

## THE TAPPING TEST: A MEASURE OF MOTILITY

by

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*CONTENTS.*—*Previous uses of the tapping test; the present problem; apparatus; method of procedure (type of movement and positions in performance, arm position in tapping, finger positions in tapping, the length of the tapping period, the optimum number of trials, directions for giving the test, sources of error in tapping, the effect of practice on the tapping rate, rates and norms); age and sex differences; relevant correlations; factors conditioning rapidity of performance in tapping, application and future experimentation; bibliography.*

### *Previous uses of the tapping test*

The tapping test has had a long history in experimental psychology. There has accumulated a great variety of methods of procedure which the standardizer must investigate one at a time. This diversity of procedure is accounted for by the almost endless array of uses to which the test has been put. Some of the principal ones have been:

- (1) A part of a general ability scale for school children. Kirkpatrick (26), Pyle (34), Bickersteth (4).
- (2) Part of a scale of tests for adolescents. Woolley (56).
- (3) Part of a scale of tests for college freshmen. Bingham (7).
- (4) A measure of sex differences. Burt & Moore (11), Thompson (43).
- (5) An index of voluntary motor ability. Gilbert (17), Dresslar (14).
- (6) An index of native rapidity of movement. Bryan (10).
- (7) A measure of the duration of the contraction and of the relaxation of a movement. Franz (16).
- (8) An index of right-handedness. Wells (50), Bolton (9), Bryan (10).
- (9) The effects of cross-education. Davis (13).
- (10) An index of fatigue. Gilbert (17), Kelly (24), Wells (47), Thompson (43), Moore (32), Johnson (23), Trace (44).
- (11) The effects of practice and warming up. Wells (48), Stecher (41).
- (12) One of a series of tests of working efficiency with reference to
  - (a) The effect of caffeine. Hollingworth (20).
  - (b) The effect of alcohol. Hollingworth (22), and Poffenberger.
  - (c) The effect of restricted diet. Benedict, Miles, Roth, and Smith (3).
  - (d) The effect of humidity. Stecher (41).
  - (e) The effect of loss of sleep. Gilbert and Patrick (33).
  - (f) The effect of dental treatment on school children. Kohnky (27).
  - (g) The most efficient working period of the day. Marsh (31), Hollingworth (21), Stecher (41).
- (13) A test for the selection of employees (shell inspectors). Winchester Arms Company (29).

- (14) A measure of occupational efficiency in hand sewing. Hollingworth and Poffenberger (22).
- (15) The motor effects of nervous and mental disease, particularly mania and melancholia. Franz (16).
- (16) The effect of attention on the maximum rate of voluntary movement. Effect of distractions. Bliss (8).
- (17) The relative rapidity of movement of different body joints. Bryan (10).
- (18) The relation of physical ability to mental ability at large. Bagley (2), Bolton (9).

*The present problem.* The present problem is, in general, to measure a basic motor capacity; in particular, the problem is to plan a test which will call into play a simple repeated movement, fundamental, native in character and easy to measure, and which will *not* call into play accessory, coördinated, and learned movements. This fundamental capacity for speed in a simple repeated movement we call *motility*. It has usually been known as *motor ability*.

As a measure of motility, the tapping test has the following advantages: it is one of the most objective that can be applied; the test is simple, easily given, and quickly learned. It has the advantage of readily stimulating the observer.

In the standardization, the idea of general use was continually kept in mind, so at all times a standard commercial article or piece of apparatus was chosen over a highly technical piece of laboratory apparatus, provided such a preference involved no sacrifice of accuracy in the test. Another guiding principle has been that there is no need for further refinement of procedure, recording instrument, or timing device than the variability of the test justified. For example the least variation of a single trial of five seconds from another trial would be one tap, or approximately .12 of a second. The latent time of the electro-magnet was found to be approximately .003 of a second on the make. So for all practical purposes of the test this latent time could be entirely disregarded.

#### *Apparatus*

*The tapping instrument.* The ordinary telegraph key has been used as the tapping instrument by Wells (47), Bagley (2), Davis (13), Dresslar (14), Link (29), Smith (39), and Woodworth (54).

The tapping board and stylus, fully described by Whipple (51), was the instrument chosen by Hollingworth (20), Marsh (31), Stecher (41), Whipple (51), Woolley (56). Von Kries (45) has a very similar device, a wire attached to the finger with which the observer taps on a metallic plate.

The method of pencil dots on paper was employed by Binet and Vaschide (6), Franz (16), and Burt and Moore (11). Essentially the same was the making of pricks in paper with a pointed stylus used by Abelson (1) and Burt (11). This method, modified slightly by making small vertical lines on paper, was used by Kirkpatrick (26) and Franz (16).

Scripture and Moore (36) used a thumb and finger key, with two slides; the thumb slide held stationary and the finger slide movable. Trace (44) used a heavy resistance thumb and finger key. Similar to this was a finger movement, directly recorded on a revolving drum by means of a marker attached to the finger, the method of Benedict, Miles, Roth and Smith (3).

Johnson (23) devised a triangular key whose equilateral slides measured 20 cm. The subject tapped successively at each of the corners.

The tapping board and the telegraph key have been used by the majority of experimenters. The following experiment was designed to get actual data on the relative value of the two tapping devices:

Sixteen observers, nine men, seven women. Tapping board and stylus, telegraph key; 1 mm. amplitude, 100 g. resistance, clamped to top of table. Ten trials taken with each individual, five on each apparatus. Eight observers were given the first five trials on tapping board and the other eight observers were given the first five trials on the key.

