeinander folgenden Schalleindrücken," ii. 362-394.

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[34] N. Lange, "Beiträge zur Theorie der sinnlichen Aufmerksamkeit und der activen Apperception," iv. 390-422.

[35] H. K. Wolfe, "Untersuchugen über das Tongedächtniss," iii. 534-571.

[36] See MIND, x. 454. The formula given by Wolfe and Ebbinghaus respectively are:--

$$r = \frac{kf}{\log t} + cf \text{ and } b = \frac{100k}{(\log t)^c + k.}$$

[37] M. Trautscholdt, "Experimentelle Untersuchungen über die Association der Vorstellungen," i. 213-250.

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