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THE TIME-RELATIONS OF MENTAL PHENOMENA.

THE study of the time-relations of mental phenomena is important from several points of view: it serves as an index of mental complexity, giving the sanction of objective demonstration to the results of subjective observation; it indicates a mode of analysis of the simpler mental acts, as well as the relation of these laboratory products to the processes of daily life; it demonstrates the close inter-relation of psychological with physiological facts, an analysis of the former being indispensable to the right comprehension of the latter; it suggests means of lightening and shortening mental operations, and thus offers a mode of improving educational methods; and it promises in various directions to deepen and widen our knowledge of those processes by the complication and elaboration of which our mental life is so wonderfully built up. It is only within very recent years that this department of research has been cultivated; and it is natural that the results of different workers, involving variations in method and design, should show points of difference. In spite of these it seems possible to present a systematic sketch of what has been done, with due reference to the ultimate goal as well as to the many gaps still to be filled. It is with the object of furnishing such a general view that the following exposition has been attempted.

Rate of Nervous Impulses.

While it follows, as a very natural consequence of the modern view of the relation between body and mind, that mental processes, however simple, should occupy time, it must be remembered that the very opposite opinion has been held by serious thinkers. It has been argued as a proof of the immateriality of thought that its operations were out of relation to time, and the expression "quick as thought" has come to indicate a maximum of speed. It being established that so comparatively simple a process as sensation involves the passage of an impulse along nerve-fibres, it is plain that the rate of travelling of this impulse sets a limit to the time of the entire process, as well as of all more complicated mental operations in which sensations are involved. The physiologist Johannes Müller, writing in 1844, despaired of our ever being able to measure the time of so excessively rapid and short a movement; but before the close of the same decade, Helmholtz measured the rate in the nerve of the frog, finding it to be about 86 feet per second. Though somewhat greater in man, 110 feet per second, this movement is extremely slow compared with the velocity of light or even sound: indeed, it is only slightly faster than the fastest express train.

Müller writes: "We shall probably never secure the means of ascertaining the speed of nerve activity, because we lack the comparison of enormous distances from which the speed of a movement, in this respect analogous to light, could be calculated;" and again: "The time in which a sensation proceeds from the periphery to the brain and the spinal cord, and is followed by a re-action at the periphery by means of muscular contractions, is infinitely small and immeasurable." It is interesting to note how very crude were the conceptions of the older physiologists upon this point. Haller (1762) tells us of one who, following the view that the nervous impulse was a fluid, and its action analagous to that of the blood, found the "nerve tubes" of the heart to be 2,880 million times as narrow as the aorta, and concluded that the nervous impulse travelled proportionately faster than the blood, thus making its rate 57,600 million feet per second. Haller himself measured the maximum rapidity of short rhythmical movements, and (falsely), assuming that the impulse travelled to and from muscle and brain between each contraction, found an (accidentally not very erroneous) speed of 9,000 feet per second. The method introduced by Helmholtz, and improved by himself and others, consists in excising a muscle with a long stretch of nerve attached, and connecting the muscle with a lever, so that every contraction of it is registered upon the quickly moving surface of a revolving drum or a swinging pendulum. By electrically stimulating the nerve first at a point near to and then at a point far off from the muscle, two curves are recorded, the latter of which is found to leave the base line a trifle after the former. A tuning-fork writes its vibrations beneath these records, and enables us to measure how much later the second contraction began, while the distance travelled in this time is that between the two points of stimulation on the nerve. It has been attempted to measure this rate in man by having the subject re-act once to a stimulus applied to the foot, and again to a stimulus at the hip, or some point nearer the spinal cord, and counting the difference in time as due to the difference in length of nerve traversed. While the method is necessarily inaccurate, and other factors contribute to the difference in time, the majority of the determinations indicate a rate of between 30 and 40 metres (100 to 130 feet) per second. These determinations apply to sensory nerves: for the motor nerves of man, Helmholtz has found, by a method closely similar to that employed upon the frog, a rate of 110 feet per second. The most influential of the conditions affecting this rate is temperature: cold decreases and heat increases it, the extremes of variation being 30 to 90 metres. Under normal conditions it seems fair to regard the rate for both motor and sensory nerves of man as about 110 feet per second.