The results show an average faster rate of 1.3 taps in a five second period of tapping. Eleven subjects showed faster work on the key and five on the tapping board. Four of the later five, however belonged to the group of eight tappers whose five trials on the tapping board *followed* their five trials on the key. This brings in the effect of warming up. The second five trials were faster on the average by 1.7 taps during a five second period.

There are, however, some manifest objections to the tapping board device. The amplitude of the up and down movement

can not be regulated: some observers will make large movements in spite of all charges to the contrary on the part of the experimenter. Whipple's (51) fear that to impose a restriction on the type of movement would reduce the record of many subjects seems unfounded. To make the movement uniform is just what is desired. A similar source of error is a scraping movement on the tapping board. A very slight tap, for example, when the stylus is allowed to bounce on the board, is not accurately recorded. The telegraph key on the other hand is not open to these objections. The telegraph key was therefore adopted as the tapping instrument. It has an additional advantage in being a staple article, purchasable anywhere.

*The amplitude of the telegraph key.* The amplitude as here considered is measured at the button of the key, the distance the observer must move the key to make a tap. Bryan (10) found that extent of amplitude made no difference in the number of taps accomplished. Binet and Courtier (5) suggest that the shorter the movement, the slower it is made; within limits, a series of fast movements are made in approximately equal time regardless of length of movement. Von Kries (45) considered a certain median distance of about 10 mm. the optimum amplitude. In Bryan's (10) figures no more than seven records were made for each amplitude. Binet and Courtier (5) offered no data in support of their statement.

The matter was therefore again put to experiment, as follows:

1mm., 3mm., 7mm. amplitudes. Amplitude measured at the button of the key. 100 g. resistance. Average time per tap given in hundredths of a second, computed for 25 taps. Hence, the smaller score, the faster rate. 18 observers, 6 trials taken double fatigue order. Result: average time— 1 mm., .128 sec.; 3mm., .130 sec.; 7mm., .134 sec.

Thus the 1 mm. amplitude results in slightly faster tapping than the 3mm. amplitude, and noticeably faster than the 7 mm. When asked to state which amplitude they liked best the observers were evenly divided between 1 mm. and 3 mm. preferences. It was evident in giving the test that the 7mm. distance was too long. It was very difficult to make observers go the full amplitude of 7 mm., they would try to shorten the distance of the tap. Without doubt it takes more time to move 7 mm. than 1 mm.

The same was true of 3 mm. but to less extent. It seemed that for an occasional person, a rapid movement of only 1 mm. in extent was too tiny for his motor set-up; i.e., for natural work. But this disadvantage was so slight and occurred so rarely, that it was not considered of sufficient importance to forsake the small amplitude. Because of the faster results obtained it was decided to adopt the 1 mm. amplitude.

*The recording instrument.* There are two general classes of recording methods: (1) the graphic record and (2) some form of counter, either electrical or mechanical. The following investigators recorded the tapping by the graphic method, usually the smoked drum: Whipple (51), Johnson (23), Woodworth (54), Smith (39), Dressler (14), Moore (32), Kohnky (27), Wells (47), Bingham (7), and Benedict, Miles, Roth and Smith (3). The following used some form of electric counter: Hollingworth (20), Davis (13), Pyle (34), Stecher (41), Link (29), Marsh (31, and Bagley (2). Some kind of mechanical counter was used by Bickersteth (4), Bolton (9), Thompson (43), Kelley (24), and Gilbert (18). Gilbert's (18) counter was an ingenious arrangement of an alarm clock.

The graphic method furnishes accurate detail. It is the only method by which the time of separate taps can be studied, and consequently is the sole means of measuring the regularity of the tapping throughout the tapping period.

In the early part of the present investigation, the graphic record with Seashore's duplicate recorder was used; the time line was marked off by a pendulum beating seconds. By this method the number of taps made in a given second could be ascertained but not the duration of a single tap. The method of the phonograph chronograph, as developed in the Iowa laboratory, proved a much more refined graphic procedure. The taps were graphically recorded on a revolving paper disc. By placing the disc on a large ruled dial scale, the duration of each tap would be read directly in thousandths of a second when the disc was accurately timed to revolve once per second. A good phonograph revolves to an error of .001 second per revolution.

The disadvantages of the graphic record, however, are as evident as its merits. The chief drawback is the laborious process of reading the records. This factor practically limits its usefulness to the laboratory.

To facilitate the recording, the counter method was investigated. The first tried was the Harvard tapping machine with its Veeder chronometer. This apparatus was neat and compact but it was discovered that it would not record accurately as high as ten taps per second for the following reasons: the armature of the magnet was poorly arranged, the magnetic pull being diagonal and of least force at the beginning of the armature's movement, where it should be direct and strongest; too long a movement of the armature was necessary to operate the ratchet; and the chronometer counted on the break which made it susceptible to tremors. The Hollerith dial chronometer also proved to be unsatisfactory.

*The timing instrument.* Besides the selection of the recording device is the choice of an appropriate and accurate means of timing the tapping period. Moore (32), Seashore (37), and Johnson (23) used a 100 vd. fork in connection with the graphic record; this is, of course, the most accurate method and is of value when the purpose is to study the duration of a single tap, but it is manifestly too cumbersome when the duration of the tapping period is five seconds (and with many investigators the period is much longer). Whipple (51) used a seconds' pendulum, Dresslar (14) a clock for recording seconds, and Benedict, Miles, Roth and Smith (3) a Seth Thomas clock which divided the tapping into two second intervals. These methods are all dependent on a graphic recording instrument. Of the investigators who used counters, Wooley (56) and Woodworth (54) used the stop watch and Davis (13) an ordinary watch. Many experimenters made no mention of the means of measuring time.

