

SERIAL ACTION AS A BASIC MEASURE OF MOTOR CAPACITY

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An historical résumé of serial action and related experiments; conditions affecting the time and character of serial action measurements; apparatus and method; the effects of practice upon performance in the test of serial action; distribution of the groups tested according to speed and accuracy; the distribution of errors in relation to the sequence of stimuli; the relation of serial action to other measures used; the relation of serial action to other motor tests; application to vocational guidance and selection; conclusions; bibliography.

During recent years, tests and experiments involving continuous reactions after discrimination and choice, or "serial action," have been making their appearance in various garbs and for varying purposes. These developments have uniformly testified to an effort on the part of the psychologist to reproduce, in dealing with his laboratory problem, the actual conditions of ordinary daily motor activities more closely than occurs in the traditional forms of reaction time experimentation.

These newer measures of motor activities recognize the essentially fluid character of stimuli and reactions—their flux and flow within mutually interdependent continuous series. The stimulus constantly changes its nature and appeal, as the reaction process occurs; and the reactions, in turn, are always being adjusted to meet new conditions appearing in the stimuli.

Continuous discriminative reactions thus have their counterparts even in the early motor performances of the child, and they play an essential rôle in such simple acts as walking, manipulating objects, writing, and in fact, most of the responses of the individual to the world of things. They can be regarded as simple and basic indices of motor capacity, describing the motor efficiency of an individual with faithfulness limited only by the imperfect degree of standardization conditioning the measure. In the diagnosis, therefore, of motor weaknesses or incompetence, the performance of a subject in serial action may serve as evidence

of his ability to deal in a formal fashion with common situations demanding motor adjustments.

Furthermore, proficiency in serial action is a basic factor in the development of skill in many vocational and avocational pursuits, such as those of the musician, the stenographer, the telegrapher, or certain factory inspectors. All organized series of activities in which there occurs a continuous interplay of successive stimuli and corresponding reactions involve this type of motor capacity. And success in these complex achievements will be conditioned fundamentally by the underlying ability of the individual in this sensorimotor performance.

It is possible, therefore, that the psychologist can so strip the reaction process of its secondary features, and so control its variables, both subjective and objective, that he can secure, by means of a test of serial action, a useful index of motor capacity. For he can postulate that the individual showing superior ability in this measurement, will, provided other factors do not interpose, achieve success in these various complicated attainments; while the subject of poor achievement in this test will probably be disqualified for attaining success in those same activities.

The purpose of the present investigation, therefore, is, first, to secure a simple and practical device for measuring speed and accuracy in serial action; second, to standardize thoroughly the variables in the procedure, thus leading to the gathering of reliable data; and, third, to measure the performance, in this test, of certain representative groups of persons. We may then be in a position to judge whether a test of this character possesses any utility for meeting certain problems of a clinical, vocational or industrial nature, wherein such sensorimotor capacities are involved.

For the apparatus used in the following tests, a simple commutator, serviceable in conjunction with many kinds of visual and auditory stimuli, has been attached to an ordinary typewriter, the keys of which were manipulated by the subject. In the procedure, as many of the numerous variables as possible were eliminated or at least considered, with an eye, however, constantly

to practicability more than to laboratory infallibility. Four groups of subjects have been tested with this device: first, a group of 152 university sophomores who at the same time were taking seven other tests of motor capacities; second, 173 members of the Army Vocational School, who were beginning the army training for radio-telegraphers; third, 90 students in the schools of music at Northwestern and Iowa Universities; and fourth, 237 students in stenographic and commercial courses in Des Moines and Cedar Falls, Iowa. An effort is made, in each case, to discover the closeness of relationship between performance in the test and achievement in the vocational pursuits involved, by means of practical criteria.

*An Historical Resumé of Serial Action
and Related Experiments*

The first experiments to measure the speed and accuracy of serial action were the card-sorting tests used by Bergstrom in 1893 and by Jastrow in 1897. The former (8, p. 356) introduced two methods of sorting a pack of cards into three piles, for the purpose of studying interference in practice. The latter (40) recognized in card-sorting a test of wide applicability. He devised a box containing eight compartments, in two rows of four each. A small set of twenty-four cards, or a larger of forty-eight cards, designed, sized and marked to facilitate speedy manipulation, was used for distribution into the correspondingly designated boxes. The symbols used for the classification consisted variously of eight numbers, letters of the alphabet, geometrical forms, and other designs. The subject held the cards, backs up, in his left hand, and distributed them while the experimenter gauged the time for the total performance with a stop watch. This type of test, with numerous variations in details, has been used by many later investigators, such as Bagley (4 and 5), Culler (22), Woolley and Fischer (82), Thompson (69), Whitley (76), Henmon (34), Link (46 and 47), Burt and Moore (14), Calfee (15), Cornell (21), English (28), Woodrow (79), and Weidensall (72). This form of serial action test has thus been extensively employed for many experimental, clinical and industrial purposes.

Laboratory apparatus for the automatic production of stimuli in series and the recording of serial reactions first appeared in the "psychergograph" devised in 1902 by Seashore (62), for "measuring mental work." This device consisted of a disc which revolved a distance of one one-hundredth of its circumference whenever any one of four reaction keys was struck, thus exposing singly through a small aperture in the screen above the disc, a series of one hundred visual symbols. Four kinds of stimuli, distributed in chance order, made up these symbols; and four fingers (the index and middle fingers of each hand) were associated with the respective stimuli. A multiple recorder for registering the time and the character of each reaction was attached. Seashore's aim was "to devise means by which it shall be possible (1) to call forth a relatively simple and definite complex of mental activity; (2) to repeat the same for any desired length of time without interruption; and (3) to measure (a) the amount of work done, (b) the time taken, (c) the quality of the work, and (d) fluctuations in speed." The subject faced the following simple problem: "Given, one of four known signals, to recognize it and make the corresponding one of four simple responses." Following this method, Florence E. Brown in 1904 made some experiments on "mental fatigue," to which reference will be made below.

In 1907, Coover and Angeli (20) investigated the effects of practice in one type of serial action—Jastrow's card-sorting—upon efficiency in a related form of the test, arranged as follows. Attached to the carriage of a Blickensderfer typewriter was a strip of paper on which had been typewritten a series of the four letters, a, t, e, and n, in chance arrangement. Over the typewriter was fitted a screen, with an aperture of such diameter as to permit only one letter of the series to be seen at a time. Since the spacing of the letters in the series was the same as that of the typewriter action, the strip on the carriage could be so adjusted that for each stroke of a key, a new letter appeared in the aperture. The subject simply placed the index and middle fingers of both hands on the keys marked respectively a, t, e, and

n, and responded to the successive stimuli by striking the corresponding keys. The time of reaction to each letter was recorded in another room by means of a kymograph.

McComas (49) in 1917 experimented with serial responses to differently colored lights, obtaining 10-minute records from a number of subjects. Through a small window in a screen were visible four differently colored electric lights, which were illuminated successively, and in chance order, by means of an automatic switchboard. The subject manipulated four telegraph sending keys, which were so wired that each of the four reaction movements broke the circuit by which one of the bulbs was illuminated, and at the same time made a circuit which actuated a marker on the kymograph. Having learned the proper associations between the lights and their corresponding reaction keys, the subject proceeded to extinguish the successive lights as rapidly as possible by pressing the respective keys. A series of sixty stimuli, each following upon the heels of the preceding reaction, was thus presented before the order of their appearance had to be repeated.

The serial action experiments of these investigators, although varying widely in purpose, method, exactness, character and complexity of stimulus and response, and other factors, all belong to the "B" type of reaction (Donders), in which the stimulus must be discriminated and the movement selected accordingly. Continuous reactions by the Donders "C" method, involving the discrimination of the stimulus and choice between movement and no movement, have also been the subject-matter of experiments. Dockeray (26) in 1915 measured "mental efficiency" over periods of sixteen minutes each, by means of four telegraph sounders, operated respectively by four keys under the control of the experimenter. The subject sat at a table with his hand on a reaction key. The experimenter, in beginning the test, operated one of the sounders several times in rapid succession, as a signal, to designate the particular sounder to which the subject was to react. The four sounders then followed each other, in chance succession, one second apart, for a period of one minute. The

subject, discriminating the successive sounds, pressed the reaction key only in response to the sounder which had been designated. At the end of one minute, the experimenter signalled with a different sounder, to which the reactions of the following minute were to be made. The omissions and errors in reacting, and not the reaction times, were recorded. The purpose of Dockeray in these tests was to gauge mental efficiency before and after a period of physical work.

While these experiments compose a unique group of investigations, all involving the successive presentation of stimuli, one after another, each of which is disposed of, as it were, by a characteristic mode of reaction, there is a considerable number of other tests sharing with them certain general processes. Classifying them generally under such heads as tests of "association," "perception and attention," "discrimination," or "learning ability," psychologists have introduced many "cancellation," "code," "substitution" and "motor coördination" tests, which should here be briefly considered.

The "substitution" test, particularly in that form known as the digit-symbol (or symbol-digit) test, has been used repeatedly for studies of "the speed of formation of new associations." The stimuli for which the associated elements or designs are to be substituted have consisted variously of: 20 letters of the alphabet associated each with one of the other letters (Longh, 48, Kirkpatrick, 42); the 26 letters associated with numbers (Jastrow; Starch, 66; Dearborn, 24); symbols, including the star, circle, square, cross, and triangle, each enclosing a digit for association (Woodworth and Wells, 81); nine such kinds of symbols similarly associated with digits (Dearborn, 24; Healy and Fernald, 33; Whipple, 74, I pp. 496-515; Pyle, 60; Pintner and Paterson, 57; Pintner, 56; Pintner and Toops, 58; Woolley and Fischer, 82; Army "Beta" and "Performance" tests); words to be coded into groups of short, horizontal lines, in accordance with a scheme applied to the alphabet (Gray, 32; Baldwin, 6); the dissected Maltese cross with the number 1, 2, 3 and 4 placed in the sections (Squire, 65; Carpenter, 16); three kinds of geo-

metric forms given in two different colors, associated with the the first six digits (Squire, 65; Carpenter, 16); five kinds of geometric forms, exposed for 10 seconds, together with five digits (Anderson and Hilliard, 2); and pairs of multiplied numbers to be associated with their respective products (Thorndike, 70). In all of these "substitution" tests, the stimuli are presented *en masse* in company with their associated designs; but three diverse methods have been followed with respect to the length of time during which the key or standard is exposed. Whipple, Woolley and Fischer, and Healy and Fernald permit the subject to refer repeatedly to the key during the forepart of the performance, and at the end determine how well the associations have been stamped in, by removing the key. Gray, Squire, and Anderson and Hilliard expose the key for only a certain brief period, and upon its removal, the subject proceeds to make his responses from memory, by logical analysis, or by whatever means of recall he finds serviceable. Most of the other investigators permit the subject to utilize the key throughout the test. The first of these methods occupies a middle ground, with respect to difficulty, between the second and third, which are respectively the most complex and the simplest.

But even in its simplest form, the "substitution" test exceeds in complexity the serial action experiment. The stimuli are generally more elaborate, the associations more numerous and artificial, and the responses include the reproduction of designs instead of the simple stroke of a key. As a result, the time per reaction is greater, the "learning curve" is steeper, individual differences appear more extensively, and the variability in records is wider.

When the process of "substitution" is directed by reference to organized memory images or to conceptual processes, rather than by attention to a discrete series, either present to sense or recalled in terms of simple imagery, the test becomes analogous to the "Civil War" code test, used by Goddard (31), Terman (68), Healy and Fernald (33) and Chassell (19) in their classified mental tests.

