INVESTIGATIONS IN REACTION-TIME AND ATTENTION

BY

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Introduction.

The work described in the following pages occupied the greater part of my time during the academical year 1892–93. As I was the first to carry on such experiments in the Yale psychological laboratory, a large part of my fall term was spent in preparing the apparatus and in developing a method which should serve for all future experiments. The result is a method for measuring reaction-time which is in some parts entirely new. In operation it is simple and accurate, having been built up step by step as the needs required. In the hope that the whole or parts of it will be of value to other laboratories, the description has been made as complete as seemed necessary.

In the experimental part of the work I am especially indebted to the following persons for valuable time which they have spent in the reaction-room. To Messrs. Thomas J. Lloyd, William I. Cranford and Joshua A. Gilbert of the Graduate Department, and to Mr. Joseph Roby, a member of the senior class in Yale College.

During the second term, Abraham Fisher, the laboratory steward, recorded all the experiments, thus leaving me free to do my own reacting. The advantage of doing my own introspective observing was an important one.

Dr. Scripture not only suggested the first problem but has always been ready to assist me in carrying out the experiments and in arranging the apparatus. In fact, parts of the apparatus were invented by him. One line of research was carried out at the suggestion of Professor Ladd, who has always shown a kindly interest in my work.

In the drawing of the diagrams valuable suggestions were received from Mr. Walter I. Lowe, a member of the Graduate Department.

Apparatus.

Apparatus for measuring reaction-time must furnish some means for giving the reactor a stimulus and for measuring the interval of time between the moment in which the stimulus is given, and that in which the reaction takes place. The time-measurement must be accurate to thousandths of a second and the person experimented upon must, so far as possible, be free from all influences which would distract his attention.

This last requirement was met by placing the reactor in a separate room, so constructed as to be free from light and sound. In the center of the building a room was finished off, twelve feet long, nine feet wide and nine feet high. Inside of this room a smaller one was constructed with a door and ventilator corresponding to those of the outer room. This inner room was supported on thick cushions of felt and rubber, the only connection with the outer room being heavy canvas around the doors and the ventilators for the purpose of holding back the sawdust with which the space between the two walls was filled. The door was likewise made double with beveled edges, like a safe door, so that it shut tightly against the canvas connecting the two rooms. A thick mat, made of hair felt and covered with cloth, was hung up over the door on the inside. This acted like a heavy curtain to check any sounds which might creep in around the door.

During the experiments the door of the dark room was not shut more than five or ten minutes at a time. For that period the ventilator could be kept closed without producing any bad effects. In the case of longer experiments it is proposed to open a ventilator in the floor and pass a current of air through the room by means of a blower. The ventilators can then be packed with wool or some other material, which will allow the passage of air, but effectually shut out all sound. The experiments described in this paper were all taken in the winter, and the temperature of the room was the same as that of the rest of the building. Very loud sounds in adjacent rooms can still be heard in the reaction-room. Heavy wagons, which occasionally pass along the street, jar the whole building and with it this room ; the shaking can be felt but not heard. When the adjacent rooms are kept quiet, the reaction-room is free from sound. The reactor is thus practically removed from all external disturbances in sight or hearing.

There are two methods in use for measuring intervals of time to thousandths of a second, the graphic method and that of the chronoscope. The Hipp chronoscope is the most perfect piece of mechanism thus far constructed for recording such short intervals of time on a dial. An immense amount of time and labor has been spent in perfecting this chronoscope and in investigating its accuracy. In its most perfect form there is always a very large error in the results as they are read off from the dial. This error depends on the relative strength of the electric current passing through it and that of a spring which pulls back the armature when the circuit is broken. A control-apparatus must be used which consists of a hammer so arranged that it can be made to fall certain distances. The time required for this fall is carefully measured by the graphic method and the spring of the chronoscope adjusted until the chronoscope itself measures the time of fall with the same result. Other times are accurately obtained by correcting the recorded results. The chronoscope in one of its forms is then accurate only for times of about that length. G. E. MÜLLER claimed[1] that Münsterberg's experiments contain a large error even though he had corrected his chronoscope by a control-hammer. That particular hammer was made to correct the chronoscope for intervals of 160 thousandths of a second, whereas many of Münsterberg's experiments gave times as high as half a second. Although Münsterberg seems to have avoided the error supposed, yet the danger is evident. A more elaborate control-hammer has been constructed by Wundt.[2] By means of this hammer correct times can be given up to 616 thousandths of a second. The mean variation of this hammer in 200 experiments was 1.04 thousandths of a second. The mean variation of chronoscope and hammer combined was also 1.04^{σ}. This, the best result which has yet been obtained from the chronoscope, is ten times as great as the mean variation of the graphic method in its simple form.[3]

In the graphic method a tuning-fork, kept in constant vibration by a current of electricity, is allowed to trace a curve on a revolving drum covered with smoked paper. This gives a representation of a period of time divided according to the rapidity with which the fork vibrates. Using a fork which vibrates one hundred times a second the drum is revolved with such rapidity that the single waves are so long that we make no error in estimating tenths of a vibration and so reading the results in thousandths of a second.

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[1] Göttingische gelehrte Anzeigen, 1891, p. 398.

[2] KÜLPE and KIRSCHMANN, *Ein neuer Apparat zum Controle zeitmessender Instrumente*, Phil. Stud. 1892 VII 145.

[3] WUNDT, Physiol. Psych. 3 ed. II 282.

Now, given this tuning-fork curve, all that is needed is some method of registering alongside of it the exact instants at which the stimulus and the reaction occur. Fig. 1 shows the usual way in

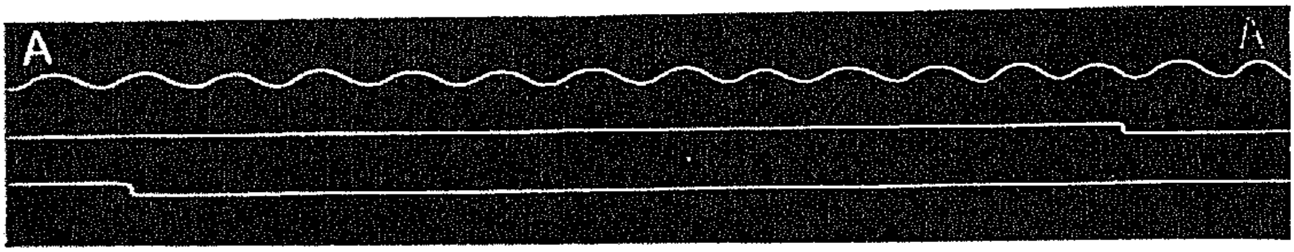


Fig. 1.

which this is done. The upper curve is drawn by the recording point of a tuning-fork which vibrates one hundred times a second. The other two lines are drawn by electro-magnetic time-markers. The current passing through one passes also through the key whose closing produces the stimulus. The current through the other passes through a key in the reaction-room. The movement of each key is thus recorded by a break in the straight line drawn by its time-marker. These points are then transferred to the tuning-fork curve by dropping perpendiculars from the points to the curve. The measure of the time which has elapsed between the movement of the two keys can then be counted off on the time-curve.

The objection to the use of this method in making a large number of experiments is that it takes a long time to drop the perpendiculars and that great variable errors are likely at the two points. These errors are increased by the fact that the time-markers must be adjusted so that they shall both touch the drum in the same perpendicular line. Moreover, the latent times of the markers may not be the same.

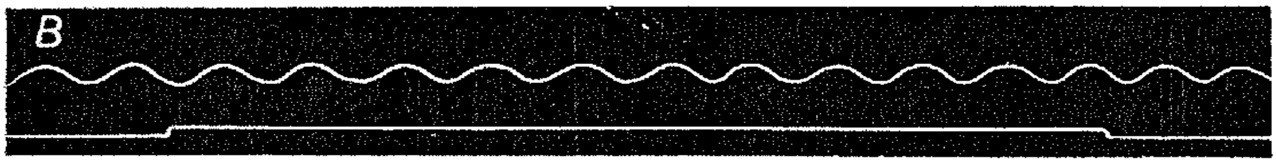


Fig. 2.

An improvement upon this method has been made by doing away with one of the markers. The same current is passed through both keys and through one time-marker. Fig. 2 shows a measurement made by this method. Closing the stimulus-key draws the lever of the marker toward its magnet, making a break in the straight line. Opening the key in the reaction-room breaks the circuit and allows the lever to fly back again, thus making a second break in the same straight line. These two points are transferred to the time-curve and the interval is counted off as before. The result is that the number of lines on the smoked paper is reduced by one-third, allowing more experiments to be taken on the same paper and making the records easier to count. But more important than this is the fact that one large source of error is removed. The accuracy of the result no longer depends on the adjustment of the two markers so that they shall touch the drum in the same horizontal line.

The latent time for the two movements is generally different. And there still remains an error and a great loss of time in transferring the two points to the time-curve. What is wanted is some means of registering the interval directly upon the curve itself. This has been accomplished after trial of various methods. The first suggestion was to arrange an apparatus so that the stimulus-key when it was closed should start the curve and the reaction-key stop it by being opened. This was done by taking the fork from the drum and replacing it by one of the electro-magnetic markers. The current was run through the tuning-fork, the time-marker and the reaction-key, but it was short-circuited through the stimulus-key.

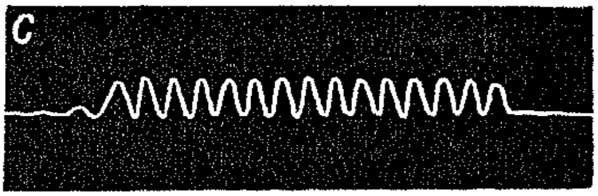


Fig. 3.

As long as the stimulus-key remained untouched, the marker did not vibrate; but as soon as it was touched, the record began. When the reaction-key was pressed, the entire circuit was broken and the record ceased. Such a record is shown in fig. 3.

At first sight this might appear to solve the problem but a closer examination shows that this is not the case.

Fig. 4 shows the way in which the Pfeil marker works. B is the battery, F the tuning-fork, M an electro-magnet, S a steel armature which serves as a spring; the lever is attached at O. This lever swings on a pivot at H; when the circuit is complete the vibration of the fork alternately makes and breaks the current at X. As soon as it is made the coil in the fork becomes a magnet, pulls the prongs inward and breaks the circuit. This demagnetizes the coil, the prongs fly back and the process is repeated indefinitely. But when the current is closed at X, the magnet M draws down the armature and its lever. When the current is broken in the fork the armature flies back carrying the lever with it. Thus the point P vibrates in unison with the fork.