It was decided to determine by experiment the relative accuracy of the ordinary timing methods. Five methods were tried: two auditory (metronome, and click in the receiver from the revolving disc of a timed phonograph) and three visual

(swinging pendulum, the stop watch, and the ordinary watch). Three observers. Five trials on *each* method.

<i>Auditory.</i> Av. error in estimating a five second interval:				
Metronome .....	.055 sec.	M.V.		.026
Click in receiver .....	.116 "	" "		.030
<i>Visual.</i>				
Swinging pendulum .....	.179 "	" "		.104
Stop watch .....	.212 "	" "		.067
Ordinary watch .....	.317 "	" "		.156

The inaccuracies of timing with the stop watch and the ordinary watch are evident.

*The new tapping apparatus.* An attempt was made to construct a counter which would obviate the main difficulties in recording and timing which have been mentioned. In its final form the counter devised consisted of a Veeder chronometer mounted with a double coil door-bell magnet of eight ohms' resistance, size of each coil approximately 1 1-2 inches by 1 inch. The magnetic pull on the armature was direct and it was attached to the chronometer at a small radius, thus necessitating but a short movement of the armature to operate.<sup>1</sup>

The counter was further equipped with a double action key which, connecting with the metronome circuit, insured accurate timing of the tapping period. (See Fig. 1.)

Tests showed that it would record a 20 vd. fork, and no tapping reaches that speed. The voltage required is listed as follows:

Insufficient to operate	3.8 volts
Sufficient to operate a 10 vd. fork accurately	5.3 volts
Sufficient to operate a 20 vd. fork accurately	6.8 volts

The method of manipulation is as follows: The tapping is started when the contact is open in the metronome, at which time the bar (SK) is horizontally thrown to the contact at (M 2). The recording will then begin as soon as the circuit is closed in the mercury cup of the metronome. During the succeeding second, when the wire is in the mercury, the bar (SK) is pressed down to a contact at (S), thus the circuit is shunted from the metronome. The purpose of the shunt, is of course, to keep the

<sup>1</sup> This apparatus is now made by C. H. Stoelting Co., Chicago.

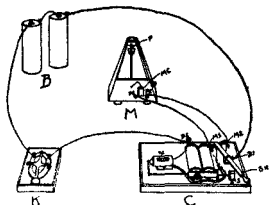


FIG. 1. The tapping apparatus.

M is a metronome with a mercury contact; B, a battery; K, a telegraph key; and C a counter. The Veeder counter VC is operated by the magnet. The key SK closes the circuit through the mercury contact by a horizontal movement. A downward pressure of this key makes contact at S and shunts the mercury contact.

circuit closed while the mercury contact is broken. On the fifth second, when the wire is again in the mercury, the key (SK) is raised; this permits the metronome contact to determine the end of the tapping period. Immediately after the breaking of the circuit in the metronome, the experimenter breaks the horizontal connection at (Mz) and tells the subject to stop tapping.

Thus the experimenter's own reaction time is entirely eliminated. Any exact interval of time can be taken, with the single reservation, however, that the interval of time must be an odd number of seconds. The limit of accuracy is set by the accuracy of the metronome beat.

#### *Methods of Procedure*

*Type of movement and positions in performance.* Tapping tests have been made use of in various movements. Most of the arm joints have been subjected to experimentation; tapping has been done even by the foot and the big toe. The full arm shoulder joint was involved in one of Kelly's (24) experiments. Binet and Courtier (5) used the forearm movement and asserted that it was faster than either the finger or the full arm and also the most natural movement. Dresslar (14), Binet and Vaschide



(6), and Wooley (56) rested the forearm on a firm support and confined the tapping to the wrist as far as possible. Bolton (9), Moore (32), and Benedict, Miles, Roth, and Smith (3) used the finger movement only. To do so, it was required in most cases to strap the forearm and wrist to the table. Bryan (10) tested the speed of all the joints of the upper extremities and found the elbow and the wrist the fastest joints. His results are as follows:

	Taps per second
Shoulder .....	5.2
Elbow .....	8.8
Wrist .....	14
Metacarpo-phalangeal .....	7.5
First interphalangeal .....	6.0
Second interphalangeal .....	4.3

McAllister also found the elbow and wrist to be the fastest joints. Kelly (24) stated that tapping with forearm is faster than with the forefinger in about the ratio of 15 to 13.

With all this unanimity of opinion, it was not difficult from the point of view of maximum speed to adopt the forearm movement. The wrist was allowed free play in so far as it contributed to the forearm tapping movement; in short, the movement chosen was the easiest to perform, the most natural, and in addition the most rapid.

An extended comparison of horizontal and vertical tapping under various conditions revealed a very slight advantage in speed for the horizontal position when the horizontal key was located in a convenient position under the table, 70 cm. from the floor. However, the vertical tapping was adopted as the standard method of giving the test because: practically all former investigators have used this position; the key is more easily set up on the top of the desk or table; the vertical tapping has the psychological advantage of holding the attention better, and therefore getting better effort from many observers.

*Arm position in tapping.* Many experimenters rested the elbow and forearm on the table: of these Binet and Vaschide (6), Stecher (41), Davis (13), and Dresslar (14) are examples. Gilbert (17) on the other hand maintained that the arm held free from any support was the most rapid way of tapping. The

two positions were subjected to experimentation as follows: (1) observer sitting alongside the table with arm resting on it; (2) observer facing table with arm held free from any support. The free arm position gave noticeably faster results—.120 sec.: .129 sec. Resting the arm on the table appeared to interfere with the tapping. With but one exception, all observers expressed a preference for the free arm position. The free arm position also showed greater regularity of tapping.