In the less complex form of "code" test, the subject is given a very simple design, with only a small number of associations, as in the MacMillan "cross-line" tests, used by Healy and Fernald (33), and by Brigham (13, pp. 184-5), and the similar test employed by Wyatt (85, pp. 125-7). The responses, as well as the stimuli and the associations, are simplified by Healy and Fernald, who require the subject merely to designate the digits which are represented by the various sections of the diagram drawn by the experimenter, rather than demanding of him the active reproduction of some complex code message. In the Civil War code test, experimenters have found that the most significant process involved is, not the utilizing of a particular kind of imagery, but the need of an intense, purposive attention, inwardly directed for the analysis and association of the problem in hand. The improvement appearing with practice in the code test has been brought out by Dearborn and Brewer (25), requiring the subject to write long passages in terms of the code language.

Another group of related tests, generally called "cancellation" tests, require the rapid striking out, or cancelling, of certain letters, numbers, groups of letters or numbers, parts of speech, or other units, from a page of heterogeneous stimuli. As is evident from the summary made by Whipple (74, I, pp. 305-6), the psychological elements involved have been differently analyzed and interpreted by different experimenters; and this lack of concord may be partly due to the wide individual differences which, as Hollingworth (38) concludes, characterize performance in the test. A more elaborate form of test, using numerals, was developed by Taylor. The arabic numbers, from one to fifty, were scattered irregularly over the surface of a small sheet of paper. The subject then connected the numbers by drawing lines, beginning at one and continuing up to fifty; or in the form of this test used by Benedict, Miles, Roth and Smith (7), he simply pointed successively to the numbers in proper order. The use of spoken and written language in allied tests of association and discrimination occurs in such methods as the naming of colors or forms displayed successively; or the speaking or writing of words associated with those on a given list.

Various "motor coördination" and "dotting" tests are also related to serial action. In Dearborn and Brewer's (25) "Complex Dotting Test," each square on a sheet of coördinate paper bears a digit—one, two or three—indicating the number of dots to be placed therein by the subject. Woodworth's (80) subjects made efforts to strike rapidly in succession, with a pencil, the centers of squares, one-fourth inch in diameter, on coördinate paper. Following a suggestion from Whipple, the Healy and Fernald (33, p. 42) "Motor Coördination" test requires the placing of a dot in each of 150 half-inch squares on similar paper. In these tasks, simple discrimination and selective response are complicated by the need of precision of movement, and hence these tests seem to occupy a ground between serial action and the so-called "target" tests.

In considering the relation of these numerous "substitution," "code," "cancellation," or "coördination" tests to serial action, certain fundamental characteristics are found common to both the former and the latter. Broadly speaking, the entire group involves a "reaction" process, more or less analogous to that in the classical "choice reactions." Thus the "substitution" and serial action tests present similarities to the reaction experiments by Donders' "B" method, wherein each stimulus requires a selective reaction in accordance with a definite associative process. The "cancellation" tests demand repeated choice between movement and no movement, as in the Donders' "C" method. The more complex tests are usually types of "association reactions." In the code tests, however, the relationship is more remote: the stimuli appear *in toto*, as words or sentences, to be so retained, analyzed, and associated, unit by unit, with corresponding elements of some other retained, represented, analyzed and associated scheme, as to result in a series of appropriate complex responses. In this situation, the central process bulks so large and becomes so intricate as to minimize the parts played by sensory and motor factors. It is the bold features of these various tests which proclaim their relationship to reaction experiments; and they all vary from their prototype in the continuous, rather than isolated, character of the reactions demanded.

A second fundamental characteristic of the group is the demand for that "close attention and steadiness of purpose" which Healy and Fernald (33) found essential to the transliterating of words into a code in the absence of the code alphabet. As Woodworth and Wells (81) remark in their discussion of "measures of mental alertness," "In a test of either free or controlled associations calling for a series of responses in quick succession to a series of stimuli, the speed of the performance depends on maintaining the proper adjustment throughout the series, in opposition to the many interfering tendencies generated by the successive stimuli." A unity of purpose, signified by an alert attention, must bind together the concatenated responses. Distractions continually appear, whether caused by competing irrelevant letters, as in cancellation, or disturbing imagery, as in the code test, or the conflicting associations of the substitution test, or that anticipatory "set" which tends continually to assert itself with false prophecies, as in serial action. The efficiency and inefficiency of attention is reflected in all the tests by processes of "overlapping," and "interference"—the former characterized by a synthetic organization of the reactions, so that perception and discrimination of the new stimulus take place while the reaction to the previous stimulus is still under way; and the latter occurring when conflicting irrelevant associations accumulate and interpose with false leads, resulting in confusion and error. The successful performance of all these tests, therefore, involves a riveting of attention to relevant factors despite a host of distracting rivals. Accordingly, Meumann's (51, p. 393) insistence that the cancellation test is at bottom a measure of capacity for observation in line with a definite purpose, would largely apply to these related tests.

In comparing serial action, as outlined above, with these "substitution" and other related tests, certain general differences also appear. The fundamental distinction to be drawn is that, while the related tests involve various complications of attention, and of association and response, the serial action test strips the process of as many secondary and acquired features as possible.

Specifically, in serial action, the visual field presents to attention only one discrete stimulus, which cannot be succeeded by any other until a discriminative response has been made to it, while the other tests set the relevant stimulus in the midst of an array of foreign appeals, including the stimulus which will next demand a response. This simplifying of the situation in serial action becomes apparent also in a comparison of the characters of stimuli, associations, and reactions. In related tests, the stimuli consist of letters, symbolic designs, numerals, diagrams or other characters savoring of the academic. The real complexity of such characters, quite unrealized by the literate observer, becomes apparent when a totally illiterate subject faces the test, as occurred repeatedly when unschooled army recruits were helpless in dealing with the "Digit-Symbol" test. The tendency in the development of serial action tests has been to approximate the simplicity of the simple reaction, in choosing the visual or auditory stimuli. The associative processes, moreover, are to be stripped down to fundamental, natural coördinations. The object is not to measure the time required to form certain intricate, arbitrary associations, but to gauge the native efficiency of the subject in those associations which need only be pointed out in order to be permanently acquired. A similar contrast is apparent in the nature of the respective motor expressions. While the other tests employ such fine coördinations as occur in writing, and involve such uncontrolled variables as the extent, fineness and accuracy of pencil marks, serial action reduces the various responses to their simplest terms, following, once more, the character of the simple reaction. Thus, instead of employing the motor refinements of a single hand or member, serial action tests seek out the motor capacities of various members, in their simple, basic forms. And thus, while the "substitution" tests are of service chiefly in exemplifying the learning process, and while the "cancellation" test bears a somewhat complex and varying relationship to attention and perception, the serial action measurement takes its significance from its isolation of a basic "personal equation" in motor capacities.

*Conditions Affecting the Time and Character
of Serial Action Measurements*

Before undertaking to standardize a test of serial action and harvesting data for comparative purposes, it is essential that the experimenter should appreciate the enormous number of variables, both objective and subjective, which are involved in any reaction test, and the extreme sensitiveness of the time measurements to every factor in the situation. On the basis of the multitudinous reaction experiments of the past fifty years, therefore, a summary of the chief conditions which have been found to play parts in the reaction process should be made, even though it be rough. In thus sifting the available data, the point of reference is, throughout, the applicability of these considerations to the particular type of reaction measurements involved in this investigation.

Objective Factors: (1) *The Stimuli.* Summaries of the relationships between reaction time and the quality, intensity, duration and extensity of the stimulus have been made by Wundt (83), Jastrow (39), Ladd and Woodworth (45), Todd (71), Henmon (35), Wells (73), and others. Thus in comparing the data from disparate senses, it is found that simple reactions to auditory stimuli are quickest; to tactual stimuli, intermediate; and to visual, longest. Wundt adds (83, p. 429) that the 'differences in the different senses disappear in the neighborhood of the threshold.'

With reference to intensity, there is also some agreement. Wundt, (83, p. 428-30) found that the reaction time decreases rapidly as the stimulus rises in intensity above the threshold, but reaches a plateau where it remains constant despite greater intensity. Froeberg (30) laid down the law that, within the middle range of visual reactions, the reaction time tends to increase arithmetically as the intensity of the stimulus decreases geometrically; in auditory reactions, he found a somewhat proportional shortening of time with increase in intensity. Dunlap and Wells (27) did not entirely corroborate these relationships.

The size or extensity of the stimulus seems to be significant,

Froeborg (30, p. 23-4) formulating the general law that the time of reaction increases with decreasing size of the visual stimulus.

Wundt asserted (83, p. 430) that, apparently, in all the senses a very brief stimulus produces a quicker reaction than one distinctly continuous. Froeborg (30) stated that the time of reaction increases with decreasing duration of the stimulus. In 1913, Wells (73, p. 59), using successively and not indiscriminately, auditory stimuli of various lengths, found that their duration did not materially affect the reaction times. The results of his visual experiments were equivocal, very small differences being apparent. However, the suggestion was that the reaction time decreased regularly as the duration of the stimulus decreased.

In considering the relation of the attributes of sensation to the time required for reactions, several experimenters have pointed to the "dynamogenic effect" of increased or diminished intensity, extensity and duration of the stimulus.

When the reaction involves a "cognitive" process in addition to perception, it is found that the cognition of qualities occupies a shorter time than that of intensities. The cognition of direction or position, whether visual, auditory or tactual, requires less time than that of the corresponding quality or intensity. Experiments show that the cognition of distance from our own body, by means of sight, consumes the same average time as the cognition of visual qualities. Various considerations are summarized by Külpe (44, p. 417).

The investigation of "discriminative" reactions yields proof that the discrimination of the positions of two or more stimuli is extremely rapid. Thus Bourdon (10) discovered that it was easier to perceive that a color was at the right or at the left of another color, than to perceive that it was identical with, or different from, another. Successive discrimination has, in general, been found more difficult than simultaneous discrimination.

However, in all "discriminative" reactions, the primary factor in the reaction time is the relative difference between the stimuli; a secondary factor is their absolute difference. The more similar the stimuli, the more difficult is the discrimination, and the longer

the reaction time. In the words of Woodrow (78), "As the difficulty of discrimination varies, there is a variation in the corresponding discrimination reaction times." If the objective differences are decreased successively by equal amounts, the reaction time is lengthened proportionally, until the threshold of discrimination is approached. The explanation of this relationship seems to be two-fold: (1) If the stimuli are very similar, complete apprehension of them is necessary before the reaction can occur; and (2) under the more difficult conditions, the preparation to react quickly is less thorough-going, and innervation is not so completely accomplished.

Absolute differences between the stimuli are also significant in determining the time of discriminative reactions. From his experiments with the "chain reactions" of six subjects, wherein the particular reactions were determined by the discrimination of the lengths of lines, Münsterberg (53) found that the reaction times decreased somewhat as the absolute differences between the lengths of the lines were increased. He concluded that "for our subjective discrimination, therefore, the stronger effect of the relative differences of stimuli is constantly influenced by the weaker effect of the absolute differences in stimuli." Henmon (34, p. 53) corroborated this conclusion but found the influence of absolute differences not as pronounced as had Münsterberg.

The time of discriminative reactions having been found to vary in accordance with differences in stimuli, Cattell (18) proposed to apply the principle in a broad way as a new psychophysical method. As described by Henmon (35, p. 31), this method would proceed on the assumption that "differences in sensations should be equal if it takes equal time to perceive them, while if the differences are unequal, the greater the difference, the shorter the time of perception. By this method, it should be possible to arrange in accurate series, groups of differences in quality, or intensity, in every department of experience, simultaneously or successively perceived." As early as 1893, Cattell had applied this principle to the study of the time of perception of differences in intensity. Henmon (34) in 1906 carried the

method into the fields of discrimination of differences in color, in the length of lines, and in pitch. He later asserted (35, p. 31) that "the fact shown in all these experiments that the discrimination reaction time varies uniformly with the differences to be distinguished, suggests the possibility of a wide application of the method in individual psychology, comparable with that of the association reaction already accomplished."