Let CDE be a section of the curve which would be traced by the marker. From C to D the motion of the point comes from the spring that causes the armature to fly back. From D to E the motive force is a combination of the spring and the magnet. Now if the stimulus-key, which starts the current through the marker, is opened between C and D, no effect will be produced until the point D is reached for no current is passing through the circuit. Therefore the chances are one in two that the beginning of the movement will be too late by anywhere from 0 to 5^σ, the section of the curve from C to E being 10^σ with a tuning-fork which vibrates 100 times a second.

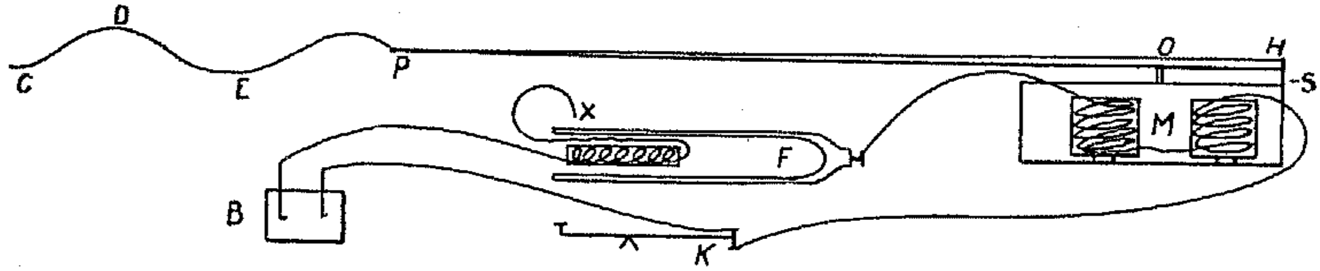


Fig. 4.

At the end of the interval the case is not quite so clear. If the reaction-key breaks the circuit between C and D, there will be no effect until the point D is reached. But, unlike the beginning, the effect will not be shown at D. For, when the marker is in motion the motive force, between D and E is a combination of the spring and the magnet. Near D the spring is stretched. The tension gradually decreases passing from a positive to a negative quantity somewhere below the middle point, while the force of the magnet gradually increases the nearer the armature approaches it. Therefore the effect of a break in the current is not shown until the magnetic component of the motive force reaches a certain strength in proportion to that of the spring before it is interrupted. Suppose that this takes place when three-fifths of the distance DE have been passed over, then the chances are seven to ten that the end of the interval will be registered anywhere from 0 to 7^σ too late.

In a large number of experiments these errors at the beginning and end would partially balance each other, but their presence would still be shown by the large mean variation. The beginnings would on the average be 1.25^σ too late and the ends too late by 2.45^σ. In a small number of experiments the results are not accurate beyond hundredths of a second. By using a fork which vibrates 500 times a second, the error would be reduced to 2^σ and by using a fork vibrating 2000 times a second, the method would be accurate to thousandths of a second. This however is impossible since the time-markers are not delicate enough to record such rapid vibrations. Even if they were, the task of counting so many wave-lengths would render the method of no practical use.

The next step was to arrange the apparatus so that the time-marker vibrated continually in unison with the tuning-fork, but yet

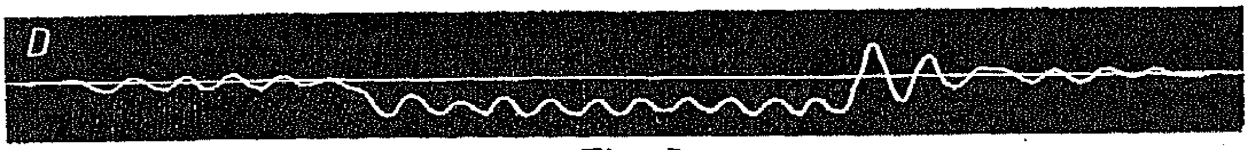


Fig. 5.

so that closing the stimulus-key sent an additional current through the time-marker, which additional current was released by opening the key in the reaction-room. The result is shown in fig. 5. During the interval to be measured the vibration of the marker continues in a different line from that of the normal time-curve. Here we have the beginning and end of the interval accurately marked. By adjusting the strength of the two currents and the rapidity of the drum, this method will probably be quite successful. If so, it will be superior to any other method heretofore used. It is possible however only with the Pfeil marker which has a steel spring as shown in fig. 4; for it consists in a partial magnetization of the electro-magnet which draws the spring part way but still leaves room for it to be affected by the current passing through the tuning-fork.

This method was not used in the following experiments for the reason that a much better plan suggested itself. Instead of trying to change the curve to mark the beginning and end of the interval the apparatus was so arranged that closing the stimulus-key broke the primary current of a spark-coil and sent a spark from the tuning-fork to the metal drum through the smoked paper. Opening the key in the reaction-room likewise broke the same current and sent another spark through the smoked paper. Fig. 6 gives a speci-

Fig. 6.

men record taken by this method. Here we have both ends of the interval marked exactly, there is no time lost and no error arising from transferring the interval to the time-curve or in adjusting the markers on the drum.

The question now arises whether the spark occurs at the exact time the primary circuit of the spark-coil is broken. In a large dynamo the spark might be delayed several seconds, but in a small coil such as is used for this purpose there is no delay sufficient to affect the result. Fig. 7 is one of a series of experiments made to test this point. The time-curve represents hundredths of a second. The straight line was drawn by a pointer attached to the lever of a key, the least motion of which broke the primary current of the spark-coil, sending a spark from the key to the drum through the smoked paper. None of these experiments show any latent time.

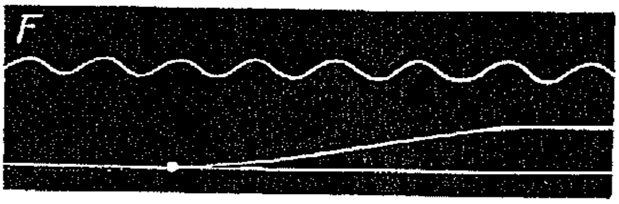


Fig. 7.

Even if there were a latent time which could be detected by reading to ten-thousandths of a second, that would not affect the reliability of measurements taken by this means. For the same coil, under the same conditions, this latent time would remain constant. The spark which marks the end of the interval would be delayed just as much as the spark which marks the beginning; the interval between the two would be exactly the same as though both sparks were in their proper places.

Presupposing the accuracy of the tuning-fork, this method is absolutely accurate to thousandths of a second. In counting the records one falls into the habit of counting by threes, making use of the psychological fact that three things can be kept in consciousness at the same time as easily as one. In this way a paper containing twenty-two records of simple reaction-time can be counted in four minutes. This is a much shorter time than is required to record the readings of the Hipp chronoscope and correct them for the variable error.

The only justification for the use of the chronoscope lies in the supposition that it saves time. The method here described is much simpler and quicker, in addition to being absolutely accurate. For simple reaction-time this method is far more accurate and rapid than any hitherto described. But for longer times, such as association-time or discrimination-time, some easier method must be devised for counting the records. It is suggested that another time-marker be placed on the drum; this marker to be connected with a pendulum or clock work which shall mark every third or fourth wave of the tuning-fork curve. With this assistance it will be possible to count long records quickly and accurately.

Two drums were used in these experiments, an electric drum and a König drum.

The electric drum consists of a brass cylinder mounted on iron brackets so as to turn on its axis. It is rotated by a small electric motor clamped to the right side of the table. Linen thread serves for a belt. The tuning-fork, or the marker is mounted on a carriage which moves along a track parallel to the drum by means of an endless screw turned by a crank at the left side of the table. One turn of the screw moves the marker on the drum one-quarter of an inch to the right or left. By regulating the strength of the current which runs the motor considerable variation can be produced in the speed of the drum, while a switch near at hand allows the motor to be stopped or started at will.

Two kinds of curves are produced by this drum. In fig. 8 the marker, or the fork itself, is kept vibrating on the drum all the time

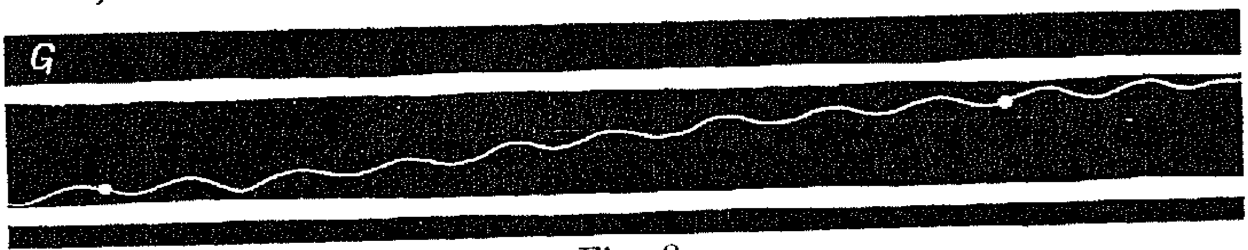


Fig. 8.

When a record is taken, the marker is quickly moved to the right or left by a turn of the screw. The record is made during this sidewise movement of the marker, the result being two white bands with the record on a curve passing obliquely from one to the other. The first spark comes from the stimulus-key, the second from that in the reaction-room.

At first it is somewhat difficult to make these two motions, the one with the right hand, the other with the left, just at the right instant, but a short practice enables one to do it with ease and accuracy. The whole difficulty, however, is removed by the multiple key to be described below. Using that, together with the electro-

Fig. 9.

magnetic time-marker, we produce the curve shown in fig. 9. The marker remains stationary, simply drawing a white line around the drum. Opening the stimulus-key starts the marker vibrating and an instant later gives the stimulus which is marked by a spark on the curve. As soon as the spark from the reaction-key has been recorded, the multiple-key is released, and the marker ceases to vibrate before the drum has made a complete revolution. The marker is then moved to the right or the left by a turn of the screw and another record is taken. A similar record on an ordinary drum is shown in fig. 10.