*Finger positions in tapping.* Bagley (2) made use of the rather novel method of "trilling" a Morse key. The objection to "trilling" as practiced by pianists is that ability in this line is a result of training. It would be quite difficult for some and easy for practiced pianists. Any such movement, which is essentially accessory rather than fundamental, would be unfair as a measure of motility.

A more common finger position has been that of holding the finger just free from contact with the key. A second finger arrangement was the holding-key position in which the key was grasped by the thumb and two fingers.

Experiment on twenty subjects revealed no significant difference in the speed for the two methods. (Key grasped, .127 sec.; key free, .129 sec.) The important defect of free-key tapping movement is that the amplitude of the movement can not be kept constant. Some observers insist on lifting the fingers from the key during the tapping, unless they in some way have hold of the key.

*The length of the tapping period.*—The literature on tapping shows a great assortment of methods in regard to the duration of the test. Bolton (9) chose 5 seconds, Davis (13) 8 seconds, of which only the last 5 seconds were recorded. Smith (39) used 8 seconds; Abelson (1), Kirkpatrick (26), and Benedict, Miles, Roth and Smith (3) 10 seconds; English (15) and Burt and Moore (11) 15 seconds; Wells (50) 20 seconds; Gilbert (17) 45 seconds; Kelly (24), Link (29) and Bickersteth (4) 60 seconds; Thompson (43) 2 minutes unless the subject had already given out; and Moore (32) continued the experiment until the

subject could tap no longer. Some investigators record time instead of number of taps. Seashore (37) measured the duration of one complete movement of the finger (a tap) in hundredths of a second. The record was taken at the end of 7 seconds of tapping. Marsh (31) took the time for 100 taps, Dresslar (14) for 300, and Hollingworth (21) for 500 taps.

Doubtless the use to which the test is put will have an important bearing on the duration of the tapping period. If, as in the present investigation, the purpose is to measure rapidity of movement, it would be useless to continue the experiment after the speed had begun to decrease noticeably. Wells' (50) figures for 30 seconds of tapping showed a continuous decrease in speed, the first 5 seconds being fastest and the last 5 seconds slowest. Davis (13) noted in this connection that on lengthy series of taps there were waves of rapidity, followed in each case by slowing-up. The ease of rapid tapping varied.

The work of Benedict, Miles, Roth and Smith (3) is an example of the ten seconds' period. Their work is the latest thorough study of this problem. But a period of ten seconds is too long for a test of mere speed: this was clearly shown in the records of these investigators. Fatigue soon became operative, there being a steady fall in each of the five two-seconds' intervals throughout the ten seconds. The progressive decrease from each two-seconds' interval was uniformly 0.3 or 0.4 of a complete finger movement. Bolton (9) stated that even five seconds was too long for the most rapid work.

To study the tapping throughout the five seconds' interval it was necessary to revert to the graphic method of recording. The average number of taps in each second of the five-seconds' interval for 18 observers, 5 trials each, was: 1st second, 7.2; 2nd second, 7.4; 3rd second, 7.2; 4th second, 7.1; and 5th second, 7.1. Within an interval of 5 seconds the decrease in speed is very little.

Related to the duration of the tapping period, is the selection of the proper time to start the recording. Bingham (7) insisted that the very first taps should be recorded. In the present study

it was decided to exclude the first few taps because a study of the graphic record showed frequent irregularities in the first part of the second of tapping, probably due to the inertia of getting started. Accordingly in the standardized procedure, the stimulus "Go" is given about a second before the recording begins.

*The optimum number of trials.* No investigator recorded more than five trials. Wells (50) and Bolton (9) each took five series, English (15) recorded four, which were preceded by a ten seconds' practice trial, Bagley (2) and Benedict, Miles, Roth and Smith (3) took three and Smith (39) only two trials. In the study of this question which follows it is quite clear that the observers do not reach their maximum speed in five trials. An initial warming up period seems to be necessary. Thirty observers, ten men and twenty women were given twenty-five trials of tapping, preceded in each case by at least two preliminary practice trials. The results of the thirty observers were averaged for each trial. With conditions standard, the following figures show average number of taps in five seconds for successive periods.

1st practice	2nd practice	1st	2nd	3rd	4th	5th	6th	7th	8th
36.6	38.3	38.8	38.9	39.4	39.5	39.5	39.9	39.5	40.4
9th	10th	11th	12th	13th	14th	. . .	23rd	24th	25th
40.1	40.3	40.7	40.6	40.1	40.8		41.1	41.4	41.1

The results show that fatigue does not operate to any noticeable extent during twenty-five successive trials, when the tapping period of a single trial is no more than five seconds. After the fifteenth period there is essentially no further improvement and no falling off. The average performance for different number of trials in terms of taps per 5 sec. is as follows:

Average for 20 trials	40.3 m.v. .6
Average for 20 trials	40.3 m.v. .6
Average for 15 trials	39.9 m.v. .3
Average for 25 trials	40.4 m.v. .7

Obviously it would be desirable to give as few trials as possible, if in doing so, there would be no sacrifice of speed or accuracy. The scores computed from twenty-five trials, showed a correlation with scores, computed from twenty trials, of  $r .99$ ,  $P.E. .012$  (Pearson's product-moment formula). Twenty trials,

then, give just as reliable a score as twenty-five. Twenty trials may therefore be adopted as the standard method of procedure. Twenty trials would obviously be impracticable with a graphic recording method, but with a counter which is thoroughly reliable, they can be quickly and easily taken.