In the more complex discriminative reactions, such as those involving letters, figures or other symbols as stimuli, clearness of outline plays a very important role. Numbers require longer reaction times than do colors, or rectangles of various sizes, according to Bourdon (10). Any test based upon the discrimination of such stimuli lends a primary advantage to literate subjects, since they readily grasp the character of the symbols.

The greater the number of possible impressions, the longer is the reaction time. That this lengthening of the time is partly due to the process of distinction between the various impressions, and is not entirely dependent on the number of associated movements, has been shown by the use of "incomplete" or "subjective" methods, wherein the number of distinctions is varied while the number of movements remains constant. The experimental work of Cattell, Friederich, Tischer and others (39, p. 35) points to "a slight increase of distinction time with the increase of the range of impressions, but complicated with other factors as well."

In all reaction measurements, the latent time of the stimulus must be considered. A standard tachistoscope involves a latent time of perhaps 3 sigmas.

(2) *The Reaction Movement.* In spite of frequent criticisms, the telegraph key has been generally used for registering reactions (83, p. 390, footnote). Many other forms of keys and reaction movements have, however, been tried out. In his study of various reaction movements by means of graphic records, Williams (77, p. 102) found proof that "the form of key has a marked influence on the reaction time," and also upon the character of the attention.

Both the "lift" and the "press" type of reaction have been

widely used. The former entails the disadvantage of frequently involving "antagonistic reactions." Williams (77, p. 149) found that "reaction time work which is done with the 'press' reaction will be free from the complications due to the antagonistic movement." On the other hand, Breitweiser (11, p. 46) concluded that the resistance offered by keys in the "press" reaction is an important variable, since, within certain limits, the greater the resistance, the longer the reaction time. For the "lift" form of movement, variations in resistance naturally affect the time only in a very slight degree. Breitweiser did not confirm Féré's conclusion that when the subject knows beforehand the weight to be encountered, the length of the reaction time will not vary with the weight.

The amplitude of the movement also has a bearing on the character of the result. In discussing reaction movements, Wundt (83, p. 390) states that "the combined movement of arm and hand, considering the natural use of which it takes advantage, is to be preferred, because it not only is accomplished the most rapidly, on the whole, but also may be repeated for the longest time without fatigue." The amplitude of movement, however, like the resistance offered by the key, must be strictly limited and uniform throughout a series of measurements, if fast and reliable reaction times are to be secured.

A certain excess force is usually exerted by the subject in making reaction movements, sometimes thus reflecting his habitual energy in responding to stimuli. Breitweiser (12) found, in his experiments with the variable in the manipulation of reaction keys, that the excess force "did not seem to vary in a marked or definite way with the resistance" of the key. This characteristic ponderosity and surplus force in the reactions of some subjects may point to individual differences in motor control which justly are reflected in lengthened reaction times.

Although wide experimentation has been carried on regarding the comparative reaction times of the two hands, universal agreement is lacking in the results of the various students. Tischer, Merkel and Cattell found the reaction time approximately the same for two hands. Poffenberger (59, p. 65) concluded, with

respect to both Kiesow's data and his own, that "there is a difference in the reaction time of the right and left hands, in the subjects tested." He found (but with very slight difference) that in the right-handed subjects, the right hand is somewhat faster than the left; while the case is *vice versa* with the left-handed persons.

According to Henmon (35, p. 11), however, there seems to be general agreement that "in motor reactions, and in choice reactions, the differences are insignificant."

In measuring the reaction time of each of the five fingers, with simple reactions, Münsterberg (52) found that while at first the thumb and little finger reacted more slowly than the others, after some practice the times of all were substantially the same. Féré, however, gathered some data suggesting that the fingers making the strongest movements react in the shortest times. In 1910, Kiesow (41), using auditory stimuli, made a series of experiments on the reaction times of each of the ten fingers. Fifty reactions of the sensory type were made with each of the five fingers of each hand. The results showed that, in the right hand the speed of reaction of the fingers, from quickest to slowest, ran in the order: third, fourth, first, second and fifth. In the left hand, the order was: fifth, first, third, fourth and second. The differences between the respective times were very small throughout, while the mean variations ran from 13 to 19.5 sigmas. With respect to the relative speed of the fingers, the generally accepted point of view among experimenters has been that the reactions of unpracticed or slightly-used fingers are the longest.

As demonstrated by Merkel and others, the time of the choice reaction varies directly with the number of possible movements coördinated with corresponding sensory cues. If the difficulty of discrimination remains constant for all the series an increase in the number of choices, from two progressively to ten, lengthens the reaction time consistently until, with ten movements, it has been found to exceed the time for a "cognition" reaction by 300 or 400 sigmas. Külpe (44, p. 419) explains this result by the fact that "the degree of liability of reproduction and the quickness with which it is realized by connection in the

particular instance, are certainly dependent upon the number of equally possible connections—and the greater their number, the greater will be the inhibition or retardation of the individual reproduction." It has been shown that if the associations between stimuli and movements be very natural and simple, an increase in the number of movements will not have a very marked effect upon the length of the reaction time.

From the experiments of Seashore, Coover, and McComas it is evident that, in tests of continuous discriminative reactions, the most convenient and satisfactory number of movements is four. Less than that number brings into consideration too high a degree of anticipation, while more than four movements has proved to be cumbersome and confusing.

Subjective Factors.—The character of the instructions and their manner of presentation are profoundly significant for the performance; and this importance extends to the minute details of phraseology as well as to the main principles given to guide the subject's behavior. The wide differences and the high variability shown in many reaction measurements are partially due to the variations in the completeness, the emphasis, and the clearness of the directions. The continual use of spurs—such as telling the subject the best time he has made, or encouraging him to break another individual's record—is extremely effective.

Closely bound up with the general character of the instructions is the "charge," or the degree of effort induced into the subject's attitude. By proper suggestion, the energy and application of the subject can be maintained at a maximum. While a certain tedium or monotony appears in reacting to isolated stimuli, continuous reactions call out a spontaneous and sustained interest; as McComas (49) remarks, the subjects consider it "fun" to plunge into the test and rush through the ever-changing series of responses.

The great importance of expectation on the part of the subject has been emphasized by Wundt (83, p. 435) and others. For fast and steady reactions, the reagent must be familiarized thoroughly with the stimuli. Jastrow (39, p. 39) formulated the general law that "the more definite the foreknowledge of the

subject, the quicker the reaction." The increase in time when any factors relative to either the stimuli or the responses are not explicit has been made very patent by various cognition and discrimination experiments. Anticipation is inextricably interwoven with expectation in the subject's attitude; that is, he not only knows the characteristics and details of his prospective task, but also predicts the precise nature of each next-appearing stimulus, and prepares a corresponding reaction. Out of such forecasting develop premature, delayed and wrong reactions. Some preliminary trials are usually necessary, in order to clear up and define the subject's expectation. These initiatory reactions at the same time can supply the place of the "shock-absorbers" suggested by Link (47, p. 155) for introducing the subject to the test.

That the time of reaction is a function of the degree of attention has long been a demonstrated fact. Thus Dallenbach (23, p. 507) states that "introspectively distinguished variations of attention (*i.e.*, clearness) are closely paralleled by corresponding differences at the same level in accuracy of work performed, in rate of reaction, and in degree of precision as expressed by the *m.v.*" So intimate and regular is this dependency that the time of reaction has been used by Woodrow (78) for measuring degrees of attention.

The complex reaction is considered by some experimenters to involve a nicer concentration of attention than does the simple reaction. Thus Henri (37, p. 245) proposed the use of discriminative reactions for the study of attention, pointing out that the "mean variation, the time, and the irregularities in the curve of reactions will give a relative idea of the state of attention with the subject."

Out of the long dispute regarding the real significance of the "direction of attention" in simple, and also in complex reactions, there has grown general agreement that, as Woodrow (78, p. 14) declares, "a time measurement cannot be a satisfactory measurement of efficiency except when the work is done with the sole idea of doing it as quickly as possible; as, for exam-

ple, in the case of a 'motor' reaction." Among the chief objections to the use of "sensory" reactions in the tests may be mentioned: the complication of the reaction by adding observing to reacting (Breitweiser); the fact that the sensory form tends to change with practice to the motor form (Ach); the varying degrees of determination to react as quickly as possible (Ach); the ambiguity of the instructions, which leave to the observer the task of determining the promptness with which to react (Woodrow).

Somewhat analogous are the objections to the use of any possible "sensory" form of complex reaction, as suggested by Münsterberg. It is indeed evident that in reactions after discrimination and choice, the attention should be bound down to specific functions, which cannot well be varied: First, for discriminating the particular sensory impression received; and second, for inaugurating the appropriate movement. This delimitation of attention is particularly effective in ordinary complex reactions because: (1) the performing of each reaction is a discrete problem, preceded by a definite preparatory stage; (2) the associations of stimuli—such as colors, words or sounds,—with movements are usually somewhat artificial; and (3) the number of reactions made is not usually great enough to stamp the characteristics of an automatism—or "automatic coördination" upon the performance.

Investigations of the function of attention in continuous discriminative reactions have shown that some modifications of the attentive process appear. Instead of consisting of an aggregation of isolated reactions, each characterized by the preparation and sharp focalization of attention, the whole series of movements becomes unified by a common purpose and by an habitual attitude, just as in the fused serial actions of daily life, like reading or playing a musical instrument. Experimenters therefore find an "overlapping" process occurring, by which a flow, rather than a chain, of reactions takes place. The discriminative and the volitional processes in the subject's responses are somewhat "telescoped." In this kind of serial adjustment, "inter-

ference" also appears, as the associations accumulate. The attention moves along, with the consciousness of new stimuli impending over the present responses, and a varied finger-play accompanying the shifting signals. Thus a "motor" type of attention develops, in an efficient subject: that is, an attention directed predominantly neither to stimuli nor to reacting members, but to achieving a seriated adjustment as rapidly as possible.

In continuous reactions, furthermore, the number of reactions usually aggregates so great a total, that "automatic coördination" develops, and attention is liberated for dealing more synthetically with the discriminative and selective processes.

As analyzed by Külpe (44, pp. 418-19), the certainty of the association between impression and movement may be (1) originally given as a result of previous individual development; (2) consciously effected by practice, or (3) involuntarily produced by repetition in the course of the experiments.

The associative connection of reaction movements with definite directions in space is particularly easy, making use, as it does, of previously developed habits. Bourdon's (10) experiments with colors, numbers, and sizes, in which reactions were made by the right or the left hand to the corresponding one of two stimuli, showed in a marked way the "close association which exists between the sensation at the right and the movements of the right hand, or between that at the left and the movements of the left hand." He found, for example, that if the association be reversed, and the stimulus at the right be reacted to with the left hand, the reaction times were, on the average, 50 sigmas longer. The direct association of position with hand was found to be so strong that reaction with the right hand to a red stimulus when it appeared at the right was just as rapid as a simple reaction to red. He concluded that "there exists normally an intimate association between the sensation at the right (or left) and movements of the right hand (or left). Ordinarily, when we grasp an object situated at the right, it is with the right hand." Anatomically, as Poffenberger (59, p. 64) points out, the right hand is most directly associated with objects

in the right visual field—that is, with the left-half of the retinal field of each eye.

The simpler and more natural the association between stimulus and movement, the shorter the reaction time. Thus Münsterberg (52) found that the reaction times for the five fingers, when associated respectively with the numbers 1, 2, 3, 4, and 5, were considerably shorter than the times of the same fingers when associated with the declensional forms of a Latin noun. Simple associations also involve less probability of the entry of superficial or adventitious complications; and they lead to better initial performances and less pronounced improvement curves than do the more complex types.