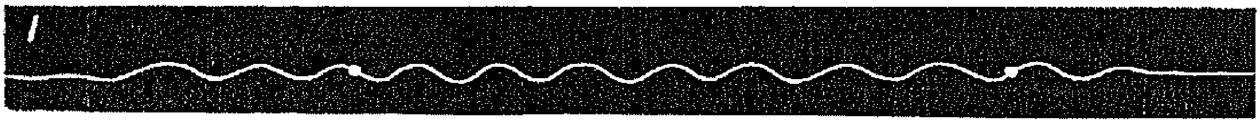
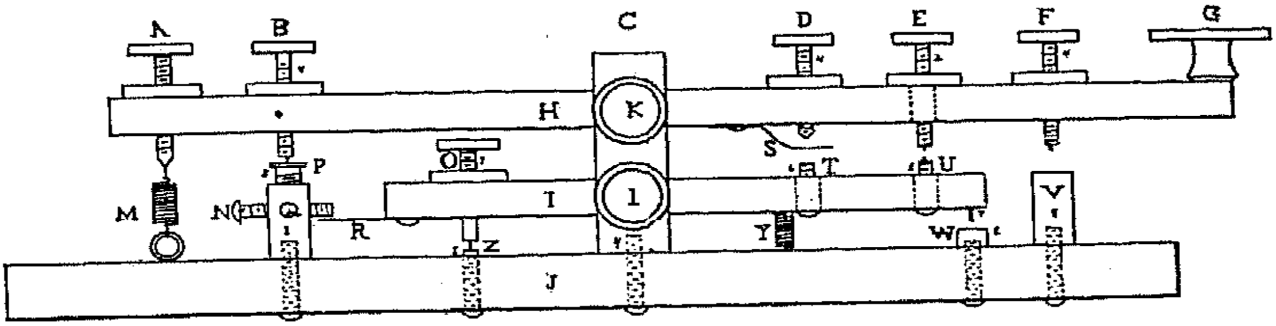


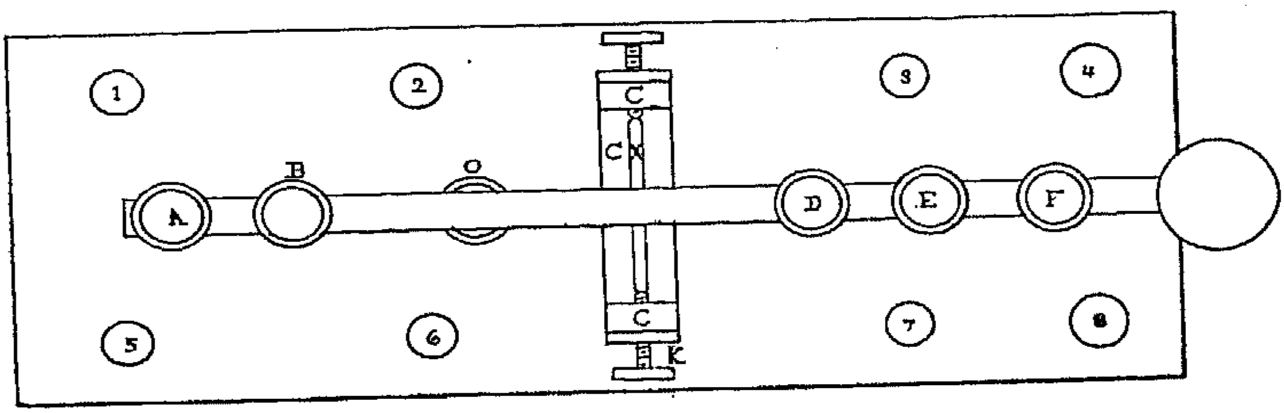
Fig. 10.

The other drum is constructed, as can be seen in fig. 13, so that every turn of the crank moves the drum itself half an inch to the right or left. In this case the standard holding the marker or the tuning-fork remains stationary. One hand turns the drum once around while the other closes the stimulus-key. The reaction always follows before the revolution is completed. For simple reaction-time this is much the better drum of the two. The records are always the same distance apart and can be made to begin in the same horizontal line on the drum, thus making the counting of the records much easier than those of the electrical drum which are scattered over the paper and are liable to be cut in two when that is removed from the drum. For other purposes the electrical drum is to be preferred.

It is evident from the various functions ascribed to the stimulus-key that something more than the ordinary telegraph-key is implied. In every case it is assumed that it produces the stimulus and records it at the same instant on the drum by means of a spark. In addition to this it sometimes starts the tuning-fork curve just before the stimulus and stops it just after the reaction has taken place. The necessity for some contrivance by which such things might be done was felt at the beginning of the work and led to the invention, by Dr. Scripture, of the multiple-key.

Figs. 11 and 12 show drawings of this key. It consists of two square bars of brass I and H rotating on small steel axles X held in place by check-screws K L passing through the upright parts C of a firm brass frame which is screwed to the wooden base J. One end of each bar is held by a spring M, Y; the strength of M is regulated by the screw A. Besides this there are four other screws B, D, E, F, which pass through the upper lever, one of them F being insulated from the lever by hard rubber. The screw B rests upon a small steel plate P, insulated by a hard rubber screw from the brass stanchion Q and connected by wire on the underside of the base with binding-post 5. None of the binding-posts are shown in the elevation because they would conceal important parts of the key. The screws B, D, F are connected through the brass rod, steel axles and upright support with a screw that passes through the base and thence by insulated wire with binding-post 4.





Figs. 11 and 12.

The screw B being adjusted so that the upper lever is level, the screw F regulates the amplitude of its movement. By means of this screw it makes contact with the brass stanchion V. The screw E which is insulated from this lever, is connected to post 2 by insulated wire running along the lever, down the standard through the base. The screw U with which it comes in contact is also insulated from its lever and connected in a similar way with binding-post 3. By means of screw D the copper spring S can be made to make contact with screw T which is insulated from its lever and connected with binding-post 6.

The lower lever is adjusted to a level position by screw O; it is insulated from its steel axle and together with screw O is connected with binding-post 7. The screw Z, with which it makes contact, is connected with binding-post 4. So are the brass stanchion Q and the screw N, passing through it, as well as the mercury cup W. The screw E is so regulated that just before F makes contact with V the lever I breaks contact with the screw Z and immediately after makes contact again in the same circuit either through the screw N or the mercury cup W.

We have six contacts: three makes, two breaks, and one break followed by a make in the same current. One of these breaks, if used at all, must always come first and one of the makes, if used at all, must always come last. According to actual count this gives forty-four different ways in which currents can be passed through the key. When more than one current is being passed through the upper lever at the same time, care must be taken to have this lever connected with the same pole of all the batteries.

A few of the uses to which this key may be put will be mentioned here together with the contacts used in each case.

1. As an ordinary key where the contact is made by pressing down the key; circuit through E-U or F-V.

2. As an ordinary key in which the contact is broken by pressing down the key; circuit through B-P or O-Z.

3. To close two circuits at the same time; E-U, D-T.

4. To close to circuits at the same time and one an instant later; D-T, E-U, F-V.

5. To close one circuit and break another at the same time; E-U, O-Z.

6. To close two circuits and break a third at the same time; E-U, D-T, O-Z.

7. To break one circuit just before closing a second; B-P, E-U.

8. To break a circuit and an instant later close the same circuit again; O-Z, R-N, or I-W.

In the second method of recording reaction-time on the smoked drum, according to the arrangement of wires in fig. 13, the tuning-fork current is short-circuited at P-B while the key remains closed. When this contact is broken, the current passes around through the marker on the drum. A moment later the contact E-U closes a telephone-circuit which passes through the apparatus in the reaction-room and so produces the stimulus. But the primary current of the spark-coil is passing through O-Z. At the same instant in which the contact E-V is made, this contact O-Z is broken and a spark passes through the smoked paper. This primary circuit is made again at W in time to be broken a second time by pressure upon the key in the reaction-room. As soon as this reaction takes place the operator releases the multiple-key, the tuning-fork curve is short-circuited again at B-P and the time marker ceases to vibrate. As the reaction always follows the contact E-U within three-tenths of a second, the key need not be kept open longer than is natural in slow movement.

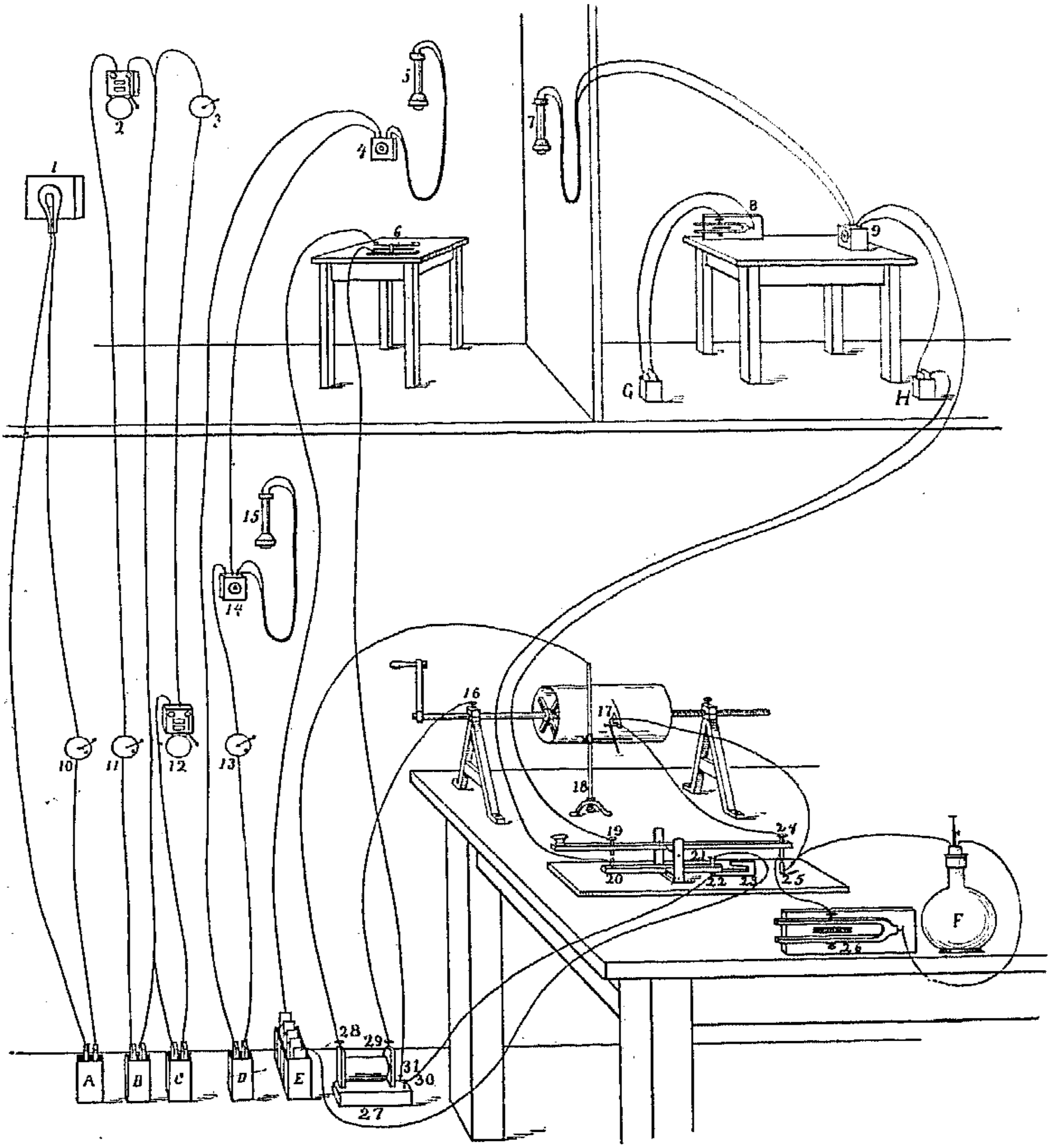


Fig. 13.