Analysis of Re-actions.

A great variety of actions may be viewed as responses to stimuli. There is a flash of light, and we wink; a burning cinder falls upon the hand, and we draw it away; a bell rings, and the engineer starts his train, or the servant opens the door, or we go down to dinner; the clock strikes, and we stop work, or go to meet an appointment. Again, in such an occupation as copying, every letter or word seen acts as a stimulus, to which the written letter or word is the response; in piano playing, and the guidance of complicated machinery, we see more elaborate instances of similar processes. The printer distributing "pi," the post-office clerk sorting the mails, are illustrations of quick forms of re-action, in which the different letters of the alphabet or the different addresses of the mail matter act as the stimuli, and the placing them in their appropriate places follows as the response. In many games, such as tennis or cricket, the various ways in which the ball is seen to come to the striker are the stimuli, for each variation of which there is a precise and complex form of response in the mode of returning the ball. In military drill the various words of command are the stimuli, and the actions thus induced the responses; and such illustrations could be multiplied indefinitely. In all these actions the time-relations are more or less definite and important, but a useful study of them presupposes a careful and systematic analysis of the processes therein involved. We recognize that certain of the above actions are more complicated than others, and we must inquire in what this complication consists. In the process as usually presented the nature of the re-action depends upon the nature of the stimulus, a variation in the one being concomitant with a variation in the other. The piano player, seeing a certain mark on the page, strikes a certain key on the key-board, but strikes a different key if this mark be differently placed; the soldier varies his movement according to the word of command, and so on with most of the others. All such actions involve at least three processes: (1) the recognition of the sense impression, (2) the performance of the appropriate action, and (3) the association of the one with the other. The recognition involves the appreciation of the *presence* together with the appreciation of the *nature* of the sense-impression; and the movement involves the contraction of muscles together with the initiation of the impulse. We obtain the simplest form of re-action by limiting the stimulus to a single definite one, and having one and the same response irrespective of the nature of the stimulus. The subject expects the stimulus the nature of which he knows, and is ready to signal, by a simple movement agreed upon in advance, *merely* that the impression has been received. This we shall speak of as a "simple re-action." It occurs whenever a certain sense-impression is agreed upon as a signal for the execution of a simple movement. The time-keeper pressing the spring of the stop-watch, or the racer starting off as soon as the pistol is fired or the word is given, are instances of simple re-actions. It should be noted that the simplicity of the act refers primarily to the subject's fore-knowledge of what is to occur; the nature of the sense-impression, as of the motion, is known in advance, the association between the two being in the main artificial. Inasmuch as the more elaborate mental processes involve those of the simple re-action, our first step must be to determine its elements and their time-relations.

The Elements of a Simple Re-action.