Although the subjective factors in reaction measurements be standardized as thoroughly as possible, yet more or less pronounced inherent differences in the attitudes of subjects continually appear. In accordance, perhaps, with Meumann's (50) two-fold classification of reagents—the "impulsive" type, persons of will, whose motor development has been vigorously extended, and the "intellectual" type, consisting of the observant and reflecting group,—subjects seem to fall naturally into either of two characteristic attitudes, when continuous discriminative reactions are undertaken: they either actively "push" the signals along by means of vigorous reactions, or else passively follow their beck and call. The experimenter puts a premium on the former type of reagent. This stress upon the greatest possible speed must be tempered by a recognition of the difference in native capacity and habitual performance. Some allowance or "leeway" must be granted the subject, in the direction of Stern's (67, p. 86) position: "For differential psychology, 'maxima' are not unimportant, but much more significant for it are 'optima'; that is, such performance-values as are indicative of the natural inner disposition. The method followed in the latter cases runs thus: 'make your behavior now what seems most natural and agreeable.' Not the fastest rate of speed that an individual can attain under the pressure of great haste, but the natural pace which he selects for proceeding, when he is not

subject to temporal considerations, is indicative of his temperament."

Practice and Fatigue.—The time of both simple and complex reactions decreases with practice, rapidly at first, but tends soon to approximate a limit. The greatest decrease occurs in the time of those processes which are most complex and of greatest initial duration. The "sensorial" form of reaction shows the greatest improvement in speed, and its character at the same time seems to approach that of the "motor" reaction (Wundt 83, p. 419). In their study of the types of reactions, Angell and Moore (3) found that "continued practice in the two modes of coördination with a constant stimulus, under constant conditions, results in two highly reflexive forms, not of widely different, but of about equal time values." The "motor" reactions remained a little the faster.

With practice in simple reactions, a kind of "automatic coördination" of impression and reaction develops. Following longer practice, the same coördination is built up in complex reactions, thus gradually eliminating the psychical processes and giving to the reactions a generally physiological significance. Wundt (83, p. 471) found that this tendency toward automatism develops most readily in persons of naturally "abbreviated" mode of reaction. It appears most rapidly in those experiments where the number of impressions and of movements is small, and the associations between them are natural.

Diversity of opinion reigns with respect to the influence of practice upon individual differences. The experiments of Wundt (84, p. 222) and his collaborators, especially Alechsieff (1, p. 15 ff) led the former to conclude that "when the experiments are carried out with proper care, these individual differences (which belong to the discussions of psychological character-ology) disappear more and more. As the individual differences disappear, the influence of the variable conditions, such as differences in preparation and in the direction of attention, become clearly apparent."

On the other hand, the experiments of Henmon and Wells (36) showed the persistence of distinct individual differences in

the simple and complex reactions of two long-experienced subjects. "Of the fact of these individual differences, preserved long after practice could essentially change them, there can be no dispute. . . Distinct individual differences also exist in the discriminative or choice reactions, but in the opposite direction from those of the simple reactions."

In reaction experiments, fatigue manifests itself through a lengthened reaction time, greater variability, fluctuations of attention, and, in complex reactions, an increased number of errors. Since the first investigations of Exner (29) upon the effects of fatigue, the improvement in performance due to practice has been regarded as somewhat offset, in any continued series, by a deterioration due to fatigue.

The extent of this decline in efficiency, when long series of reactions have been made, has generally been found to be relatively small. Cattell (17) conducted a number of experiments to determine the precise effects of fatigue. In the most thorough-going of these, 1950 reactions, consisting of a combination of different groups of reactions—to light, white surface, letter, association and sound—were made without interruption during the day, from 8:30 a. m. to 11 p. m. in B's series, and to 1:30 a. m. in C's series. Only very slight changes attributable to fatigue were apparent in the results. Similarly Patrizi's (55) series of tests, in which only two seconds intervened between successive reactions, showed a very slight lengthening of time and increase of variability. From allied experiments, Woodworth (80) concluded that the central apparatus for the precise adjustment of a movement is susceptible to fatigue, but only slightly so.

Cattell found that the most automatic processes were the least affected. To determine the rate of fatigue of different factors—attention, accommodation and convergence—Scripture (60) produced flashes in a Geissler tube, at regular intervals, and the subject pressed his key in response to each flash. It was concluded from the experiments that "the fatigue in reaction time increases with the complexity of the adjustments required for

perceiving the stimulus," and that "the tendency to fall into a condition of daze depends on the fact of repetition of stimulus (fatigue of attention) as well as fatigue from adjustments."

The analysis of achievement in two-hour periods of continuous reactions led Oehrn (54) to conclude that, first, occurred a stage in which practice outweighed fatigue, and then a stage wherein fatigue was dominant. On the basis of their immense number of experiments—particularly with the continuous addition of columns of digits—the Kraepelin school analyzed the "work curve," finding characteristics which generally are applicable to serial action. Fundamental in every continuous process, they held, were the effects of practice and fatigue—immediate effects, and permanent effects. Among secondary factors were the preliminary incitation (*Anregung*), the preliminary spurt (*Antrieb*), a fall preceding the best achievement of the work-period (*Ermüdungsantrieb*), a periodic succession of spurts and falls in performance (*Willenspannung* and *Störungsantrieb*), and a final spurt (*Schlussantrieb*) occurring if the subject discovered that he was near the end. An analysis of each of these processes was attempted. "Variations in attention" were seen in the wave-like periods extending, from crest to crest, over about $2\frac{3}{5}$ seconds.

An intensive study of the characteristics of continuous mental work involving (1) sensitivity, (2) discrimination and (3) memory, was made by Seashore and Kent (64) in 1905. The general conclusions drawn from three widely divergent series of experiments were: "A thorough-going periodicity of mental activity" was found. "There is a continuous gradation from the period of the momentary active impulse up to the hour-long waves of mental efficiency. The efficiency in a given period, say two hours, may be represented by an irregular wave, the resultant of a series of partials." Three kinds of waves were found: (1) second waves, extending over not more than a few seconds; (2) minute waves involving more than one second wave, but less than 20 minutes long; (3) hour waves, whose periods lie between the minute waves and diurnal waves. In all

continuous work, progressive change, with respect to time, accuracy and variability, is found.

Individual types in efficiency of continuous work have been described by Kraepelin (43). Five typical kinds of "work curves" were discerned: In the first or "positive" curve, practice dominates the performance to the end of the two-hour tests given; in the second, fatigue is the dominant factor throughout. The third form of curve follows the trend of the first, but shows fatigue effect opposing the spurts of improvement. The fourth type illustrates the counter-balancing of practice and fatigue; while the fifth includes characteristics of the other types except the second.

In an unpublished study of mental fatigue by the use of the Seashore psychergograph, Florence Brown Sherbon at the University of Iowa in 1904, made a continuous series of "choice" reactions, totalling 16,000 in number, in one period of four hours and fifteen minutes. Characteristic of the time curve were: a high initial speed, a long period of constancy, a heavy drop in speed after 10,000 reactions, followed by considerable variability until the end of the "work." The number of errors increased and became more variable as the test progressed, to the close.

In his investigation of the accuracy of various observers in continuously performing a certain series of calculations mentally, and registering their results by means of a lip or finger-key, Yoakum (87) found a "fluctuating character" in the totals of errors per minute, the errors tending to group themselves. The error-groups persisted throughout practice; and were interpreted as evidence against "the possibility of considering mental work as anything apart from specific, coördinated, muscular responses." A condition of strain continually appears, and the shifting of the seat of the 'strains' leads to the production of a new center for the 'vis a tergo' sensations. This periodic transition shows—as is generally evident in consciousness—that "a center of kinaesthetic activity is calling for readjustment." (87. pp. 108-10.)

From his own experiments in distributing the physical expression of the work among various members, such as the fingers

and the lips, and from related experiments of Lombard and Hall, Yoakum (87, p. 107) concluded that "as a theoretical result, the fluctuations in errors, and mind wandering may perhaps both be largely eliminated by the arrangement of a series of tests that alternate the processes used in tapping the records. Thus the habitual working rhythm of the various subjects could be eliminated so far as concerns an inferior quality of work appearing at certain periods."

Apparatus and Method

The apparatus used in the following experiments consists essentially of a commutator attached to a typewriter in such a manner that every movement of a key on the typewriter completes one of four possible circuits, the order of appearance being determined by chance for a series of seventy-five reactions. In these four circuits may be placed any series of four stimuli, such as colors, forms, words, lights, tones, or noises. Four keys of the typewriter, in the middle of the keyboard (such as y, t, u, i, or 5, 6, 7, 8), are so marked as to be distinguishable, to both sight and touch, from the other keys. Each of the four keys is associated with one of the four stimuli. The subject then places four fingers—the index and middle fingers of both hands—lightly on these keys, and proceeds to make an unbroken series of "reactions after discrimination and choice," in the following manner.

Assume that the four keys, designated for convenience as 1, 2, 3 and 4, are associated respectively with four tonal stimuli of the same pitch, intensity and timbre, located in four easily discernible directions, 1, 2, 3 and 4. The experimenter then inaugurates the "work" by turning on the current, thus causing a tone, for example, in direction 2. The subject must identify this signal, and press the corresponding key, 2, as quickly as possible. By the consequent action of the typewriter carriage, the commutator is moved forward a step, and immediately produces the next signal, *e.g.*, 4. In response, the subject must press key 4, thus causing the appearance of the following signal. In the same manner, signal follows signal, each with its appro-

priate reaction, to the end of the line—seventy-five spaces. Meanwhile the typewriter keys have recorded the successive reactions, so that they can be checked over for accuracy.

Time is kept in gross for each line, with a stop-watch; or for certain purposes a graphic recorder is wired with the keys in such a way as to furnish a graphic time and error record for each act. Or, the starting and stopping of the stop-watch may be mechanically controlled by attaching its lever to the armature of a magnet which is so connected that the circuit through it is closed while the reactions are in progress. For most purposes, this is an unnecessary refinement.

The commutator consists of a brass plate (A, in Figure 1) which has seventy-five insulated contacts, arranged in four rows, with a contact brush (B) running in a groove over each row.



FIG. 1. The commutator

- A. Brass plate, overlaid with fiber surface.
- B. Contact brush, of spring-brass wire, running in grooves.
- C. Clamp attaching commutator to stem of typewriter.
- D. Common terminal through body of typewriter.
- E. Block of fiber bearing the brushes.
- F. Clamp attaching block to carriage of typewriter.

The commutator plate is attached by a clamp (C) to the back stem of the typewriter, with the contact-surface facing away from the subject. In these experiments, only Remington machines were employed; for use on other kinds of typewriters, the form of the clamp would have to be modified. The brushes (D), made of spring-brass wires, are fastened through an insulated block of fibre (E) attached by a clamp (F) to the carriage, so that with each stroke of a key the brush-carrier moves one step forward, thus shifting the circuit to a new line. In the arrangement of the contacts, a chance order is followed, except that no line is allowed two successive stimuli; and an equal number of contacts, with one exception, occurs on all the lines.

The wires attached to the four brushes lead to the corresponding terminals upon the signal apparatus, and each circuit is then completed through a battery, a rheostat, and the base of the typewriter. The current used in these experiments is simply taken from the 60-cycle, 110-volt alternating current which is the source of illumination in the university buildings. Beside being always available, this alternating current, when placed directly in circuit through telephone receivers, gives rise to a low, steady tone of pleasing timbre and uniform intensity. The rheostat is introduced in order to cut the voltage down for both visual and auditory experiments. A switch under the experimenter's hand enables him to produce the first stimulus precisely when desired.