The most important pieces of the apparatus having been described in detail, its general arrangement can easily be understood from the diagram in fig. 13. The reaction-room is indicated above on the left. The room used for the production of sound stimuli is shown next to it, although it is situated in another part of the building so that no sound from the loud tuning-forks can penetrate the walls of the reaction-room. The recording-room is on the floor below. These figures are all diagrammatic, being drawn to show the meaning of wires and apparatus rather than actual positions or proper proportions.

Taking the diagram from left to right, the first pair of wires belongs to an electric light circuit. The lamp 1, which was used in these experiments, was a miniature incandescent lamp of 6 c. p. By a switch, 10, the light could be turned on or off.

The next three wires connect two electric bells, 2 and 12, with the Leclanché elements B and C. Closing key 3 rings the bell in the recording-room. The gong being removed from bell 2 and the contact made permanent, closing key 11 only produces a click in the reaction-room. Otherwise the sound would be so loud as to distract the person reacting.

The next pair of wires forms a telephone-circuit by means of which the experimenter can talk freely with the person in the reaction-room. The switch 13 breaks this circuit during a series of experiments and so prevents any noise reaching the reaction-room through this telephone. This telephone connection is a new feature in reaction-time apparatus and its advantage cannot be overestimated. In some of the German laboratories the reactor and experimenter are in the same room, separated only by a cardboard partition. The reactor is thus influenced by every sound in the building, by the changing lights and shadows and by the noise of the chronoscope. In other laboratories the reactor is placed in a separate room in another part of the building. When the operator desires to speak to the reactor he must leave his work and go to this room, often breaking up the whole series and producing more or less distraction. With this arrangement the reactor is in a dark room, free from sound. By a turn of the switch he can hear even a faint whisper from the experimenter.

Next on the diagram comes a one-inch Ritchie spark-coil ; 31 and 30 are the poles of the primary circuit. The current from battery E, consisting of two to four Grove cells, passes through the closed key 6 in the reaction-room and through the contact 21-22 in the multiple-key (O-Z of fig. 11). When the key is pressed down the circuit is broken at 22 and closed immediately after at 23. In practice it was found better to use the mercury cup W, fig. 11, for this second contact as the contact with the copper spring and iron screw R, is a sliding contact liable to produce additional sparks and thus to confuse the record. The mercury must be kept covered with water as alcohol takes fire with a current of the size used.

The poles of the secondary coil are 28 and 29. One was connected with the brass cylinder of the drum by being attached to the iron frame at 16, the other with the point which marks on the drum. When the electro-magnetic time-marker was used, a light aluminium point was substituted for the ordinary straw or quill point. Every time either key is pressed a spark passes from the marker to the drum through the smoked paper scattering the smoke and making the white dots shown in figs. 6–10.

Numbers 19 and 20 are two ends of a second telephone circuit. H is the battery, 9 the transmitter and 7 the receiving telephone. Before the transmitter there stands a tuning-fork 8 run by the battery G. When the multiple-key is pressed down, this telephone circuit is closed at 19-20 and the tuning-fork is heard in the telephone in the reaction-room. At the same instant a spark is made on the drum by the breaking of contact 21-22. The strength of this sound was regulated by passing the telephone-current through a resistance-board, not shown in the diagram. For purposes of simple reaction it was not necessary to use tuning-fork 8. The short, sharp click made in the telephone by closing the circuit at 19-20 was sufficient. By changing the resistance in the telephone-circuit this sound could be varied from one too weak to be heard to one too loud to be endured. It was found necessary to run the wires of this circuit from the recording-room to the reaction-room without allowing them to come near any other wires which were in use at the same time. Otherwise sounds were produced in the telephone by induction from the currents in those wires.

During the latter half of the experiments the two receiving telephones, 5 and 7, in the reaction-room were each connected with both transmitters, 4 and 9. By this arrangement the sounds from the recording-room and from the sound-room were heard in each telephone. One of them was fixed by rods and clamps in such a position, that the right ear of the person experimented upon naturally rested against it. The other was held to the left ear by the left hand, while the right hand was free to manipulate the reaction-key.

A still better plan would be to use a head telephone with a receiver at each ear. This would always be in place, leave both hands free and allow the person reacting to take the most comfortable position and to move about instead of keeping the body in one fixed position. However, as a series of experiments never lasted over five minutes, the disturbance from the act of holding one of the telephones cannot have been very great.

The remaining wires shown in the diagram all have to do with the time-curve. The tuning-fork 26 is run by a dip-battery F. This current passes through the contact 24-25 when the key is closed as shown in this figure. When the key is opened, this contact is broken and the current passes around through the electro-magnetic time-marker 17 communicating to its lever the vibration of the tuning-fork.

In most of the experiments made with the hand-drum this time-marker was not used. The fork itself was placed on the standard and allowed to vibrate continuously on the smoked paper.

In addition to the wires shown in the diagram another pair was used to connect an electro-magnet in the reaction-room with a battery and switch in the recording-room.

All of these wires are part of a system of wires running through the whole building. At first seven wires were laid from each room to a switch-board in a central position. This number not being sufficient for the currents required between the reaction and recording-rooms seven more were laid to each of these rooms. All of these wires where the resistance is of small importance, such as the telephone and bell circuits, are number 16 B. and S. office wire. For the electric light and the primary circuit of the spark-coil, where stronger currents are required, number 10 heavily insulated wire was put in. These were run directly from the reaction-room to the recording-room independent of the switch-board.

Experiments in reaction-time.

In all the experiments the stimulus to which the person in the dark room reacted was a sound produced in the telephone.

A warning click was given on the bell in the reaction-room just before each experiment. Experiment has shown that when the interval between warning and stimulus is always the same the mind is soon able to estimate the interval correctly and always reacts just at that time whether it hears the stimulus or not. Therefore this warning cannot be produced by any mechanism connected with the drum but must be given by the voluntary act of the experimenter. The effect of this warning on the reaction-time depends on the interval between the warning and the stimulus. If the interval is too short there is not time enough to concentrate the attention and the warning hinders the reaction instead of helping it. If the time is too long the effect dies away, as the mind is not able to keep its maximum tension for more than one or two seconds. L. LANGE[1] mentions about 2 seconds as the best interval. WUNDT[2] places it at 2.5; Estel[3] says 2.25; MEHNER[4] and GLASS[5] agree on 2.5. BERTELS[6] found that it took the mind 2⅜ seconds to reach the maximum degree of attention. The interval used in these experiments was 2½ seconds, as nearly as the experimenter could estimate it by counting.

Much also depends upon the interval between the successive experiments. If it is too long the series covers too much time. Changes in the mental and bodily condition of the experimenter come in to change the reaction-time. If the interval is too short there is not time to recover from the preceding experiment. About fifteen seconds was the interval between the successive experiments in the present case. As reaction requires close attention, not more than twenty-five experiments can be taken at one sitting without showing marked effects of fatigue. In the larger part of these experiments the number was limited to twenty-two and at least five minutes intervened between successive series. Seldom were more than five series taken at one time.

An important point in which there is less agreement is that of the rejection from the records of unusually long or short times. These have usually been regarded as errors and ascribed to two sources, to a faulty action of the electro-magnet in the Hipp chronoscope, and to inattention on the part of the reactor. The present apparatus eliminates the former error but the latter still remains. Inattention may give long times and the person may react before he actually hears the stimulus. By keeping a careful watch most of these cases will be noticed on the spot and be rejected without question as errors. But still the tables will contain an occasional long or short record which largely affects the average of the series. What shall be done with these cases? Some have refused to omit any, claiming that individual differences disappear in the final average. Most writers use their judgment in each particular case and reject all records which they think unduly affect the results. It is always hard to draw the line between normal attention and the next grade below it, to decide

[1] *Beiträge zur Theorie der sinnlichen Aufmerksamkeit*, Phil. Stud. 1888 III 492.
[2] Physiol. Psych. 3 ed. II 361.
[3] *Neue Versuche über den Zeitsinn*, Phil. Stud. 1885 II 37.
[4] *Zur Lehre vom Zeitsinn*, Phil. Stud. 1886 II 560.
[5] *Kritisches und Experimentelles über den Zeitsinn*, Phil. Stud. 1888 IV 454.
[6] *Versuche über die Ablenkung der Aufmerksamkeit*, Inaug. Diss. Dorpat 1889.

which are correct reaction-times and which are errors. The purpose of the experiments may have an influence in deciding this question. For instance, if it is to get the average reaction-time of a certain person in a series lasting five minutes, then more marked cases of inattention would be expected and let pass unchallenged than if the purpose was to detect the influence of a slight distraction on the reaction-time. In the former case the variation in attention is the quantity to be measured. In the latter case it is desired to eliminate all variations in the attention save that due to the one cause whose effect is being investigated.