#### *Directions for giving the test*

To insure uniformity of procedure in the use of this as a standard test, the following directions to the experimenter have been formulated:

Start the metronome and say "Ready" when the wire enters the mercury cup and say "Go" when the contact is open, at the same time throwing the key to the left. The tapping will then begin while the circuit is broken in the metronome, but the record will not begin before the metronome circuit is closed, approximately half a second later. During the succeeding second, when the wire is in the mercury, press the key down, thus shunting the circuit from the metronome. On the fifth second, when the wire is again in the mercury, raise the key, thus breaking the shunt, and permit the metronome contact to determine the end of the period. During this break in the metronome circuit call "Stop" and throw the key to the right.

Seat the observer facing the key. Adjust the stool to his height so that the forearm is in a horizontal position. The hand not in use should grasp the table. Direct him to plant both feet firmly on the floor and lean slightly forward with the entire body in an alert and tense position, ready for action. Drill the observer on the importance of being in the same attitude as in starting for a race—a race of five seconds.

Then engage in preliminary practice so that the observer may become familiar with the working of the key. Demonstrate the thumb and finger method of holding the key. Correct any wrong procedure, such as excessive arm movements, or attempts at trembling. This practice tapping should serve also as a warming up process in which the observer gets set for the heat. The amount of this corrective preliminary work should vary with the need of the individual. One individual may be nervous and needs to be quieted down. Another may be lethargic and needs to be spurred. Emphasize speed only; not regularity. Do not start the recording until you are assured that the best form and the best effort are secured for speed. If insuperable difficulties appear in this preliminary practice, make full and detailed note of these for the interpretation of the record.

At the end of each trial announce the result, and challenge the observer to excel his record. Remind him of the importance of focusing all his effort into the short period of five seconds. Allow a few moments between trials and see that the observer relaxes completely. If there occur noticeable breaks in the tapping of more than twice the duration of a single tap, throw out that record before reading what the record is, and give him another trial. Record results for twenty trials.

To help get the maximum effort from the observer the object of the test is briefly explained; then the "Charge" is given, and finally praise of his efforts and a word of encouragement after each trial.

Just before the preliminary trials and again before the first recorded trial, give this charge: "Remember it is speed that counts. Let nothing interrupt you until I call 'Stop.' Keep your eyes on the key. Do your utmost. Tap as fast as you possibly can."

If the charge does not seem to be effective, use any device to stimulate the observer or quiet him, as the case may demand. The test is made under the supposition that the experimenter has been successful in securing the observer's very best effort.

*Sources of error in tapping.* A sudden muscular rigidity in the arm, a sort of momentary paralysis in which the arm moves neither up nor down, occasionally interrupts the tapping. These "breaks" can often be avoided by having the observer tap less forcefully and with a less tense position of the arm. It is not uncommon to have attempts at increased speed result in merely increased force. Too much muscular effort in tapping interferes with the subject's maximum speed.

Smith (39) called attention to "tremor" and considered its rate as different from the rapidity of voluntary movement. The observer should be shown that distinct up and down movements of the forearm are necessary.

The following movements call other joints into play and slow down the rate: shoulder joint movement of the full arm, a finger movement, a hand and wrist movement of large amplitude while the fingers still hold the key, and side movements of the hand. They are all examples of wrong procedure which must be corrected.

Lifting the hand high from the key between taps is but another example of wrong procedure. Another is the attempt to alternate the tapping between the pointer and middle fingers, as in the trilling movement on the piano, which interferes.

More central, subjective factors sometimes lessen the reliability of the results: unfamiliarity with key, a hesitancy in bending all effort to show a maximum speed, a failure to assume an alert, tense position of the body; wandering of attention (most noticeable in children) from the tapping to the clicking electrical counter; and the tendency of those experienced in telegraphy to want to send symbols, etc. Proper cautioning and tact are usually effective in overcoming these difficulties.

*The effect of practice on the tapping rate.* Practice in tapping resulted in increased regularity of performance rather than in increased speed according to Johnson (23) and Raif (35). Dresslar (14) thought that practice had no effect after the third

day but Wells (48) stated that the practice curve was very gradual in ascent and fluctuated somewhat from day to day. Johnson (23), after experimenting with the toe tap, asserted that the effect of practice is greater in proportion to the undeveloped state of the muscles. Davis (13) concluded that the results of practice were central rather than peripheral, the central factors being a development of motor centers and an increased will power and concentration of attention during the tapping period.

To determine the effect of practice on ability in this test, six normal adults were chosen to repeat the test daily, under uniform conditions for a period of twenty days.



FIG. 2. Twenty day practice experiment, six subjects; numbers at bottom, successive days; numbers at left, average number of taps in five seconds.

The results of this practice series are shown in Figure 2. The mean variation is so constant for all observers that there is no object in representing it in the graph. The amount of gain by practice is very small. The curve is quite different from the learning curve in a more complex process. Three observers showed improvement, three did not; where gain was found, it was due to improved technique, less perversion of procedure in attempted trembling, etc. Where improvement did not occur, the observers developed good technique the first day, were quite regular in their performance and put forth their maximum effort.

The experiment bears out the statement of Binet and Courtier (5) to the effect that low variability is a sign that the effect of practice has already been accomplished, and there is no chance for much further improvement. Of two persons having the same average score, the one with the high variability has better chance for improvement.