The commutator and other apparatus used in the following experiments were so simple and reliable that they operated daily for many hours, during several weeks, without irregularities. Other commutator-standards, giving new orders of the seventy-five stimuli, could readily have been made, and substituted in the attachment without difficulty; but, for tests wherein each subject was given only 5 or 10 trials, such changes in order were deemed unnecessary.

As finally developed, after many preliminary experiments¹

¹Five kinds of stimuli were tried out and finally discarded in favor of the two described above. Auditory-motor tests based upon intensity differences were made, by mounting a single telephone receiver directly in front of the subject and so wiring the commutator brushes as to produce four tones of widely different intensities. In producing these tones, the primary circuit, which led through the commutator, was interrupted by a 100 dv. fork. The brushes were wired with coils of varying inductance, so that the secondary circuits which were induced and conducted through the receiver, produced four tones differing only in intensity. The subject was instructed to respond to the weakest tone by pressing the key farthest to the left; to the next in intensity he pressed the second key, etc.

The experiments with pitch differences were made with electric bells of widely varying pitch. The subject simply associated the four tones, from lowest to highest, with the four reaction keys, from left to right. Timbre differences were produced by varying the richness of the tones in four uniform bells, telephone receivers, or buzzers.


The auditory stimuli used in the first extensive series of tests were noises produced by four small electric buzzers located exactly as the telephone re-

the stimuli for these experiments were of only two kinds: auditory and visual, both demanding discrimination of position for the reactions of the subject. The signal apparatus for the auditory series consisted of four ordinary telephone receivers located respectively 90° left, 30° left-front, 30° right-front, and 90° right, in the horizontal plane of the ears, each at a distance of 45 cm. from the center of the subject's head. "Confusion points" in localization were avoided by this arrangement, and very little difficulty in the discrimination of the source of sound was ever reported. The low, even tones induced by the alternating current furnished very definite sensory stimulation to any subject of normal acuity. The intensity of the tones was such as to render them easily audible within a radius of four meters.

In their final form, the visual stimuli consisted of four ordinary candelabra electric lights, mounted side by side directly in front of the subject's eyes, in a horizontal position. The four reaction keys were then naturally associated by the subject with the four corresponding lights, in order, from left to right. The candelabra globes had been frosted; and when mounted, the distance between the centers of the two outside lights was 12 cm. They were located at a distance of two meters in front of the subject, and a large black background eliminated reflection or other distracting factors. By these arrangements, accommodation and convergence were easy and natural, and movements of the eyes in following the shifting lights were minimal.

Since the alternating current used was the same as that employed for auditory stimuli, a simple switch was introduced, by

ceivers described above. The buzzers were padded and tightened in such a manner as to equalize roughly their intensity.

For visual stimuli, a wooden screen in the center of which was an aperture 1.3 cm. in diameter was set just above the typewriter, facing the subject. Four electric magnets were so screwed to the reverse side of this screen, that the prong attached to the armature of each, bearing a small disc, was drawn before the aperture whenever the circuit was closed; when the circuit was again shifted, the particular disc withdrew, to be succeeded by another. After some experiments with colors and other designs, for use on the four discs, the letter E in four positions () was chosen. They were associated in that order with the four keys.

which the current could be shifted at will from one mode of stimulus to the other. As all the tests were given by daylight, and the lights seemed more intense on dark days, the resistance of the rheostat was varied slightly from day to day. Very few subjects ever complained of eye-strain; a few found the after-images slightly annoying.

For one short series of tests, the commutator was eliminated altogether, and the method suggested by Coover and Angell—attaching a strip of typewritten digits to the carriage and thus exposing the digits successively through an aperture in the screen—was followed. The digits used in that series were 5, 6, 7, and 8.

Three general considerations favored the use of the tones and the lights as stimuli: the great ease of discrimination; their reliability for long-continued, uniform work; and their non-fatiguing character. The sensory discrimination was basic and immediate; the association with movement was almost equally natural.

The reaction movement consisted, throughout, of pressing the typewriter keys—5, 6, 7, and 8—with the fingers which were placed over them. Two groups of variables were here involved, due (1) to the character and condition of the typewriter, and (2) to the previously acquired skill, or the lack of skill, of the subjects in typewriting. Among the variables of the first class were the "make" and model of machine used, the amplitude of movement of the keys, the amount of use or misuse which it had undergone, the degree of lubrication, and the tension or "springiness" of the carriage-movement.

There was, accordingly, an extensive latent time in the successive stimuli, and in the registering of the reactions. The greater part of this latent time was due to the mechanism of key and carriage. As a consequence, the reaction times were not comparable with those recorded by any former investigators of complex reaction times. But, since this latent time, in spite of its extent, was constant and uniform throughout any series of tests, the reaction times were certainly of relative value, and

exhibited the individual differences in those times with great reliability.

The extent of previous training in manipulating typewriters was also considered. Unskilled subjects were coached on the proper use and economy of energy in their reactions, since some were prone to waste time on ponderous movements, while others did not strike the keys heavily enough to record the reactions. The subject kept all four fingers constantly in touch with the surface of the proper keys, so that time would not be consumed in movements to establish those contacts when they became necessary. In general, however, all subjects, even twelve-year-old children, who were experimented with, found the reaction movements simple enough to liberate their attention for the work as a whole.

The procedure followed in giving the tests was directed toward securing the subject's maximum achievement in speed, together with reasonable accuracy—not more than five errors in one trial. When the subject was seated comfortably before the typewriter, in a position free from awkwardness or strain, he was told to place the index and middle fingers of both hands upon the four cloth-covered keys. Then the experimenter pointed to the lights (or telephones, if the test was auditory), and said: "You see these four lights. When this first light comes on, press this finger (pointing); when this second light appears, press the second finger," and so forth.

The current was then turned on and the subject was introduced to the task by reacting successively to about twenty-five stimuli, the experimenter encouraging him and watching his fingers to verify their accuracy. Then, during a pause, the complete instructions were given in colloquial language:

"This is a test of speed and accuracy. Throw every effort into the work so as to make the very best time that you possibly can, with approximate freedom from error. After you begin a line, do not let anything stop you or confuse you even for a fraction of a second. Time counts.

"Work at such speed that you will not make more than five errors in a line. This is a standard of certainty which should determine your speed. You can fail by being over-cautious and slow or by being reckless and fast.

"Now prepare yourself for the movements. Be on the alert all the time, to move. Push the lights. The faster you push them, the better your record will be."

This emphasis on a "motor" form of attention was continued through the test. At the end of the practice trial, the experimenter asked, "Are you making many mistakes?" and proceeded to compare the record with the key. Complimenting the subject on either his speed or his accuracy, as the case might justify, the experimenter said: "Now we want to get ten records from you." The warning "Ready," was given from one to two seconds before each trial began. The stop-watch in the left hand was started simultaneously with the turning on of the current with the right hand. When the last stimulus of the trial appeared, the experimenter directed his attention to it, and stopped his watch immediately following the reaction which extinguished it.

The intervals between the successive trials were simply long enough to permit the experimenter, assisted, perhaps, by the subject, to check over the record for errors. If less than five errors had been made, the subject was complimented; if the trial contained more than five errors, he was advised to "cut down the mistakes a little next time." The subject was kept informed of his time in seconds for each performance; and his "best record so far," or the "highest score of anybody today," was emphasized. A competitive attitude and an ambition to "cut the time down a little more" were encouraged. The experimenter, however, constantly sought to avoid a stereotyped, or "professional" habit of giving encouragement.

For some types of subjects, this continual prodding was highly successful. Many persons began with ease and composure, by assuming a very moderate pace, one which represented a fairly low level of their potential rate. Repeated spurring, with the incentives of pride and competition, simply aroused such habitually low-gearred persons to keener effort and higher efficiency.

On the other hand, some subjects, naturally "high-strung" or tense, selected an *optimum speed*—one representing that rate of performance which they had generally found most successful. This habitual gait, timed in accordance with natural motor capacities or long motor experience, could not be broken without a

serious loss of efficiency. Undue pressure simply resulted in their "going to pieces," losing the coördinations, making long series of indiscriminate responses, or pausing in complete confusion. Instead of "rising to the occasion," they were "rattled" by the demand for unusual self-control. Accordingly, some caution was exercised in the use of suggestion.

*The Effects of Practice upon Performance in the
Test of Serial Action*

In order to determine the effects of practice upon performance in serial action, three groups of experiments, involving tests with five different kinds of stimuli, were undertaken. Since, during each of these practice series, no substitution or change of commutator standards was made, the order of the seventy-five stimuli remained exactly the same throughout. Consequently the improvement curve includes as a significant factor the gradual acquisition of the order of stimuli and reactions.

In addition to this increasing retention of the sensory and motor sequence, the learning process involved the attainment of "automatic co-ordination." A fast, rhythmic rate of reaction, economizing both time and energy, was built up, and the experimenter did not usually interfere with this steady gait even when more errors than the instructions permitted were left in its wake.

Series A.—The first of these experiments, Series A, consisted of an intensive investigation by Mr. H. R. Fossler, of the effects of practice. Each subject—all being university students—reported every third day for a considerable period, on each occasion taking first a set of five trials with visual stimuli, then a set of five trials with auditory stimuli, and alternating thus until three sets with each kind of stimulus had been made, resulting in a daily total of thirty trials. Subject A was thus given a total of 190 trials with each kind of stimulus, and his practice period involved the making of 28,120 individual reactions. Subject B totalled 130 trials each of visual and auditory reactions, with 19,240 individual responses; and Subject C made 60 trials including 8880 reactions.

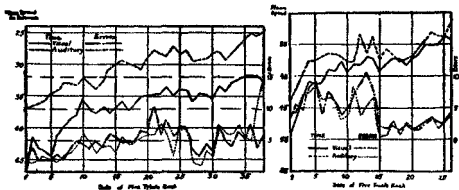


FIG. 2. Practice curves of subject A in speed and accuracy.

FIG. 3. Practice curves of subject B in speed and accuracy.

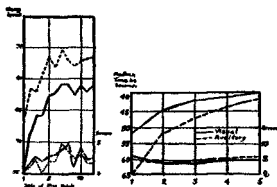


FIG. 4. Practice curves of subject C in speed and accuracy.

FIG. 5. Practice curves of speed and accuracy, 26 subjects.

Figures 2, 3 and 4 indicate the progress of this practice series in terms of mean speed in each set of five trials. A steady improvement in speed is apparent in all cases from the first set onward, with but few hesitations and plateaus. For subject A, the mean time of the thirty-eighth set was 34.2% faster than that of the first set in the auditory series, and 31% faster in the visual series. Similarly, the final record of Subject B was 27% faster than his initial set, in the auditory, and 32% in the visual series.

Inspection of the curves denoting the number of errors reveals a fairly consistent decline in accuracy concomitant with the in-

crease in speed, except after the fourteenth set of Subject B. This relationship is expressed by the correlation coefficient r , .87, p.e., .03 between speed (from fast to slow) and the number of errors, in the auditory series, and r , .77, p.e., .05, in the visual series, of Subject A. The corresponding coefficients for B are negligible, on account of irregularity in procedure. Subject C agrees with Subject A.

It was found that relatively "good sets," as well as "good days" in performance with visual stimuli were generally also "good" with the auditory. This was true of both speed and accuracy. The high speeds in the visual series were usually followed by correspondingly high scores in the auditory series, this correlation between mean speed in the visual and auditory sets being r , .93, p.e., .03 for Subject A, and r , .74, p.e., .08 for Subject B. The corresponding pairing of accuracy in the visual and auditory sets is shown by the coefficients r , .70, p.e., .05 and r , .90, p.e., .03 respectively for Subjects A and B, while Subject C, whose record is not so extensive, also supports these relationships.