In the present instance every record was rejected which seemed to the *reactor* to be a mistake. His opinion was always written down before he left the reaction-room and before he knew what the figures were. After that the criterion for rejecting readings was that laid down by HOLMAN.[1] "Take the mean and the average deviation of the observations, omitting the doubtful one. Find the deviation of that one from the mean. Then reject the observation if its deviation is greater than four times the average deviation." This is an arbitrary criterion and does not imply that all records rejected by it are errors. It means rather that in the small number of records they would have undue influence and that the average without them will be nearer the truth than if they were included.

In every case excepting the few series where the names are given in the table the writer was the person experimented upon.

EXPERIMENTS SHOWING THE INFLUENCE OF SENSATIONS OF LIGHT UPON THE TIME OF SIMPLE REACTIONS TO SOUND.

The first problem undertaken was the investigation of the influence of the presence in consciousness of different colored lights upon the time of reaction to sound-stimuli. It was suggested by the results of FÉRÉ's experiments with the dynamometer.[2] He found that with hysterical patients different colored lights had different dynamogenic effects, red being most effective and violet the least. If the energy with which the muscles can be contracted varies with the appearance in consciousness of different colored lights it seems probable that there should be a similar effect upon the rapidity with which they can be moved.

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[1] HOLMAN, Discussion of the Precision of Measurements, New York 1892, p. 30.

[2] FÉRÉ, Sensation et mouvement, Paris 1887.

These experiments are not to be confused with those conducted by TITCHENER in Wundt's laboratory where different colored lights served as the stimulus.[1] The effect of a steady influence might be detected when the effect of a momentary influence was too small to be measured. We certainly have a different tone of feeling when looking at a red light from that which we have when looking at a green light.

The different colored lights were produced by colored gelatine films between two pieces of glass placed before the box containing the electric light.

Three hundred experiments were made upon this point, but they must be regarded as preliminary and negative. They were made upon six different persons all of whom were without practice in reacting, and, as they were taken before the apparatus was completed, the method illustrated in fig. 3 was used, the error of which has already been pointed out.

The results show no difference for the different colors within the limits of error and none between those taken in the dark and those in the light. However, in all cases they show the effect of practice on reaction-time. Table I brings this out in the case of two persons, the first one of whom reacted several thousand times in the interval

TABLE I.

Name	Date	R	M V	n
C.B.B.	Nov. 13.	183	34	90
"	Mar. 31.	140	13	236
J.A.G.	Dec. 1.	250	36	59
"	Jan. 30.	161	22	28

R, reaction-time.
MV, mean deviation.
n, number of experiments.

between the two dates given while the second reacted only a few times between the dates for which his reactions are compared. In the

[1] *Zur Chronometrie des Erkennungsactes*, Phil. Stud. 1893 VII 140.

case of the first person an average of 90 experiments taken on Nov. 13, gave a reaction-time of 183$^{\sigma}$ and an average deviation from that average of 34$^{\sigma}$. On March 31 an average of 236 experiments gives a reaction-time of 140$^{\sigma}$ with an average deviation of 13.$^{\sigma}$ Thus showing not only a great falling off in the time but also a great increase in the regularity of the experiments.

A like result is shown in the record of the second person.

From these figures it is plain that we are not to expect differences due to small changes in the conditions of the experiments to show themselves until the person experimented upon has had some practice.

One other set of experiments was taken before the apparatus was accurate to thousandths of a second. These were all made upon one man, the object being to see whether, with the degree of accuracy then obtained, any difference could be detected between the time of reactions taken in the dark and those taken in the light. The averages of the separate series are given in table II. The final average of 115 experiments in the dark gives a result of 170$^{\sigma}$ with a mean variation of 23$^{\sigma}$. The 74 experiments taken in a white light

TABLE II.

Disturbance	R	MV	n
None	170	23	115
White light	177	30	74
Red light	175	25	20
Green light	160	15	20

give a time of 177$^{\sigma}$ with a mean variation of 30$^{\sigma}$. The 20 experiments in red light give a time of 175$^{\sigma}$ with a mean variation of 25$^{\sigma}$ and the 20 experiments in green light give a time of 160$^{\sigma}$ with a mean variation of 15$^{\sigma}$.

After the apparatus was correct to thousandths of a second, another attempt was made to detect a difference between the time of reactions in the dark and those in the light. A series of twenty or thirty experiments was taken in which the light was turned on in the middle of the series. Table III gives the average of five experiments before the light was turned on and five immediately after. The experiments were taken upon seven different persons only two of whom had had experience in reacting and only one of whom had had practice that year. Considering this and also the fact that only five series were taken upon any one person, too much confidence must not be placed in the results. It would be very easy to say that they show the distracting influence of the light; for in the case of each individual, save one who had had no practice and upon whom only one series was taken, the average of the reactions in the light is longer than those in the dark.

TABLE III.

Person	D	MV	n	L	MV	n	L - D
D. W. L.	148	15	15	150	11	15	+2
C. B. B.	147	7	25	151	9	25	+4
E. W. S.	184	28	25	191	24	25	+7
J. M. M.	159	12	5	191	24	5	+32
W. I. C.	146	16	20	156	9	20	+10
K. M. W.	119	30	10	139	16	10	+20
J. A. G.	181	28	5	171	15	5	−10
Weighted mean	153	18	105	160	14	105	+7

D, reaction-time in darkness.
L, reaction-time in light.

The final average of the 210 experiments is 153^σ for the dark with a mean variation of 18^σ and for the light 160^σ with a mean variation of 14^σ. But later and more reliable experiments show that the mere presence in the field of vision of this steady light would not produce that effect. A glance at the original records throws some light on this point. In eight of the series the first reaction after the light was turned on was unusually long. In the nature of the case these records could not be rejected, for though there is a possibility that they may be due to inattention yet it is far more probable that they are the very thing we are looking for. When the light is turned on it startles the person for an instant and so increases the reaction-time. Table IV shows this fact very clearly. It contains the first, second, third, fourth and fifth experiments before and after the light was

TABLE IV.

Person	Dark					Light					n
Number of exper.	*5.*	*4.*	*3.*	*2.*	*1.*	*1.*	*2.*	*3.*	*4.*	*5.*	
D. W. L.	181	153	141	128	140	149	171	144	146	139	3
C. B. B.	139	150	132	153	150	158	145	142	156	153	5
E. W. S.	175	179	172	147	202	178	187	192	177	223	5
J. M. M.	165	151	155	138	139	248	194	167	166	179	1
W. I. C.	135	154	139	158	140	198	150	142	163	123	4
K. M. W.	114	131	103	135	108	151	122	118	136	167	2
J. A. G.	183	148	123	299	153		197	177	176	134	1
Weighted mean	154	156	142	153	155	165	162	155	160	166	

turned on in each series, so arranged as to show the averages for the first, second, third, fourth and fifth experiments in the case of each individual and also the final average of all together. In the final average and in the case of most of the individuals, notably in the case of those who were practiced, the first experiment after the light was turned on was longer than the other and enough so to affect the averages in table III.

When the light was turned on, no care was taken to have it come exactly half way between two experiments. Sometimes it would be nearer the one before, sometimes nearer the one which followed. This may explain the reason why some of the series show no distraction. The light was turned on in the early part of the interval and the person had time to accommodate himself to it before he heard the stimulus. Doubtless if the interval between the moment of turning on the light and that of the reaction immediately following it were carefully measured it would be found that this first reaction would be lengthened the more the smaller this interval.

The next attempt to detect a difference between the time of reactions in the dark and those in the light was made later on in the year, after considerable practice. In the experiments already described the electric lamp was carefully concealed in a box, the sides of which were lined with tin reflectors, so that the person sitting at the reaction-table saw only a brightly illuminated square of white card-board in the back of the box. Since the effect was so slight the box was dispensed with in these later experiments and the lamp hung suspended in full view. The method was the same as in the former case, except that the order of light and dark was reversed in some of the series to eliminate any effects from fatigue or acceleration which might enter into a series of twenty experiments.

The total number of experiments was 207, consisting of 97 in the dark and 108 in the light. Of the ten series, six gave a slightly longer time for those in the light while the other four gave an equally small difference in favor of those in the dark. The final averages are: for those in the light, 138^{σ} with a mean variation of 12^{σ} and for those in the dark 136^{σ} with a mean variation of 10^{σ}, thus showing a difference of only 2^{σ} both in the reaction-time and in the mean variation, a difference which is practically zero. These figures then warrant the statement that *the difference between reaction-time in the dark and reaction-time with the eyes fixed upon a bright steady light is very small compared with the constant variation due to subjective changes in the condition of the person experimented upon.*

After it was found that the presence of a steady intensely bright light in the field of vision produced no variation in the reaction-time which could be detected, it was decided, at the suggestion of Professor Ladd, to study the effect of a moving light.

The small incandescent lamp was suspended from the ceiling by a flexible cord about six feet long. Just above the lamp a piece of soft iron was fastened to the cord. This iron served two purposes: it made the lamp swing steadily and allowed it to be held in position by an electro-magnet fastened to one end of the room. The electric light current and that of the electro-magnet were then both passed through the same switch in such a way that one movement of the lever broke the electro-magnet current and turned on the light.

Ten experiments were taken in the dark ; then the operator turned the switch and the person experimented upon had a steadily swinging light in his field of vision. In addition to the moving light there was always a great variety of moving shadows and changing intensities as the lamp swung past the wires, standards and other parts of the apparatus. When the light was turned on, the eye invariably followed the lamp for one or two minutes, after which the shadows came into consciousness, then the objects which produced the shadows and finally other things in the room.

The amplitude of the motion was regulated by moving the electro-magnet. During part of the experiments the lamp commenced to swing through an arc of two meters, which gradually diminished during the experiment to half a meter. In the rest of the experiments the arc was half a meter at first and the lamp gradually approached a state of rest. Had the results warranted, a more careful determination of this amplitude would have been made. In these experiments the order of light and dark was changed to eliminate other influences. It was of course impossible to stop the lamp swinging in the middle of a series, but the light could be turned out.