Aside from the question of improvement, other items relevant to rapidity of performance were noted. Mental work immediately preceding the test resulted in increased speed, as mentioned by Dresslar (14). Nervous irritation resulted in faster work; likewise irritability due to a cold. Sitting in a cold room caused a slowing up or a longer preliminary practice period to reach normal performance. More than the usual amount of sleep resulted in muscular and nervous lethargy and a retardation.

The effect of practice is very important in considering just what the test measures. If the ability required in the test is fundamental rather than accessory, learning will play a very small part and there will be very little improvement with practice. And this is seemingly just what the practice experiment showed. No improvement would indicate that a *basic* motor capacity is being tested.

*Rates and norms.* The average rate is of course conditioned in large part by the duration of the tapping and the methods of procedure. When speed of performance is the one object in view, the average rates have been recorded as follows: Dresslar (14), 8.5 taps per second; Franz (16), 8 per second, Wells (48) found an average of 35.3 taps for the first five seconds of his thirty seconds' interval. Woodworth (54) placed the upper limit at 10-11 taps per second; Bryan (10), 11 per second for a short interval; and Von Kries (45), 10-11 per second but designated 11-12.4 per second as the maximum rate of innervation. Wells (48) found that the fastest and slowest subjects varied in the ratio of about 3.2.

Wells (48) noted that the m.v. was usually 1% to 3% of the rate and Bryan (10) stated that the m.v. was rarely more than one tap per second. Fatigue as a factor in variability began to show after ten or fifteen seconds' work, according to Bryan (10). As to regularity, Bliss (8) found that the time interval between taps was constantly varying, it was seldom exactly the same for two successive taps. This time variation within the series was quite evident in the present study's experimentation on



University sophomores. The time of day was accompanied by variations in rapidity; that afternoon tapping surpasses that of the morning was noted by Dresslar (14), Hollingworth (21), Marsh (31), and Stecher (41). Dresslar (14) placed the maximum at 4 p. m. but according to Gilbert (17) the later periods of the evening were the most rapid of all.

In the autumn of 1917 164 sophomores were tested. Three five-second trials for each individual were graphically recorded. The figures shows median time per tap (sec.) .116, m.v. .012; mean .119, m.v., .012. The distribution is given in Table I on the basis of which percentile norms are given in Table II.

TABLE I. *Distribution of tapping time*

Scale in hundredths of a second per tap	Men No.	%	Women No.	%	Total No.	%
8.0-8.4	1	.9	0	.0	1	.6
8.5-8.9	2	1.8	0	.0	2	1.2
9.0-9.4	2	1.8	0	.0	2	1.2
9.5-9.9	5	4.7	0	.0	5	3.0
10.0-10.4	13	12.2	3	5.1	16	9.7
10.5-10.9	14	13.2	6	10.3	20	12.2
11.0-11.4	18	16.9	9	15.4	27	16.4
11.5-11.9	21	19.8	3	5.1	24	14.6
12.0-12.4	14	13.2	9	15.4	23	14.0
12.5-12.9	6	5.6	5	8.6	11	6.7
13.0-13.4	2	1.8	5	8.6	7	4.2
13.5-13.9	3	2.8	4	6.9	7	4.3
14.0-14.4	2	1.8	4	6.9	6	3.6
14.5-14.9	2	1.8	4	6.9	6	3.6
15.0-15.4	0	.0	2	3.4	2	1.2
15.5-15.9	0	.0	1	1.7	1	.6
16.0-16.4	0	.0	2	3.4	2	1.2
17.0	0	.0	1	1.7	1	.6
23.0	1	.9	0	.0	1	.6
Totals	106	99.2	58	99.4	164	99.4

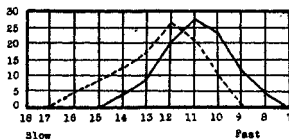


FIG. 3. Speed in tapping: dotted line, women; solid line, men; numbers at bottom, scale in hundredths of a second per tap; numbers at left, per cent of cases.

TABLE II. *Percentile ranks for adults*

(Derived from 164 cases, sophomores in State University of Iowa)

% Rank	Time per tap	Taps per sec.	Taps in 5 sec.
100	.083	12.0	60.0
95	.097	10.3	51.5
90	.102	9.8	49.0
85	.104	9.6	48.0
80	.106	9.4	47.0
75	.108	9.3	46.5
70	.111	9.0	45.0
65	.112	8.9	44.5
60	.113	8.8	44.0
55	.114	8.7	43.5
50	.116	8.6	43.0
45	.118	8.4	42.0
40	.120	8.3	41.5
35	.121	8.2	41.0
30	.124	8.0	40.0
25	.126	7.9	39.5
20	.130	7.6	38.0
15	.137	7.3	36.5
10	.143	6.99	35.0
5	.148	6.7	32.5
1	.238	4.2	21.0

*Age and sex differences.*

The tapping rate increases steadily between the ages of 6 and 19. This fact was noted by Gilbert (18), Bolton (9), Bryan (10), Smedley (38), and Bickersteth (4). Each writer, however, offered certain limitations. Bolton (9) stated that age differences of 8 and 9 year old children were less than individual differences of those ages; also that increase of motor power was less marked with mentally inferior children. Bryan (10) estimated that the rate of the child of 6 was two thirds the rate of the youth of 16. According to Gilbert (18) and Smedley (38), the increase of speed with age had one marked exception, at ages 13 to 14 there occurred a slight but noticeable falling off. Gilbert (18) attributed this to puberty. Bickersteth (4) noticed a slight falling off at age 15. Gilbert's (18) table of norms for ages 6 to 19 is typical of experimentation of this kind and is reproduced for purpose of comparison with results of the present study, in which the children of the University Elementary School were tested. About one hundred and thirty children of Grades I to VI inclusive were given the tapping test under standard conditions.