Series B.—Twenty-six students in the Northwestern University School of Music, all girls, composed the second group of subjects for the study of practice in serial action. This investigation was made by Dr. E. A. Gaw. On each of five days, at intervals of from three to seven days, two sets of tests were given to each subject, the first set consisting of five trials with visual stimuli, and the second of five trials with auditory. For the former, the four digits, 5, 6, 7, 8, typewritten in chance order on a strip of cardboard, and exposed, one at a time, through an aperture in a screen following the method suggested by Coover and Angell, were used. The auditory stimuli consisted of tones produced by telephone receivers as previously standardized.

An effort was made to control the number of errors more completely than had been the case in the previous experiment. At the beginning of each day's work, each subject was told what her average record, in both time and accuracy, had been on the previous day. If the average number of errors had exceeded five, the subject was cautioned on the following day to be more

accurate. If she had been painstakingly accurate at the expense of speed, she was urged to work for more speed. Figure 5 shows the median speed of the entire group of subjects, with both visual and auditory stimuli, for each day. These medians are figured from the means of the individuals' five daily visual, and of their five daily auditory trials. A similar procedure is followed with respect to the errors.

Pronounced improvement in both visual and auditory series is evident during the entire period, as is shown in Fig. 5. The last day's speed is twenty-five per cent faster than the first day's, in the visual series, and thirty-seven per cent faster in the auditory. The subjects thus make more improvement in the twenty-five trials given, than did the subjects in Series A in the same number of trials; but the latter had made these reactions all in one day rather than at intervals for five days.

In the twenty-five trials given (as also appeared in the first part of the previous practice series, with Subjects A and C), accuracy did not decrease with the acceleration of speed in reacting. The series of tests was not extensive enough to determine whether or not this uniform degree of accuracy had become a permanent characteristic of the subjects' reactions.

A comparison was made of the ranks of the twenty-six subjects on the basis of speed on the first day, and then on the basis of mean speed for all five days. The correlation between these ranks was r , .88, *p.e.*, .03 in the visual series, and r , .89, *p.e.*, .03 in the auditory, thus showing that the first day's performance generally gave a fair index of the potential speed of the subjects. The correlation between rank on the first day and that on the last day was r , .76, *p.e.*, .07; and r , .63, *p.e.*, .09, respectively, in the visual and auditory tests.

The ranks of the subjects on the basis of their speed in reacting to one kind of stimuli corresponded only roughly with their ranks when using the other kind of stimuli. This correlation between ranks in visual and auditory scores on the first day was r , .48, *p.e.*, .11; and the correlation between visual and auditory rankings based on the total achievement of all days was r , .52, *p.e.*, .11.

Series C.—The third series of practice tests was given to six students, all men, each of whom was given ten trials on each of seven successive days, reacting to the candelabra lights as stimuli. On every day, each subject was encouraged to try to surpass not only his own best record, but also the record of the fastest man. As the tests progressed, the number of errors increased, and in spite of repeated cautioning, tended to gain in number from day to day. In the later days of the series, several subjects remarked that the errors seem bound to come, whether they tried to slow up and be careful, or not.

The mean time for the ten trials of each subject on each of the seven days is shown in Figure 6. From this figure it is seen

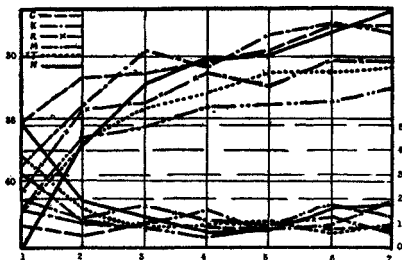


FIG. 6. Speed and variability in speed of six subjects on seven days. Figures at left, time in seconds; at right, mean variation in seconds; at bottom, days.

that: (1) the greatest diversity of performance appears on the first day; (2) progress is most noticeable during the first three days or thirty trials, after which it becomes very gradual; (3) with one exception subjects tend to maintain their relative positions on successive days.²

² Only one subject, N, shifts his position. This man evinced a remarkable

The mean of the first day's record is a more reliable index of the potential performance of an individual than is his "best time," since the most erratic subjects may show remarkable spurts of speed.

There is no relation discoverable between speed on the first day and the per cent of improvement in seven days.

On the first day, wide individual differences in variability appear; thereafter, all subjects seem to cling very closely to their mean performances, and those differences are not so evident.

The amount of improvement made on each day, and also the relative speed of the ten trials of each day, are indicated in Fig. 7.

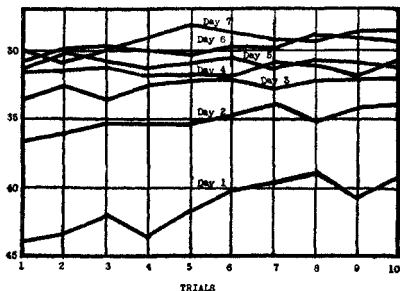


FIG. 7a. Mean time of all subjects in each of ten trials on all days.

ability for learning the order of the stimuli. By the second day, he had acquired the sequence of several "patches" of stimuli and would run these off, each immediately following its own stimulus, just as smoothly and regularly as a pianist playing a familiar musical number, but guiding himself by the notes. On each successive day, this subject extended the range of these memorized sections, and by virtue of this coup, rose from the rank of slowest to that of fastest. The other subjects did not carry the memorizing of sequence to so high a degree of success.

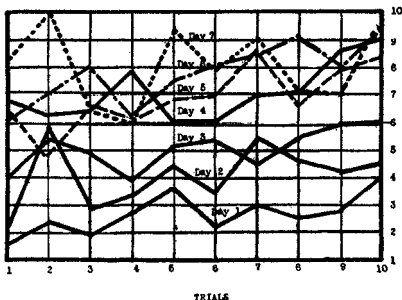


Fig. 7b. Mean number of errors for all subjects in each of ten trials on all days.

on the first and second days does any "warming up" seem to occur during the day's ten trials, and from the 7.6 seconds of total improvement on the first day to 2.5 seconds on the second day, a great diminution in gain is evident. No consistent crest of good performance, and no particular "breaking point" in the ten trials, can be found on any day.

As the subject becomes more familiar with the test, he loses caution and tends to keep up a fast, automatic gait, at the expense of accuracy. However, with one exception, each subject tends to maintain his relative accuracy in the performances of subsequent days. (See Fig. 8b).

While all the subjects become less accurate with increase of speed, it cannot be said that those who accelerate most in speed degenerate most in accuracy. Thus, the subject making the most gain in speed (*N*) declines the least in accuracy; while two other subjects (*M* and *T*) whose time records show high improvement, degenerate greatly in accuracy. Neither does the subject who

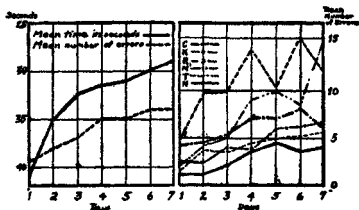


FIG. 8a. Speed and accuracy of six subjects combined, for seven days.

FIG. 8b. Number of errors of six subjects for seven days.

accelerates least (R) distinguish himself for accuracy. At any stage following the first day, just as on the first day itself, subjects are classified as fast and accurate, slow and accurate, fast and inaccurate, or slow and inaccurate. The individual tends to cling to his relative position, even during an extended period of practice.

"Hard" and "easy" places within the seventy-five reactions of each trial were very evident throughout the tests, both from the pauses and smooth flows in rhythm of reactions, and from the grouping of the errors in certain places within each row of the record. Investigation proved that these particular regions tended to appear uniformly among all the subjects, and tended to persist throughout practice.

The correlation between the distribution of errors on the first day, for all subjects, and on the second day, was $r, .61$, $p.e. .05$. The same distribution showed a correlation of $r, .61$, $p.e. .05$ with that of the seventh day; and of $r, .68$, $p.e. .04$ with that of the total of all days.

The distribution of errors in relation to the four respective fingers involved in committing them brings out the following results: (1) There is greater inaccuracy in the reactions of the two index fingers, with only one exception; (2) of the two

index fingers, the one belonging to the right hand is generally the less accurate; (3) individual differences, while apparent in the errors committed by the index fingers, are much more pronounced with respect to the two extreme fingers. The relative accuracy of right hand and left hand fingers is subject to individual differences.

The general conclusions derived from these experiments are, that under the conditions obtaining,

(1) Whatever kind of stimulus be used, the speed of serial action increases with practice, rapidly during the first twenty-five or thirty trials, and then slowly for an indefinite period. Increase in speed is accompanied by a decrease in the variability of speed, as the subject strikes his "gait." Improvement during the day's trials, or "warming up," appears chiefly on the first day. When practice series with two kinds of stimuli are run in parallel, the characteristic rises, drops and plateaus in speed of one series are usually accompanied by similar changes in the other.

(2) Unless a rigid habit of accuracy is built up from the initial trial, accuracy degenerates as speed accelerates. But a habit of accuracy does not hamper the rise in speed, if developed consistently. Each day's performance is most accurate at first and least accurate at the end. Variability in errors does not generally decrease with practice. "Hard" and "easy" places, and tendencies of certain fingers to commit a disproportionate number of errors, persist through practice.

(3) Individual differences in speed and accuracy do not disappear with practice. The diversity of performance of subjects is greatest at first and tends to decrease. But subjects usually maintain their relative positions with respect to each other, in both speed and accuracy, throughout a practice period.

(4) Five trials are generally sufficient to indicate the relative capacity of subjects for speed and accuracy in this test; but the high practice curve renders ten trials more reliable.

*Distributions of the Groups Tested,
According to Speed and Accuracy*

Together with a number of other tests, the serial action test was given to four classes of persons: (1) students, (2) army recruits, (3) musicians, and (4) stenographers.

Series I, Students.—The first group tested consisted of 152 university sophomores, 100 men and 52 women. In January, 1918, these were each given the series of motor tests described by Seashore (63, Chap. IX). For the serial action test, auditory stimuli, consisting of electric buzzers, were used.

The scores for speed in serial action (Fig. 9) showed a wide range—from 37 to 70 seconds, with the median at 56.4 seconds. Women did not, as a group, quite equal the men in speed, and they also tended to make more errors (Fig. 10).

Series II, Army Recruits.—The visual form of serial action (E symbols) test was one of several tests given to miscellaneous recruits applying for admission to the army school in radio-

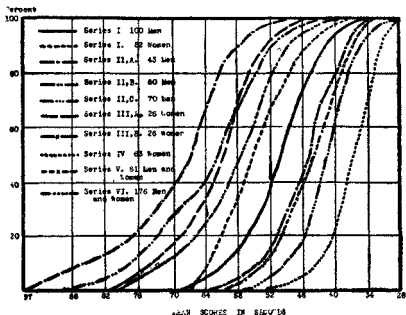


FIG. 9. Distribution of speed scores by groups.

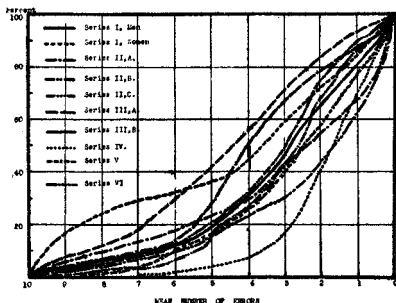


FIG. 10. Distribution of errors by groups.

telegraphy at the University of Iowa during the summer of 1918.

A. Forty-three recruits arrived and were tested early in June, 1918; nine were rejected on the basis of poor performance in this and other tests. This group showed wide diversity in ability, the scores in serial action ranging from 52 seconds to over 100 seconds, with the median at 73 seconds. The distribution is the most irregular of any group. Errors also showed great irregularity.