The mean variations are fairly low and regular. Therefore the results may be regarded as quite trustworthy. In twelve out of the sixteen series the reaction-time while looking at the swinging light was from 2^σ to 20^σ longer than the reaction-time in the dark. The final averages for those in which the long swing was used were : in the dark, 137^σ with a mean variation of 13^σ ; in the light, 142^σ with a mean variation of 11^σ. For those with the short swing they were : dark, 142^σ, mean variation 12^σ; light, 147^σ, mean variation 12^σ. No difference can be detected between the influence of the long and short swings. Combining the two we have as a result of 363 experiments a mean variation of 12^σ for those in the light, the same for those in the dark, and an average of 142^σ for the reaction-time in the dark and 147^σ for the reaction-time when looking at a swinging lamp.

It is important to discover if possible whether this disturbance is uniform throughout the ten experiments with the swinging light, or whether it is confined either, as in the earlier experiments, to the first reaction after the light was turned on or to those first few experiments where the eye follows the moving light. For this purpose the averages of the first, second and third experiments and so on of all the sixteen series were calculated and found to be, before the light was turned on, (1) 145^σ, (2) 143^σ, (3) 144^σ, (4) 145^σ, (5) 142^σ, (6)

139^{σ}, (7) 144^{σ}, (8) 144^{σ}, (9) 135^{σ}, (10) 140^{σ}; after the light was turned on, (1) 154^{σ}, (2) 149^{σ}, (3) 148^{σ}, (4) 142^{σ}, (5) 144^{σ}, (6) 151^{σ}, (7) 151^{σ}, (8) 139^{σ}, (9) 140^{σ}, (10) 143^{σ}. This shows conclusively that the chief disturbance is found in the three reactions after the light is turned on. The greatest lengthening is in the first reaction. Part of that is certainly due to the same effect which was noticed in table IV, namely to the distracting effect of having the light suddenly appear. But the presence of a similar though less effect in the next two averages shows a distinct influence from the moving light after the first surprise is over. Therefore we infer that part of the lengthening in the first reaction with the swinging light is also due to the moving light.

Later on in the series there is one average which is nearly equal to the first one with the light but an examination of the individual experiments shows that this is due to the accidental presence in that average of four unusually long times.

From these experiments we conclude that *the influence of light sensations upon the time of reaction to sound is comparatively small when the light is steady, but becomes very marked as soon as the light begins to move.*

A practical application of this fact suggests itself at once. There is no advantage for purposes of simple reaction in having the room dark. But it should not be lighted by a window, else moving shadows and changing intensities will affect the reactor. It must not be lighted by a lamp or gas jet for they would each, in the case of a small room at least, raise the temperature or, in case the room were ventilated by a current of air, be made to flicker and so distract the attention. But when the conditions of the experiment do not require a dark room there can be no objection to the presence of an incandescent lamp. On the contrary the person experimented upon will feel more at ease in a lighted than in a dark room and will find it much easier to make notes of any important points which occur to him during the experiments.

Experiments showing the influence of sensations of sound upon the time of simple reactions to sound.

The experiments thus far described have had to do with the influence of sensations of light on the time of reaction to sound. A similar set of experiments was conducted for the purpose of investigating the effect of sensations of sound on the time of reaction to sound. In the first place the sound used was a steady tone produced by an electric tuning-fork vibrating 250 times a second. This tuning-fork was placed on a shelf before the transmitter in the recording-room and run by a dip battery. When the telephone circuit was closed this tone was sent to the reaction-room and, when the two receiving telephones were connected together, was heard in the same telephone in which the signal to react was heard. The moveable drum shown in the diagram makes no noise and, when the operator is careful and the rest of the building is quiet, no sounds reach the ear of the reactor through this telephone save those of the tuning-fork and the signal to react. The tuning-fork sound is so loud that none of the fainter sounds in the building or on the street can be heard. This method could not be used with the electric drum on account of the noise of the motor, except by placing the transmitter and the fork in another room.

The method of experiment was similar to that employed in investigating the influence of light-sensations. Ten experiments were taken in silence, then the telephone circuit was closed and during the remainder of the series the person heard the steady tone of the tuning-fork in the same ear in which he heard the stimulus. In successive series the order of silence and sound was changed to eliminate the influence of sequence. After eight series had been taken the method was slightly varied. It was evident that as in the case of the steady light the disturbance was very small. It was thought that possibly, as in the case of a steady light, the influence would be greatest upon the first reaction after the sound was turned on. Therefore to get the full effect of this influence, instead of taking ten experiments in silence and ten more with the tuning-fork sound in consciousness, one experiment would be taken in silence, then the tuning-fork sound turned on for the second reaction, while the third would be in silence and so on through the series. In each case, however, the tuning-fork was turned on immediately after the reaction in silence, thus giving about ten seconds for accommodation before the signal to react.

By changing the intensity of the telephone-current the loudness of the tuning-fork sound was varied at will. For the purposes of these experiments it was kept as nearly as possible equal to that of the sound which served as the signal to react.

Table V gives the averages of all these series. In it no difference can be detected between the time of reactions in silence and those in which the tuning-fork was heard. Seven of the individual series from which this table was compiled showed a slight difference in favor of silence and nine showed about the same difference in favor of those with the sound. Of those where silence and sound alternate the same thing is true. Four were longer in silence and five in sound. The final average gives a time of 153σ and a mean variation of 19σ for those in silence and a time of 152σ with a mean variation of 18σ for those with sound. The average for the writer was 141σ for silence with a mean variation of 15σ and for sound 139σ with a mean variation of 16σ, showing a slight difference in the same direction as the combined results of the three persons.

TABLE V.

	Silence	MV	n	250 fork	MV	n
C. B. B.	141	15	104	139	16	113
W. I. C.	167	26	33	174	22	33
A. F.	232	42	10	242	39	8
Weighted mean	153	19	147	152	18	154

When it was found that the presence in consciousness of a steady tone produced no appreciable effect upon the reaction-time, with the skill in reacting thus far obtained, it was thought best to try the influence of an intermittent sound, as in the former experiments a moving light took the place of a steady one. The most convenient instrument which suggested itself for this purpose was the metronome. SWIFT[1] investigated the effect of the ticking of the metronome upon discrimination-time and found different results according to the rapidity with which the metronome ticked. He also found that it lengthened the time of simple muscular reaction. In a series of 100 experiments he found the reaction to be 103σ, with a mean variation of 9σ, whereas 100 experiments taken while a metronome was ticking in the room gave 122σ, with a mean variation of 12σ.

During the first few experiments the metronome was placed in the reaction-room and so arranged that the pendulum was held to one

[1] SWIFT, *Disturbance of the attention during simple mental processes*, Am. Jour. Psych. 1892 V 8.

side by the electro-magnet until the circuit of the magnet was broken in the recording-room. Thus the metronome could be started at will during the series. But in the small reaction-room the sound was almost too loud to be endured. It was found more satisfactory to place the metronome on the shelf before the transmitter in the recording-room, as had been done with the tuning-fork. Here the operator could stop the sound as well as start it and could regulate the intensity so that it should be about the same as that of the stimulus. There was an advantage also in having the two sounds come in exactly the same direction.

The order was the same as before, ten experiments in silence, then ten with the sound and vice versa. In different series the metronome ticked 40, 80, 120, 160 and 200 times a minute. Table VI gives the averages for each of the rates.

TABLE VI.

Rate of Metronome	0	40	80	120	160	200
Reaction-time	152	156	184	186	179	169
Mean variation	13	17	26	20	20	25
Increase	0	6	32	34	27	17
Number of experiments	147	28	54	93	61	42

In the first experiments where the metronome was in the reaction-room, there was a great innervation and strain in all the muscles of the body called forth to withstand the influence of the metronome. This was not noticed while the metronome was ticking, but the moment it stopped the sudden relaxation was very evident.

At the beginning of the experiments there is a marked change due to getting acquainted with the sound but, owing to the short duration of the experiment, that influence does not continue after the first surprise has worn away. Judging from the complete inattention to a clock ticking in my room it is probable that after listening to a metronome tick for a few hours it would no longer affect the reaction-time. The stopping of the metronome might then have a temporary effect. Indeed, in these experiments the reactor soon be-came so far accustomed to the sound that an occasional vibration of the metronome spring, just loud enough to be heard, seemed more distracting than the metronome itself.

From these experiments we conclude that *the influence of a sound-sensation upon the time of reaction to sound-sensation is very small as long as that sound is a steady tone but becomes very marked when the sound is intermittent.*

Experiments showing the difference in the time of reaction to sounds when the sound is heard in two ears instead of one.

It has already been suggested that the best way to produce a sound-stimulus for purposes of reaction is to use a head-telephone with a receiver at each ear. The following set of experiments were taken to show the relation between the time of reactions when the stimulus is heard in one ear and the time of those in which the same stimulus is heard in both ears.

The arrangement of the telephones has already been described. The method of experiment was similar to that of the experiments which have been described above. The person reacted ten times with a telephone at only one ear, then without interrupting the series he placed the second telephone at the other ear and continued to react ten times more. To eliminate other influences the order was sometimes reversed and the first half of the series taken with the sound in both ears.

Table VII gives the average of twenty-one series taken in this way. With the exception of three cases, where the person had no experience, the reaction to the sound in both ears is much shorter than that of the reaction to the same sound in one ear. The average of the thirteen series upon the writer, who was the only one having experience in reacting, with the exception of Dr. Scripture, give for one ear a time of 147^σ and a mean variation of 19^σ, for two ears a time of 133^σ with a mean variation of 19^σ. The number of experiments with one ear was 108, with two ears 123. The average of eight series taken on four other persons gives for one ear a time of 207^σ with a mean variation of 38^σ, for two ears a time of 188^σ with a mean variation of 31^σ. The number of experiments with one ear was 83, with two ears 82.

A natural explanation of the difference between the reaction-time when the signal is heard in one ear and the reaction-time for the same signal heard in two ears would be found in the difference in the intensity of the sound as heard in the two ways. In order to see whether this explanation was satisfactory or not, fifteen series of experiments were taken in which the stimulus was varied in intensity from a loud to a weak sound.

This change of intensity was secured by introducing a resistance-box into the telephone circuit. The battery then in use consisted of twelve gravity elements. With the normal resistance of the circuit they gave a current of 0.5 amperes. With an additional resistance of 100 ohms the current was reduced to 0.08 amperes and the click made by making the circuit was a weak sound compared with that heard in the telephone when the normal current was used. Yet it was a sound which could be distinctly recognized. A switch was so arranged that by a turn of the lever the resistance box could be brought into the telephone circuit.

TABLE VII.