The several elements of a simple re-action have been variously analyzed by different observers, but all recognize the *physiological* and the specially *psychological* portions of the process. The physiological time-elements include, (*a*) the time for the sense-organ to respond to an impression, i.e., to overcome its inertia; (*b*) the time for the passage of the impulse inward along nerves (and spinal cord), with the various delays whenever the impulse enters or passes through cells; (*c*) the return passage of the motor impulse from the brain to (spinal chord and) nerve and muscle; and (*d*) the time for the contraction of the muscle. The time thus left unaccounted for is that taken up by the psychological process, the transformation of the sensory into the motor impulse,—a process taking place in the brain, but as to the precise nature of which we have no definite information. The separate determination of each of the physiological factors enables us to find approximately the duration of the central process. As a sufficiently typical case we may accept the estimate of Cattell, that, in re-acting to a light by pressing the key with the finger, the time needed by the impulse to travel from eye to brain and from brain to spinal cord and finger is about 50σ;[1] the latent time in the muscle, during which it overcomes its inertia, is judged from experiments upon the frog to be about 5σ to 10σ; and experiment gives a value of 15σ to 20σ for stimulating the retina and initiating the impulse. As the entire re-action occupied about 150σ we conclude that in this case the physiological and the psychological portions of the process occupy about equal times. One may obtain a fair notion of the rate of these processes by the following simple experiment. A score or so of persons form a chain by joining hands, and at a given signal a certain member of the group sharply presses the hand of his neighbor, who in turn imparts the pressure as quickly as possible to *his* neighbor, and so on until the impression has gone the rounds. An outsider keeps the time (which may be done with sufficient accuracy by counting the ticks of a watch, usually fifths of a second) from the moment of giving the signal to start to the moment of receiving the signal from the last member of the group that the impression has been circulated. The entire time divided by the number of persons in the group (or better, by that number plus two to include the re-actions at starting and stopping) gives an average simple re-action-time, which, though long at first, is reduced after a little practice to a sixth or a seventh of a second. On this basis one may calculate that if a number of men, stretching out their arms and grasping one another's hands, were stationed in a straight line, it would take three minutes to send a message in the manner just described along a mile of this human telegraph.

(*a*) The inertia of sense-organs has been variously determined. One method measures how closely impressions may follow one another without fusing. The time thus measured is the minimum time during which the sense-organ may be stimulated and recover sufficiently to receive a second stimulation. This process thus includes something more than the one we desire to measure, and may perhaps be regarded as furnishing a maximum time of the sensory inertia. Here again various circumstances influence the determinations, the chief ones being the sense-organ in question and the clearness and intensity of the impression. Sectors of black and white upon a disc revolving in daylight at the rate of about 25 times a second fuse into a uniform gray, making the inertia of the retina under these conditions about 40σ. In weak light (moonlight) the time lengthens to about 100σ. The same experiment has been made with sectors of different colors, with the disc stationary and the light reflected from a rotating mirror, with a vibrating point of light; and, while all these variations somewhat affect the result, the majority of the determinations indicate a fusion at 30 to 40 impressions

[1] The sign σ indicates one one-thousandth of a second.

a second, or a duration of 33σ to 25σ. For sound, different observers have chosen different points for measurement. The slowest rate of impressions fusing into a musical sound has been fixed at between 30 and 40 per second; but Helmholtz has shown that the interference of sound-waves perceptible as beats does not escape detection when recurring as rapidly as 132 per second. For non-musical sounds, such as electric clicks, a still higher rate has been found. In touch we distinguish differences of feeling when impressions are rapid enough to fuse but not rapid enough to fuse perfectly. The smoothness of a polished surface is not obtained until the impressions occur 480 to 640 times a second (Valentin). For taste and smell the period, though not accurately determined, is undoubtedly very long. Here the time needed to reach the somewhat concealed sense-organs is considerable, and the chemical processes involved are relatively slow in action. The influence of the mode of activity of the sense-organ upon its period of stimulation is further illustrated in the long inertia period of the probably chemical action of vision compared with the short period of the mechanical senses of hearing and touch. This view is also supported by the fact that the period for the retina is shortened if the eye be directly stimulated electrically. Another mode of experimenting consists in applying a stimulus for the minimum time during which it can be recognized. The time thus measured will be shorter than the other, for it tells us only how long is needed for initiating the process of recognition sufficiently to have it continue to completion (probably after the stimulus ceases). This is indeed a surprisingly short time. Cattell and Sanford independently found that a color or a letter could be recognized when visible for only from 1σ to 5σ, while less recently Baxt recognized 6 to 7 letters when exposed for only 5σ. Others have calculated that the maximum effect of an impression is not reached until from 50σ to 150σ, but these determinations seem to involve some mental process of recognition. Whether or not some such process of recognition is involved is not quite clear. Unless specially prevented, the recognition will take place on the basis of the after-image, a few thousandths of a second being sufficient to initiate the process. By following the impression by a strong flash of light, and thus nullifying the after-image, Baxt found a longer time needed to recognize a more complicated impression. Within 10σ to 15σ, one letter; within 24σ, three letters; within 34σ, four letters, could be recognized. This only partially excludes the effect of the after-image, so that perhaps the results with complicated impressions are minimum "recognition times," and those with simple impressions "inertia times." Another method, that of Exner, is similar to the method of fusion. It consists in finding how closely two impressions, stimulating slightly different portions of the sense-organ, may follow one another and yet be recognized as successive. Optical impressions were so recognized when falling at an interval of 44σ on two points of the retina near the centre .011 millimetres apart, a longer time being necessary if the points are away from the centre of the retina. It seems probable that this process is more complicated than the one we are attempting to study. While the data thus at our disposal do not allow us to fix accurately the time of sensory inertia, the estimate provisionally accepted in the text cannot be far from the truth, being rather over than under estimated. The methods of measuring the rate of nervous impulses (b) and (c) have already been described. The inertia of the muscle and the time of its contraction are determined upon the same apparatus by observing how much after the shock is given the curve leaves the base-line.