B. In August, sixty men appeared for the tests, thirty-two of whom were admitted to the course. The median speed in visual serial action was 63.9 seconds, almost 10 seconds faster than the previous group. The range was relatively small, and in accuracy a good record was attained.

C. Seventy recruits were tested for admission to the training course in October. Auditory serial action, with telephones, was used. The range in serial action scores is more narrow than in previous groups, and the median (60.9) shows greater speed. However, the number of errors is greater than in the preceding

group. Selection in this group was prevented by the influenza epidemic.

Series III, Musicians.—The serial action test in both auditory (with telephones) and visual forms was one of the measures used by Dr. E. A. Gaw in making a survey of musical talent in the Northwestern University School of Music, during December, 1918. Twenty-six women, all musicians of considerable training, composed this group. For visual serial action, a simple letter arrangement, similar to that described by Coover and Angell (20) was used. Each subject received, first, five trials with visual and then five trials with auditory stimuli. The speed in the visual series (median, 51.5 seconds) was fast, but in the auditory series was slow (median, 64.8). The range was wide, and in the number of errors committed these subjects exceeded any others tested.

Series IV, Music Students.—Sixty-three students in the University of Iowa School of Music, all women, were given the serial action test, in 1920, with electric lights as the stimuli. The scores show very short reaction-times, a narrow range, and few errors.

Series V, Stenographers.—Sixty-one students in the typewriting courses of the Cedar Falls (Iowa) High School and of the Iowa Teachers College were given the same test by Mr. Ben W. Robinson in 1920. The subjects were mostly women, varying considerably in age and education. The resulting scores ranked this group next to those in Series IV in speed, while the number of errors was greater.

Series VI, Stenographers.—One hundred seventy-six students taking courses in typewriting at the three Des Moines high schools were also tested by Mr. Robinson. Only nine of the subjects were men. This group stands between those of Series IV and V, in speed, and in accuracy falls below them both.

General Comparisons.—(1) No consistent sex differences are shown, in either speed or accuracy.

(2) As is shown in Fig. 11, giving the median time for each of five trials, electric lights produce the quickest reactions, digits

are second (for educated subjects), tones are third and visual symbols (E) are fourth. The nature of the stimulus does not seem decidedly to affect accuracy, but there is slightly greater accuracy in the visual tests (Fig. 12).

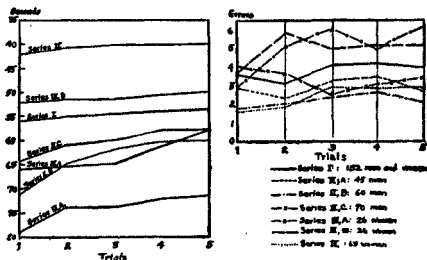


FIG. 11. Median scores in each of five trials of various groups.

FIG. 12. Median number of errors in each of five trials of various groups.

(3) The medians show improvement in speed with each successive trial. The amount of this improvement is most marked under those conditions which cause slow reactions. The number of errors tends to increase during the test, but not consistently.

The Distribution of Errors in Relation to the Sequence of Stimuli

The order or sequence in which the stimuli come has considerable significance in the location of errors. Certain regions in the succession of stimuli are "easy," calling out smooth responses, while other places are "hard," causing errors, pauses and confusion.

The number of errors is found to depend upon the probability of the appearance of each stimulus; that is, the subject is always expecting the stimulus which has been absent the longest, and expecting least the one which was most recent. The results are

as follows: The stimulus which has been absent the longest has only 36 per cent of the errors, although its proportional share would be 57.5 per cent. The stimulus which has been absent next to the longest, has 30 per cent of the errors, while its share would be 25.2 per cent. The most recent stimulus has 34 per cent of the errors, while its proportional share would be only 17.3 per cent. Thus the least expected stimulus causes three times as many errors, proportionally, as the most expected stimulus.

Other causes of errors in certain regions are the maintaining of symmetrical reactions after the stimuli have ceased to come according to symmetrical order, and the "spreading" of mistakes over successive reactions.

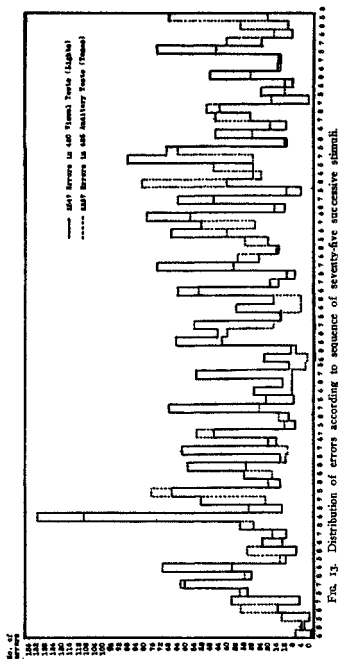
Figure 13 represents the distribution of 2547 errors in 420 trials with electric lights as stimuli, and of 2257 errors in 426 trials with tones from telephones as stimuli, the order of sequence being identical in the two series. The subjects were different. The "hard" places in the visual tests are also "hard" in the auditory. In fact, the correlation between the two arrays of errors is $r, .62$, *p.e.*, .05.

This comparison of visual and auditory stimuli shows that, while the index fingers in both cases cause disproportionately many errors, this relation is much more pronounced in the visual tests. In the latter, the index fingers make two-thirds of the mistakes. Therefore, the inaccuracy of the index finger is due largely to the fact that discrimination of position is not so easy in the middle pair as in the extremes. That is, a radical shift of position by the visual stimulus is more readily discriminated than is a less extensive shift of the visual stimulus. In the auditory tests, wide separation of all four stimuli caused the moderate shifts to be more readily discriminated than in the visual tests.

The Relation of Serial Action to Other Measures Used

The relation of speed to accuracy and variability.—The results of correlating^{*} the mean time and mean error records of the

^{*}Throughout this study, in figuring correlation coefficients, the Pearson products-moments formula has been followed, except when the number of



subjects, are shown in Table 1. There is no consistent relationship between mean speed and mean accuracy; the three largest groups of subjects fail to show definite correlation. But positive correlations appear in some of the smaller groups and these are the groups in which the most caution was observed in keeping errors at a minimum.

All subjects could be classified on the basis of their performance, into four kinds, or types: (1) quick-accurate, (2) quick-inaccurate, (3) slow-accurate, and (4) slow inaccurate. There were, however, some marginal cases which did not belong definitely in any one class.

The relation between a subject's speed, from his first to his last trial, and his accuracy, is not consistent. Usually, his first trial is the slowest and most accurate, but speed does not develop at a consistent expense in accuracy. As a result, no constant could be secured which would enable the experimenter to reduce errors to a time basis.

Several methods of evaluating errors so as to secure a single score, in terms of time, were tried out. One of these gave additional credit to the time scores of subjects who were more accurate than the median, and deducted a percentage from those who were less accurate than the median. This method was too complex for general use.

Another weighting plan for errors was based on this formula:

$$\text{Score} = \frac{\text{Total time for all trials}}{\text{Total no. of reactions minus no. of errors}}$$

The scoring method suggested by Link (47) was also tried out. However, since the subject who made more errors did not thereby secure any clear advantages in speed, over his more accurate companions, and since the errors were generally kept down to a fairly uniform level, speed alone was adopted for use as the serial action index.

Speed and mean variation in speed showed a considerable negative correlation (*e.g.*, r , .62, *p.e.*, .05 in the 70 cases of Series cases was less than 30. There the Spearman "foot-rule" was used and designated as R.

II, C). This meant simply that the subjects who worked the fastest also showed the least variability.

TABLE I. *Correlation of mean speed and mean accuracy (Speed from fast to slow, and errors inversely ranked)*

Series I	.....	151 cases	.....	r, .00		
Series II, A	.....	43 "	.....	r, .48	p.e., .08	
Series II, B	.....	60 "	.....	r, .36	p.e., .07	
Series II, C	.....	70 "	.....	r, .20	p.e., .08	
Series III, A	.....	26 "	.....	r, .31	p.e., .11	
Series III, B	.....	26 "	.....	r, .12	p.e., .12	
Series IV	.....	63 "	.....	r, .32	p.e., .07	
Series V	.....	61 "	.....	r, .13	p.e., .08	
Series VI	.....	174 "	.....	r, .13	p.e., .05	

The Relation of Serial Action to Other Motor Tests

As is evident from Table II, a low positive correlation obtains between speed in serial action and the time of simple reaction to sound; and a similar relation appears with reaction after discrimination and choice.

TABLE II. *Correlation (r) with simple reaction to sound*

Series I	.....	151 cases	.....	r, .29	p.e., .05	
Series III, B	.....	25 "	.....	r, .46	p.e., .09	

Correlation (r) with complex reactions (to sound)

Series I	.....	150 cases	.....	r, .35	p.e., .05	
Series III, A	.....	26 "	.....	r, .37	p.e., .10	
Series III, B	.....	26 "	.....	r, .37	p.e., .10	

The correlation of speed in serial action and precision of movement, as measured by the target test, is negligible. This fact appears in the tests of both Series I and II, A, and B. Furthermore, no correlation exists between accuracy in serial action and accuracy in the precision test. The performance of a wrong reaction in serial action is quite unlike inability to make a fine, steady adjustment in repeated movements.

Strength of movement, as indicated by the best of three trials with the Smedley dynamometer, was also compared with serial action records in the group of 150 students. The coefficient was $r, .28, p.e., .05$, indicating a possible low positive correlation.

Motility, measured by the maximum rate of tapping, shows a low positive correlation with speed in serial action, as is evident in Table III.

TABLE III. *Correlation (r) with Motility Test*

Series I	.....	151 cases	.....	r , .25,	p.e., .05
Series II, A	.....	43 "	.....	r , .24,	p.e., .10
Series V	.....	61 "	.....	r , .27,	p.e., .07
Series VI	.....	174 "	.....	r , .23,	p.e., .05

That these various low correlations point to a tendency of serial action to agree with the other motor tests in the classifying of subjects, is illustrated by a comparison of grades based on quintile standing. The forty-three recruits in Series II, A, were thus graded from very superior to very inferior (A, B, C, D, and E) in the motility and serial action tests. Of these subjects:

- 13 maintain the same rank in both tests,
- 20 differ one grade in rank,
- 8 differ two grades in rank, and
- 2 differ three grades in rank.

Similarly in tapping for accuracy (a test in which the examiner called out rapidly in succession the number of times which the subject was to tap),

- 16 have the same rank as in serial action,
- 17 differ one grade in rank,
- 8 differ two grades in rank, and
- 2 differ three grades in rank.

A similarly rough correspondence occurs with the other tests showing low correlations with speed in serial action.

The relation of serial action to code tests.—A low positive correlation between speed in serial action and scores in the two code tests was generally found. These code tests, the "Civil War" code as described by Terman, and the "Russian" tapping code (in which the subject is given a scheme for transliterating the alphabet into a code of taps, and then must interpret the words which are tapped by the experimenter) were given to the three groups of army recruits.

TABLE IV. *Correlation (r) with the Civil War code*

Series II, A	.....	43 cases	.....	r , .43,	p.e., .09
Series II, B	.....	32 "	.....	r , .34,	p.e., .11
Series II, C	.....	67 "	.....	r , .20,	p.e., .08

TABLE V. *Correlation (r) with the Russian tapping code*

Series II, A	.....	43 cases	.....	r , .30,	p.e., .10
Series II, C	.....	69 "	.....	r , .44,	p.e., .07

These low correlations indicate a rough tendency on the part of the tests to agree in their ratings of subjects. In terms of grades,

the relationship is shown in the following comparison of scores made by forty-three recruits in the "Civil War" code and serial action:

17 maintain the same rank in the two tests,
15 differ one grade in rank,
8 differ two grades in rank,
3 differ three grades in rank.