	One ear	MV	n	Two ears	MV	n
C. B. B.	147	19	108	133	19	123
E. W. S.	269	58	17	199	38	20
T. J. L.	182	35	39	175	26	33
W. I. C.	192	29	15	201	33	39
Weighted mean	170	27	179	158	24	215

The average for 132 experiments with the loud sound was 143^σ, with a mean variation of 13^σ. The average of 126 with the weak sound was 153^σ, with a mean variation of 16^σ. The difference between the loud and weak sound was 10^σ. That between one and two ears was 6^σ.

Attention might be called in passing to the fact that in this set of experiments four series were taken in which the succession of loud and weak intensities was irregular. The experimenter was told to make it as irregular as possible. The average of these four series for the loud sound is 143^σ, for the weak sound 155^σ. The mean variation from the average of the whole set is, for the loud 16^σ, for the weak 17^σ. The number of reactions to the loud sound was 64 to the weak sound 66.

These figures are in marked contrast to those of Wundt. With him 18 successive reactions to a strong sound gave a time of 116^σ with a mean variation of 10^σ. A set of 9 reactions to a weak sound gave a time of 127^σ with a mean variation of 12^σ. When the succession of loud and weak sounds was irregular the time for the loud sound was 189^σ, mean variation 38^σ, number of experiments 9. The time for the weak sound was 298^σ, mean variation 76^σ, number of experiments 15. The increase due to irregularity in his case amounts to 114^σ, in our case to 12^σ.

It can scarcely be that there was a greater difference between the sounds he used; the difference in the present case was so great that the loud sound, when the order was unknown, was greatly dreaded and always produced a decided shock.

There are two other series of experiments which are worthy of note, having been taken without warnings. Their average for forty experiments is 139^σ, mean variation 26^σ, whereas the average of the thirteen series taken on the same person under the same conditions but with the warning was 140^σ with a mean variation of 19^σ; total number of experiments 231. Wundt's figures on the same point are, with warning 125^σ, without warning 259^σ, total number of experiments, 61.

We have shown that a large part of the difference between the time of one and two ear reactions is due to the difference in intensity. But to test this point more closely another set of experiments was taken in which this factor was entirely eliminated, yes, more than eliminated. The reaction-time of one and two ears was compared as in the last set but at the same time the intensities of the currents were varied so that the sound heard in one ear was judged to be much louder than the combined result of a weaker sound heard in both ears. If intensity be the only factor in producing the difference between one and two ear reactions then the reaction under these conditions ought to be much longer for one ear than for two. In only two series was there any marked difference between the two. One of these is in favor of the loud sound in one ear the other in favor of the weak sound in two ears. The difference between the final averages of the ten series is only 1^σ, practically 0.

Therefore: *the reaction-time to sounds heard in two ears seems to be shorter than for the same sound heard in one ear even after due allowance has been made for difference in intensity.*

In all of these experiments the sound in two ears was located in the upper interior part of the head. Turning the attention toward the sound resulted in rolling the eyes upward ; the sound seemed closer at hand and less effort was required for reaction than when the stimulus was heard in only one ear; the reaction also seemed more automatic, especially when the attention was turned to other things.

Conclusions from the three preceding sections.

The general results of these experiments in reaction-time can be summed up as follows:

1. The experiments did not indicate any difference in reaction-time produced by changing the color of the light present in the field of vision.

2. No difference was detected between the times of reactions in the dark and those made while looking at a stationary incandescent light of six candle power.

3. When this light was in motion the reaction-time was lengthened.

4. No difference was detected between the times of reactions in silence and those made while listening to the steady sound of a tuning-fork making 250 vibrations per second.

5. When the intermittent sound of a metronome was substituted for that of the fork, the reaction-time was lengthened.

6. The reaction-time to a sound heard in both ears is shorter than when the sound is heard only in one ear, even after making allowance for the difference in intensity.

Introspective observations on reactions.

During the larger part of the experiments pencil and paper were kept in the reaction-room and immediately after each series of experiments the person reacting noted down any conditions liable to affect the time of his reaction and any observations which might throw light on the nature of reaction-time. These notes were afterwards transferred to the record blanks just below the records to which they referred in order that these records might be used more intelligently.

A careful study of the notes together with the records to which they refer brings out many interesting points. Not all of them can be touched upon here but the most important ones will be found below substantially as they were written down from day to day.

After a few weeks practice reacting becomes so much a matter of habit, that trying to recall what has taken place during a series is like trying to remember dreams. The more striking points are easily retained but the larger part of the points which are noticed during the series are gone beyond recall unless they are noted down within a few minutes. A little practice enables one to record all mistakes in reacting, all reactions to warnings, all reactions registered before the signal is heard and all cases where the reaction-time is greatly lengthened by a physical or mental disturbance.

NOTES MADE IN THE REACTION-ROOM IMMEDIATELY AFTER EXPERIMENTS.

The following abbreviations are used :

W=Warning.
R=Reaction.
M=Muscular.
Att=Attention.
"fore"=Reaction before the signal.
Met=Metronome.
Om=Omitted.
a=first, b second half of a series.

The figures are taken from the original records for comparison with the notes. The numbers of three figures are reaction-times, those of one or two figures are mean variations. Where two sets of figures are given the first pair is the first half and the second pair the second half of a series. When the note refers to a particular experiment that one is compared with the rest of the series and its figures are given first. In order to make the meaning of the notes clearer explanatory remarks have been added; these are distinguished by italics.

1. R. to light.
2. Sounds heard outside.
63. Irregularity due to novelty of M. (134–6—138–17). *Showing that the irregularity was over-estimated.*
65. Turn Att.=turn eye.
76. 6, 8–11. React with jerk. (133—135–8). *The average of these four is* 2$^{\sigma}$ *shorter than that of the rest of the series.*
78. React with full arm movement. (138–13—137–28).
79. R. to W.
82–4. Tired, nervous, slow. (134–26—118–20.) *Mistake in judgment.*
94. W. I. C. "No difference." (209–22—181–31.) *Showing lack of practice.*
95. Notice regularity with two ears. *The figures don't show it.*
96. a. 1. React in spite of resolve. (222—197–26.) *A purely automatic reaction, extra long.*
96. Trying to think of Schopenhauer. (200–27—179–24.) *At least* 50$^{\sigma}$ *longer than the normal reaction-time.*
99. One R. before will impulse.
98. R. to W.—b, 1, om. in relaxation of silence. Sound terrific. (Silence 133–7 —with sound 133–10.) *No effect from this very loud tuning-fork sound.*

100. a, usual way, b, tense muscles. (146–33—120–16.) In one case will didn't overcome pressure. Att. confused in learning a new lesson. *In spite of confusion the reaction with tense muscles are 26$^\sigma$ shorter than the others!*

105. Last four, extra effort. (163—161–10.)

106, 7. Dr. Scripture "Not used to react without W. Have to 'wake up' when only one ear is used." *Two-ear reaction is more automatic.*

108. R. to small sound raises finger but little. *Showing the reflex element in all reactions.*

109. a, 5. R. too weak to raise finger, b, 3 "fore." 7–10, absorbed in plans.

111. a, one "fore." All sorts of distractions, pain in toe, wagon, shadows, thought.

113. Last one quick. Way prepared for motor impulse. (127—156–15.) *Correct estimate.*

114. 9 "fore." Met. very loud, scarcely hear W.

115. R. to W. Last 3 good. First 2 om.

116. Met. gives terrific sound.

119–21. Effort to touch a point 6 in. away.

126. The same. Very quiet; perfect type. b, att. more to muscles. (133–13—139–11.)

128. a, one ear, b, two ears. Two slightly longer. (148–13—142–23.) *Error in judgment.*

127. One om. driven out by another idea. R. to W. Every W. heard with tendency to R.

129. Sensory—M. M. quicker, harder. (129–10—127–9.) *Not enough quicker to be detected.*

130. a., ½. Terrific scraping; = insulation worn off in key. b, Att. = rolling eyes up.

134. 2–1 ear. 2 ear quicker. (127–7—140–15.) *Correct.* a, 9 Automatic. Mind returning from wandering surprised. (124–7—183.)

136. Att. all over, affects nerve force.

137. Loud—faint. Tend to give more Att. to faint sound at first.

141. Att. wandered. (157–17.) *20$^\sigma$ longer than normal.*

142. (153–14—132–9.)
143. (129–6—127–13.) } Exercise between 142 and 143. Quick pulse, deep breathing. *Shortening the time 24$^\sigma$.*

144. Careful Att. Sensory (?). Eye turned up. a, 5, long (202). b. 6, long (226). (153–13—170–7).

145. Faint demands, loud compels Att. Att. wandered. (Faint 152–17—loud 132–4).

149. 9, "fore." M. Faint-loud. Don't notice dif. intensity. M = hard work. (150–15—156–31.) *Attempt at muscular reaction a failure.*

150. React best way. Att. good. (168–19—171–8.) *Error in judgment.*

153. Faint-Loud. Irreg. No accommodation, no guessing. (148–16—167–21.)

154. No influence from knowledge of problem. One R. too faint to be recorded.

156. Sound varies from large sound to small short sharp pops = poor contact in multiple-key.

158. 1 ear loud—2 ear week. b, 1 No R.; too weak for one ear.