Reflex, Automatic, and Voluntary Re-actions.

The term "re-action" as here used is not intended to include all responses to stimuli. The above instanced forms of re-actions present various grades of naturalness, utility, and habituation; that is, the association between motion and stimulus has by practice become more or less close and easy. Copying, for example, may become so entirely automatic that it runs on of itself without the need of renewed volitional effort. The actions recognized as reflex take place in spite of all volition. The re-actions here considered are limited to those requiring some degree of voluntary effort for their execution, though this may be almost indefinitely reduced by practice. The reflex act takes very much less time for its execution than the voluntary: the time for winking has been determined by Exner to be something over 50σ. In other words, it takes about three times as long to signal by a voluntary closure of the eye-lid that an impression has been received as to perform the same act reflexly when the eye is threatened. The utility of this quick action for the protection of the eye is evident; and other useful re-actions, such as those of flight and escape in timid animals, seem to be of a similar nature. The quick movements of defence when attacked; of regaining one's balance when slipping, are so immediately useful and so well inculcated in the organism as often to surprise us by their quickness. Most of these actions can also be performed voluntarily, but neither so well nor so quickly; it is therefore difficult to subject them to experiment. As already indicated, in the ordinary re-action there is little naturalness in the connection of stimulus and movement, the same type of movement being used for all. The experienced re-actor becomes accustomed to signal by the finger movement that the operation required of him has been accomplished, but hardly associates this movement with any particular stimulus.

It is perhaps well to add that the great saving of time in actions that have become automatic (such as is seen in the experienced piano player or post-office clerk as compared with the beginner), is in great part due to the increased facility of doing several things at once and not serially, a factor that enters only in a small degree into the simple reaction. The processes we should be most interested in measuring are those most closely approaching the operations of daily thought, so that the inference from experiment to practice shall be as direct as possible. This, however, it is difficult to do, because every-day mental processes do not present the simplicity of conditions required by experiment. Accordingly the method has been to study the simplest re-actions, and then take into account the circumstances in which our usual mental operations differ from them.

[To be continued.] JOSEPH JASTROW.

LEGISLATION ON FOOD ADULTERATION.

THE adulteration of alimentary substances has been practised from the most ancient times, and numerous laws and regulations have been adopted in various countries to check and prohibit such sophistications.[1]

France has taken the lead in protecting consumers of food from adulterations, and in 1802 the Conseil de Salubrité was established in Paris. In England as well as in France, Germany, and other Continental countries, laws against the adulteration of individual articles, such as tea, coffee, beer, and wine have been passed since the middle ages. The first general act was not passed in England till 1860, and this was amended in 1872. However, they were found unsatisfactory, and the Sale of Food and Drugs Act was passed in 1875, and further amended in 1879 in the endeavor to obtain

[1] For copies of European laws on food adulteration see Report of the Commissioner of Internal Revenue for 1888 and for 1889; and for a summary of their leading features see Science, xiv., p. 308.