TABLE III. *Age and Sex Norms*

Age	GIRLS				BOYS			
	Gilbert Taps	M.V.	Ream Taps	M.V.	Gilbert Taps	M.V.	Ream Taps	M.V.
5			16.6	1.2			18.8	1.1
6	22.3	2.2	20.3	1.3	22.1	2.1	20.8	1.0
7	24.5	2.7	22.7	.7	23.3	2.7	22.7	1.3
8	26.0	2.5	25.0	.7	25.0	2.4	27.1	.8
9	26.7	2.5	28.0	.9	27.1	2.4	28.2	.8
10	26.2	3.0	28.7	1.0	28.3	2.6	31.1	1.2
11	28.0	3.1			28.1	2.2		
12	29.3	2.2			30.1	2.9		
13	29.5	2.7			31.1	3.8		
14	29.4	2.6			32.4	2.9		
15	31.3	2.7			34.0	2.6		
16	32.2	3.1			34.0	3.1		
17	33.8	3.0			34.4	2.2		
18	34.3	2.4			36.0	3.1		
19	35.3	3.1			36.7	3.3		

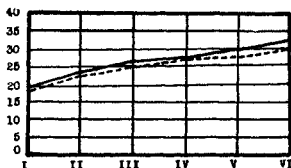


FIG. 4. Variation in tapping with grade: solid line, boys; dotted line, girls: Roman numerals, school grade; Arabic numerals, numbers of taps in 5 seconds (Ream, Table III).

A very clear verification is found in these records of the increase in tapping rate with age and physical growth. With the exception of ages 6 and 7 the rates are noticeably faster than Gilbert's (18), and on the whole, the mean variations are much smaller.

As regards sex differences investigators are practically unanimous in the conclusion that men are faster than women and that boys excel girls. Cattell (12), Thompson (43), Smedley (38), Bryan (10), and Bagley (2) are examples. Bolton (9) found that girls surpass boys at the ages of 8 and 9, Gilbert (18) from age 6 to age 8 inclusive, and Bryan (10) noted that girls excelled at age 13, but were inferior in all other cases.

Burt and Moore's (11) records showed that 68.8% of the boys exceeded the median score of the girls; Thompson (43) found 88% of men faster than the median for women; and with Hollingworth and Poffenberger (22), the tapping test ranked highest, 71%, in number of men reaching and exceeding the median performance of women. These findings were corroborated in the present investigation on adults. Sex and age differences are shown graphically in Fig. 4, and Fig. 5.

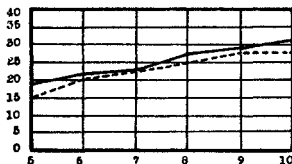


Fig. 5. Same data as in Fig. 4, expressed for age instead of grade.

Wells (49) considered women less variable than men when he prolonged the tapping test into a fatigue test but this conclusion was not borne out in the present study. The women showed larger mean variations on every trial than the men. However, the initial large variation of the women was materially reduced on later trials. A number of the women seemed to show an initial hesitancy in beginning a test of motor ability.

#### *Relevant correlations.*

A great many investigators have been anxious to determine the relationship between motor and mental capacities. The tapping test, as one of the simplest motor tests, has been frequently correlated with mental tests. Results and conclusions are far from unanimous. The correlation with mental ability was found to be positive by Bolton (9), Smedley (38) and Kirkpatrick (26). Binet and Vaschide (6) reported it positive with children of 12 years and negative between the ages of 16 and 20. Gil-

bert (18) found bright children generally better in tapping. Dresslar (14) reached the conclusion that the rate of voluntary movements was something of an index to central nervous activity. Burt (11) reported correlations with intelligence of .44 at one school and .28 at another school. Abelson (1) having tested 188 girls found marked correlations with interpretation of pictures, crossing out rings, memory for names of objects, and memory for commissions. Stecher (41) reported interesting correlations with mental multiplication  $r$ , .24; with aiming  $r$ , .31; with hand steadiness  $r$ , .07; with arm steadiness  $r$ , .03; and with eyelid tremor  $r$ , .21.

Other writers, however, were just as insistent that performance in tapping bore no relation whatever to mental brightness. Among these were English (15), Gilbert (18), and Smith (39). Three out of four highest scores, recorded by Smith were made by demented epileptics. Bagley (2) and Bickersteth (4) even maintained that the relation was inverse between mental and motor ability. From the evidence at hand, an assertion of positive relation between the two types of performance is certainly unwarranted; what is evident, however, is the need for more careful investigation along this line. Burt (11) made an interpretation as follows: "So far as motor rapidity is the function of temporary 'facilitation' of the paths of neural discharge, it appears also to be a function of intelligence; while so far as it is a function of permanent 'canalization' of those paths, it is but slightly or inversely related to intelligence."