The relation of serial action to the Vasey vocabulary test.—No consistent relationship between serial action and the Vasey vocabulary test was found. The largest group of subjects showed no definite correspondence, while the two smaller groups indicated a low correlation.

TABLE VI. *Correlation (r) with Vasey vocabulary test*

Series II, C	70 cases	r, .31, p.e., .07
Series V	61 "	r, .35, p.e., .07
Series VI	174 "	r, .14, p.e., .05

The relation of serial action to army Alpha intelligence test.—Here, again, the largest and most representative group does not show any definite relation between the tests compared. The smallest group, however, gives a fair correlation. The evidence is therefore inconclusive, although—considering the code and the vocabulary tests, as well as the Alpha test—the data point to a slight dependence of score in serial action upon intelligence.

TABLE VII. *Correlation (r) with Alpha intelligence test*

Series IV	41 cases	r, .51, p.e., .08
Series V	61 "	r, .20, p.e., .08
Series VI	174 "	r, .14, p.e., .05

The serial action test generally stands in a middle position among the different tests used; that is, it agrees roughly with them in its classifications. Thus the nine recruits of the June group who were rejected on account of low standing in the test (each given equal weight), ranked as follows in serial action: 1, B; 2, C; 3, D; and 3, E. In the August group, a score of 67 in serial action roughly divides the successful from the unsuccessful applicants.

The serial action test picked out, with considerable certainty, nervous, high-strung subjects. This type appears at the extremely slow or inaccurate ends of the distribution curves.

Application to Vocational Guidance and Selection

In this investigation, serial action was studied in its relationship with three psycho-motor activities which have vocational significance: musical action, telegraphy and typewriting. Great difficulty was experienced, however, in securing satisfactory criteria of ability or of success in these activities.

Musical action.—Such difficulties as the following must be considered in judging the test by means of criteria in music. Professors' ratings of their pupils are subject to those very individual biases and fallacies which it is the purpose of objective tests to eliminate. Each instructor has only a small number of students to rate, and there is no way of equating the instructors' grades so that they will be mutually comparable.

Again, some students enter the conservatory already drilled and polished by musical training, while others are almost unskilled novices. Some spend the entire day upon musical efforts, and others only occasional hours.

The relative performance in serial action, of persons trained

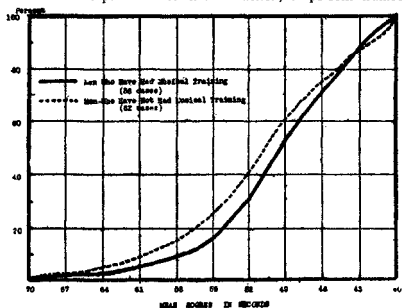


FIG. 14. Scores in serial action of men who have had musical training and men who have not.

and untrained in musical performance was studied. Figure 14 shows the percentage distributions, in speed of 36 university men who have had musical training and of 62 men who have had none. The two groups are almost identical in test scores. This fact does not argue against the value of the test for rating musical talent, since "surveys of public schools show clearly that very little correlation exists between the possession of musical talent and the selection of children for musical education" (63, p. 4). The data here indicate that training in musical performance does not, as such, confer any advantage upon any subjects taking the test. Native motor capacities, more than acquired refinements of action, determine performance in the test.

Correlations were first sought with standard tests of musical talent. The visual serial action test was found to correlate somewhat with the test of rhythmic action, the coefficients for the Northwestern and the Iowa University groups being $r, .41$, *p.e.*, $.12$ and $r, .50$, *p.e.*, $.08$, respectively.

The test was then studied in relation to the ratings which, entirely independently of the motor tests, were given to their students by the instructors in music at Northwestern University, under the following heads: Application, Achievement, Ambition, Reading Ability, Memorizing Ability, Ear Training in Class, and Sight-Singing in Class. Since it was evident that an estimate of all-around attainment, rather than of specific elements in attainment, lay at the bottom of these various ratings, the sum of each individual's ratings was accepted as the best available criterion of musical performance. Similarly, the grades of the music subjects at Iowa University, given by the instructors, under the heads of Sight-Singing, Control of Rhythm, Application and Progress, were added together to furnish a criterion. The Northwestern University ratings furnished correlations of $r, .52$, *p.e.*, $.11$ with visual serial action, and $r, .35$, *p.e.*, $.13$ with auditory serial action. In the Iowa University group, the correlation was $r, .26$, *p.e.*, $.10$. A more reliable comparison might be made by classifying the students simply as either "above average" or "below average" in general attainment. In Table I is found the result of comparison on this basis.

TABLE I. *Comparison of performance*
Serial action

		Below average			Above average		
<i>Musical Achievement</i>	Above average	Series	III, A	..... 4	Series	III, A	..... 8
		"	III, B	..... 5	"	III, B	..... 8
		"	IV,	..... 7	"	IV,	..... 12
	Below average	Series	III, A	..... 9	Series	III, A	..... 4
		"	III, B	..... 8	"	III, B	..... 4
		"	IV,	..... 12	"	IV,	..... 7

It is evident that, in each series of tests, there is a rough tendency for those who are above average in serial action to be above average in musical achievement ($\frac{8}{12}$, $\frac{8}{12}$, $\frac{12}{19}$), while those who are below average in the test tend to be below average in musical achievement ($\frac{9}{13}$, $\frac{8}{13}$, $\frac{12}{19}$).

That visual serial action indicates roughly the subject's ability for sight-reading is shown by the mean ranks in the test, of the Northwestern students, graded by letter according to success in sight-reading: A, 9; B, 10; C, 14; D, 25. The "A" and "B" students were least clearly differentiated. In the Iowa ratings, the correlation between performance in the test and success in sight-reading was $r, .43$, p.e., .09. In that group, those who were above average in serial action were generally above average in sight-reading, while those who were below average in serial action tended to be below in sight reading.

There was some correlation of serial action with professor's rating in "control or rhythm" (.37, p.e., .09). No definite correlation with such single ratings as those on Application, Ambition or Progress, has been established for either group.

While these data do not furnish conclusive proof, they give encouraging evidence that serial action measures abilities which partially determine success in musical action.

Radio-telegraphy.—The three groups of army recruits applying for training in radio-telegraphy were of a most miscellaneous character. Not only did they vary enormously in education and

experience, but also in previous training in telegraphy. Each group included expert professional telegraphers, somewhat experienced apprentices and amateurs, and "green," unskilled men-of-all-work. The relation of the serial action test, therefore, to achievement in telegraphy was greatly complicated.

The distribution of these applicants according to grades in serial action showed (as Table II illustrates) that the operators and apprentices of previous training included more than a proportional share of the superior subjects in serial action. This slight superiority of telegraphers is perhaps due, not to their training as such, but to the selective process lying behind it, by which capable men generally acquire some profession or field of interest, while less capable men remain unskilled.

TABLE II. *Distribution of 43 recruits by grades in serial action*

	A	B	C	D	E
Operators	2	1	5	1	0
Apprentices	1	4	2	1	0
Unskilled men	1	4	11	7	3

The eight weeks' course of training in radio-telegraphy which each group received, was interrupted by "fatigue" duties, military drill, transfers, and other distractions. The training of the last group was seriously disrupted by the influenza epidemic. At various times during the training, particularly of the first two groups, tests of speed and accuracy in sending and receiving words by telegraph were given to the subjects. In the second group, these tests came periodically, once a week.

Achievement in telegraphy, as thus measured, was taken as the criterion with which the serial action test was compared. No correlation between scores in serial action and ability in sending or receiving words telegraphically were apparent for the groups as a whole. Neither did accuracy in serial action evince any such relationship. Various other means of comparing the respective performances failed to demonstrate any relationship. If the comparison of achievement were limited to those men who completed the course and had entered it entirely ignorant of telegraphy—and such a comparison would alone be entirely just to the test—the number of cases would be so reduced that the

results, although favorable, would be unreliable for any general conclusions.

Typewriting.—In Fig. 15 are given the percentage distributions, in serial action speed, of two groups of university men: one group of 40 men who could typewrite, and the other, of 57 who could not. Fig. 16 shows the relative accuracy of the same two groups. A slight advantage in speed, but no advantage in accuracy, is apparent on the side of those subjects who could

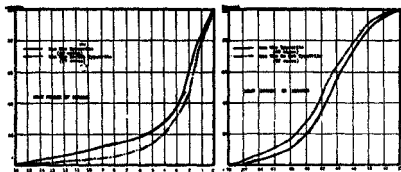


FIG. 15. Scores in serial action of men who typewrite and men who do not.
FIG. 16. Accuracy in serial action of men who typewrite and men who do not.

typewrite. This slight superiority may be attributed to the greater economy and ease of key-manipulation which comes with practice in typewriting. The distribution curves of speed, for Series V and VI, in which the subjects were students of typewriting, did not show quite as quick reactions as the distribution of musical students (Series IV). Practice in typewriting is not as significant a factor in this test as certain other variables such as maturity and native capacities.

The relation of scores in serial action to attainment in typewriting was especially investigated in the group of 176 students in typewriting at Des Moines. The criteria of ability to typewrite consisted of (1) instructors' ratings and (2) a "speed test" in typing.

When the gross scores of the 176 subjects in the speed-of-typewriting test were correlated with speed scores in serial action,

the coefficient was found to be $r, .15$, p.e., $.05$. The correlation of accuracy in the typing test with accuracy in serial action was $r, .10$, p.e., $.05$. Both of the criteria were regarded, by instructors as well as experimenters, as quite unsatisfactory.

Conclusions

The conclusions to which this investigation has led may be summarized as follows:

(1). A "personal equation" of speed in serial action has been found. There are relatively fixed types of subjects apparent in this measurement of motor capacity. Four kinds of reagents appear: quick-accurate, quick-inaccurate, slow-accurate and slow-inaccurate.

(2). No consistent relationship obtains between mean speed and mean accuracy of serial action. Relative position in speed does not generally indicate relative position in accuracy. Similarly, in the trials of each subject, a relatively fast or slow time in any trial does not consistently entail a proportionally large or a proportionally small number of errors.

(3). (a) Performance in serial action shows some correlation with attainment in other motor tests, viz., simple and complex reaction, strength, motility, and rhythmic action. The correlations are generally low but indicate a rough agreement in the classification of subjects.

(b) The test furthermore rates subjects in general agreement with scores in the "Civil War" code test and the "Russian" tapping code test.

(c) Capacity in serial action shows only a slight relationship to ability as measured by the Vasey vocabulary test and army alpha. The serial action test cannot be regarded as an "intelligence" test analogous to these tests; it measures the subject's motor capacities while the "intelligence" test involves more definitely the conceptual and higher associational process.

(4). From the comparisons of serial action scores with criteria of proficiency in musical action, evidence was found that the serial action test indicates relative capacity for musical action,

especially for sight-reading. The criteria for competence in telegraphy were so rough, and the candidates were so miscellaneous composed of experienced telegraphers and unskilled beginners, that no satisfactory comparisons with serial action scores were attained in that field. Correlations of test scores with students' proficiency in typewriting were low or negligible; but, because the factors for correlation were possibly not well chosen, the data were regarded as inconclusive.

(5). Among the factors which have affected the results of comparisons with practical criteria, the following are especially important: (1) The nature of the subject's task in the test differs from that of his vocational activities in the strain or pressure under which he takes the test. An equalization of incentive and of demand is needed. (2) The widely different training and experience of subjects, both in their vocational and avocational aspects, require consideration and sometimes the use of partial correlation. (3) The forcefulness and suggestion of the individual giving the test plays a very significant part in the subject's performance, even when the verbal instructions are strictly standardized. (4). The criteria used to gauge vocational success must be made more satisfactory. When such factors as these are definitely controlled, some measure of serial action will probably prove its usefulness.

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