Much more interesting is the question of a relation between tapping rate and proficiency in certain occupations. Link (29) tested employees of the Winchester Arms Company. In the case of shell inspectors, tapping had the smallest correlation of any of his seven tests,  $r$ , .135, P.E. .071. In this kind of work, keen eyesight was the first essential. But in the case of gaugers, tapping had the highest correlation,  $r$ , .516, P.E. .071. In this work speed of movement was most important. Hollingworth and Poffenberger (22) found a correlation of .34 between tapping rate and proficiency in hand sewing. As regards

piano playing, Raif (35) maintained that a high tapping rate was not necessary in order to become an artist in piano; for, he said, the fingers alternate in their movements, and it is never necessary to repeat any movement more times per second than the normal rate in tapping. However it can be contended that tapping as one measure of an individual's total motor set and equipment, may have a bearing on performance in music.

In the efficiency studies, Benedict, Miles, Roth and Smith (3) reported a decrease in rate with restricted diet and Hollingsworth (20) a decrease with alcoholic beverages, but the same writer reported that the use of caffeine had a stimulating effect in the tapping test.

The correlation between speed score and regularity score, (M.V., 164 cases) proved to be  $r = .32$ , P.E. .05, showing that a positive correlation is present, but it is not marked. The four combinations of speed and regularity were found: fast and regular, fast and irregular, slow and regular, and slow and irregular. For the most part, however, the fast tappers were more likely to be regular and the slow tappers irregular.

The correlation between speed in tapping and simple reaction time (157 cases) was  $r = .21$  P.E. .05. There was a positive correlation present but quite small, barely four times the probable error.

*Factors conditioning rapidity of performance in tapping.*

A number of writers have suggested that individual differences in rate are conditioned in a general way by fundamental neural factors. Wells (48) stated that physiologically the maximum rate is limited by the refractory phase of the synapses in the motor pathways. In consideration of motor development Bolton (9) similarly explained that it is based upon growth of interrelation between nerve elements. Arrest of growth is due to suspension in growth of associative connections. Von Kries (45) and Kirkpatrick (25) supported the view concerning the neural character of the limit placed upon the maximum rate. In addition to this important factor, Whipple (51) appended another condition, viz., the ability to coordinate voluntary move-

ment. Evidently a certain amount of simple coördination is required in tapping. This second factor might help to explain Wells' (48) statement that although nervous temperaments were usually fast, some are below the average rate. He also stated that a fast rate is not always related to general quickness. Obviously general motor quickness is dependent also on power of coördination, temperament, muscular habits, training and environment. But the striking individual differences in performance can not be wholly explained by these contributing factors. Every individual has his own motor set-up, one is geared slow and another is geared fast. The chief factor in the different tapping rates which result is probably a physiological openness of nerve paths which is inherited. It enables an individual to maintain his approximate percentile standing in motility among individuals of his own age and development if the contributing factors mentioned above are constant.

To what extent ability in tapping is an inherited capacity no writer has stated. The extended practice experiment of the present study seemed to indicate that the test measures fundamental, basic abilities since improvement was on the whole, conspicuously lacking. The inference is that the motive neural set, undoubtedly an important condition of such basic ability, is inherited. There are other conditions, however, which are surely subject to training. Coördination of movement, regularity and smoothness of performance, illustrated by training in piano, are mentioned by Binet and Courtier (5) as improved by practice. Raif (35) likewise, emphasized the improbability of coördination of movement. Davis (13) noted that such results of practice as appeared, were central rather than peripheral, viz., (1) those dependent on the development of motor centers, that is, their improvement through exercise; and (2) those dependent on the development of psychical factors, attention and will power.

*Subjective factors conditioning rate and regularity of performance.*

Johnson (23) enumerated several subjective factors which affected individual differences in rate: physical condition,

rapidity of heart beat, and body temperature, power of fixation of attention, and influence of emulation. Wells (48) noted increases with improvement of physical condition. However, on numerous occasions in the present study, the subject's estimate of his physical condition was no indication at all of the character or rate of his performance. Davis (13) also belittled the influence of general physical tone. But on the other hand, mental factors, as interest, effort, nervousness, or irritability resulted in increased rate. Stecher (41) said that tapping was peculiarly subject to an end spurt because of interest, rivalry, etc. Marsh (31) said in this connection: "Rapidity of tapping as it requires a minimum of control but a maximum of neural excitement, may be expressive largely of nervousness." The late evening produced the fastest scores; increased nervousness at that time of day was suggested as an explanation. The experimentation of the present study has led to the conclusion that the one subjective factor of real significance is maximum effort. Interest, rivalry, nervousness are mere accompaniments or expressions of the subject's desire to do his utmost. For this reason, the standard directions for giving the test, after the technique has been properly established, put all stress on stimulating the subject to his best effort.

To recapitulate, motor power is not a simple phenomenon but a complex of rapidity of control, steadiness and precision of movement, strength, endurance, etc. Motility is but one element of motor power, yet it is one of the most fundamental. It is stated by Bolton (9) that the muscles of the body form a graduated series, from the most fundamental to the most accessory. And all experimentation thus far points to the conclusion that the muscles' neural equipment used in the motility test are among those earliest developed and most fundamental in character.

#### *Application and future experimentation.*

In spite of all the experimentation to which the tapping test has been subjected, its use as a measure of motility has only begun. The present study has gone scarcely further than the standardization of apparatus and method of giving the test. There remains to be studied its diagnostic value in determining



proficiency in many lines of industrial work. This can be done only by testing persons engaged or about to engage in the specific line of industrial work.

The tapping test may very possibly be of value in all those occupations and activities in which rapidity of movement is an important factor. Telegraphy, typewriting, hand sewing, music, sorting, folding, and packing work in factories are but illustrations of the vast array of human endeavors in which motility counts. Motility, as a basic motor capacity, will likely become one feature of a motor psycho-graph, in which an individual's motor abilities and weaknesses are graphically represented.

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