159. b, 1, loud sound in two ears. Awful start—Quick. (128—141–7.) *A case where the reflex element shortens the time.*

160. Last half thinking of something else. (134–159.)
161. Met. magnet didn't work. Started it myself.
164. Distr. of small sounds more than Met.
171. Reverberation of Met. spring very distr. (160–12—196–21).
172. Head most aches. Not feeling well. W. don't nerve me up. Sleepy. (132–11—156–16).
176. One "fore."
177. Sleepy. Not energy enough to tell what I have done. It was pretty good. (156–17—193–29.) *Error in judgment.*
178. Not so good. Uncomfortable position. Thought distr. more than noise. (172–27—167–13.)
182. Clear mind, like crystal, a sharp frosty morning, or the clear blue sky. (149–16—155–19).
186. Thinking of key. Does it distract? (150–21—196–48). *Decidedly.*
184. Noise of met. board provokes me. (151–8—205–9.) *Showing that irreg. sounds are much more distracting than the metronome.*
195. Two om.; one slow. No light at first. 2–4, one ear. Wagon: Out of patience! (136–8—158–15.)
196. Best yet. (154–12—129–8.) a, 1–6, uneasy. b, first rate; key between fingers.
198. a. Not esp. good. (134–16—146–10.) 2–4, Att. off. 147, 138, 139. *As good as 196.*
204. Some one up stairs. Warning out of order. (151–13—158–12.)
201. Distr. small. (130–7—139–10.)
202. Too fast. Fairly good. (127–10—134–17.) Last 3 thinking of spark. 125, 180, 128.
205. a, 6. Wagon heard on the street. (122—136–13.) *No disturbance shown*— b, 3. Seashore dropped something. (156—139–12.)
208. Seems long. Att. Wanders. (159–15—161–14.) *Decided effect.*
209. Little Att. Not tired. No ability to apply myself. (171–10—151–6.)
206. First rate, last half of b, distr. by wagon because I ought not to hear it. (139–16—156–13.)
207. Not so good. Too excited. b, light steadies me. (143–9—148–17.)
208. Hard to hold att. for 20 experiments. (146–11—162–11.)
209. Impossible to do good work. Think of everything. (138–9—151–13.)
210. Old position, elbow on table. First class example of inattention. Reaction natural in the flow of ideas. (141–13—140–8.)
211. First rate; b, 1, "fore." Innervate finger and fore arm. (132–14—141–11.)
213. Very good. b, end, M. (180.) One before sensory. (129.) Perfectly passive. Not innervation enough to hold the key. (129–8—141–20.)
214. Not quite as good. (121–12—135–15.)
215. Try to get away from bodily feelings=innervate Cortex. (128-7—147–13.)
216. The same. (126–12—145–9.)

The first impression on reading over these notes is one of surprise at the number of experiments in which there is some disturbance of the attention aside from that of the stimulus and warning. No amount of care in the preparation of a reaction-room and in removing external influences can do away with skin sensations, with muscular feelings, with changes in the physical and mental condition or with the ceaseless flow of thought.

An examination of the notes shows that these disturbances vary greatly. At times they are very prominent; then again they will be scarcely noticed. Record 196 is such a case. The note says of the series as a whole "best yet," of the first half "uneasy" of the second half "first rate." The figures are: dark 154$^\sigma$ with mean variation 12$^\sigma$, steady light 129$^\sigma$ with mean variation 8$^\sigma$. Records 134–7 also ought to have more weight than the average series. Their note says "best part of the day, excellent physical condition, mind clear and sharp." The figures in this case are: two ears 129$^\sigma$ M. V. 9$^\sigma$, one ear 139$^\sigma$ M. V. 14$^\sigma$. Certainly the average of a dozen series all of which had a similar certificate of the conditions under which they were taken would give different results from those of a set made up from records like 178. The note on this record reads "Not so good; uncomfortable position. Thought distraction very great." The times are: silence 167$^\sigma$ M.V. 13$^\sigma$; metronome 172$^\sigma$ M.V. 27$^\sigma$. To gain the most trustworthy results a large number of experiments should be taken and only those used which are free from all conscious disturbance.

Though introspection is of great value in estimating the general conditions of an experiment and showing the influences which affect the results yet it is not to be trusted in estimating the results themselves. Aside from the fact that the mind is unable to accurately estimate small divisions of time under the most favorable conditions,[1] its judgment is peculiarly liable to be affected by the conditions of the reaction. Its report is what it thinks ought to be rather than what it actually sees. For instance, in series 82–84 the reactor was tired and nervous and therefore judged the reaction-time to be longer than usual. The figures are: one ear 134$^\sigma$ M.V. 26$^\sigma$, two ears 118$^\sigma$ M. V. 20$^\sigma$, showing that the nervous excitement more than counterbalanced the physical fatigue.

In series 150 after having reacted in the muscular way in the previous experiment, the person reacted in the way which he thought would give the shortest time. Accordingly he judged the time of that series to be less than that of the preceding one. The figures for this one are: loud 168$^\sigma$ M. V. 19$^\sigma$, weak 171$^\sigma$ M.V. 8$^\sigma$; for the preceding one: loud 150$^\sigma$ M.V. 15$^\sigma$, weak 156$^\sigma$ M.V. 31$^\sigma$, being just the reverse of his judgment.

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1 MARTIUS, *Ueber die musculäre Reaction und die Aufmerksamkeit*, Phil. Stud. 1891 VII 167.

The last four reactions of series 76 were made with a violent jerk. More effort was put forth and the mind inferred that the reaction must be quicker. The average of the last four was 133^σ, that of the first half of the series 132^σ.

Again, in 78 the reaction-time was judged shorter than usual. In this case the hand was raised to the shoulder in every reaction. There was more motion and more effort, therefore the mind judged that the reaction started quicker. The figures are: silence 138^σ M.V. 13^σ; with fork sounding in the telephone 137^σ M.V. 28^σ.

In several series, 126a, 126b, 127 the reaction consisted in touching a point on the table six inches from the key. Raising the finger from the key to make this motion broke the spark-coil circuit, and so only the beginning of the motion was registered. Here again the mind was mistaken in judging that the reaction-time was quicker than usual. The average of the parts of these series not subject to other disturbing influences was 141^σ M.V. 11^σ.

In connection with these experiments where the attention was directed to a motion for which the reaction was a means, the idea suggested itself, but has not yet been carried out, of having a second reaction-key in place of the point on the table. Then we should have recorded in addition to the reaction-time, the time required to make a certain movement. This would doubtless vary from time to time with changing mental and physical conditions. None of its variations could be attributed to influences acting upon the conscious part of the reaction as it would be purely automatic after slight practice. This might throw some light on the relative portion of the variation in reaction-time which is to be assigned to the purely psychical part. Possibly it might be used instead of the simple reaction as a standard for comparing the different kinds of reaction-time.

Between 142 and 143 the reactor went through vigorous muscular exercise so that, whereas 142 was taken with the body in a quiet passive state, during 143 the pulse-beat was strong and rapid, the breathing deep and heavy and the whole system generally excited. The figures for 142 are: 153^σ M.V. 14^σ for a loud sound in one ear and 132^σ M.V. 9^σ for a weak sound in two ears. The figures for 143, after the exercise, are: 129^σ M.V. 6^σ for the loud sound in one ear and 127^σ M.V. 13^σ for the weak sound in two ears. The shortening of the time by exercise was 14^σ.

But the chief value of these notes is found in the light which they throw upon the nature of simple reactions. In the first place, are these reactions muscular or sensorial?

Wundt says that, with a signal loud enough to be clearly heard, we naturally react in the muscular way. He explains the difference between the time of reactions to weak sounds and those to loud sounds as due to a passing from the sensorial to the muscular way of reacting. In all of our experiments, with a few exceptions, the signal to react was a loud sound. This would seem to indicate that our reactions were muscular. Furthermore, the two criteria, which Wundt regards as sure signs of muscular reaction, were both present. In six cases at least a reaction was registered just before the signal to react was heard, while scarcely a series passed in which there was not one or more reactions to a warning.

On the other hand, throughout the whole course of experiments the reactor believed that he was reacting in the sensorial way. The attention, with the few exceptions about to be mentioned, was invariably directed to the ear or rather, as it seemed to him, to the sound to be heard. The eyes turned in that direction and there was a distinct feeling of accommodation in that part of the head, due to a combined muscular and nervous excitation. The reactor even went so far as to attempt reactions after the muscular way, carefully directing the attention toward the hand or the movement to be made. In one case, before the reaction habit had been formed, the reaction was shortened in this way from about 140^{σ} to 100^{σ}. In one of the later series, 139, an effort was made to have the last three reactions muscular, two of these were 110^{σ} and 112^{σ} while the average of the other half of the series was 142^{σ} M.V. 8^{σ}. These would seem to be true cases of muscular reaction, if there be such a thing. But in general the attempt to shorten the reaction-time by turning the attention toward the hand or the movement to be made was a decided failure. More often the time was lengthened. It seemed very difficult to overcome the habit of turning the attention toward the ear.

It would seem that those experiments in which the attention was directed to a peculiar movement of the hand or arm, to touching as quickly as possible some point near the key or raising the hand as quickly as possible to the shoulder, satisfied the definition of muscular reaction. Yet none of these show any signs of a decrease in the reaction-time.

Finally, in none of the reactions save those in which there was an attempt at the muscular method, did the person experience that peculiar physical fatigue which is generally ascribed to the muscular mode of reacting. The fatigue was always mental. As such it was very marked at the end of five or six series. From this point of view these reactions must be regarded as sensorial.

But again, according to Wundt, the peculiar nature of muscular as opposed to sensorial reaction lies in the fact that, while the sensorial reaction contains an apperceptive link in the chain of causes leading to the reaction, this disappears in the muscular method and the reaction becomes a purely automatic brain reflex.

Turning to the notes taken in the reaction-room we read, "Reaction a, 1, series 96, was made in spite of a resolve not to react." This was certainly a purely "automatic brain reflex" and contained no "apperceptive" link. The time of this reaction in the table is 222^σ. The average of the rest of the series 197^σ M.V. 26^σ. Reaction a, 9, series 134, was made while consciousness was entirely absorbed in something else. When it returned to the scene of operations it was quite surprised to find that a stimulus had been received and a reaction made in its absence. Its servants had done better than it expected. Surely this must be an "automatic brain reflex," with no trace of conscious perception or "apperception." The time was 183^σ, that of the whole series 124^σ M.V. 7^σ.

In series 99 one reaction took place before the will to react. That was set down at the time as a brain reflex. Its time however was not materially different from that of the other reactions in the series.

Several times, for instance in 108, it was remarked that a reaction to a weak sound only raised the finger a little whereas the reaction to a loud sound raised it over an inch.

These instances all seem to show that as soon as the habit is formed all our reactions are in the main brain reflexes. But they show just as conclusively that quick reactions are something more. The reflex action left to itself is slow, compared with the reflex action with the concentrated effort of the mind to hurry it along.

Wundt lays great emphasis upon reactions to the wrong signal as proving the reflex nature of muscular reaction. Martius[1] takes him to task for this and proves that he is wrong by showing that the same phenomenon occurs in sensorial reactions. Wundt is right. They do prove that muscular reactions are brain reflexes. But they also prove that sensorial reactions are reflex in exactly the same sense. A note was made, referring to 127a, in which there had been a reaction to a warning, "every warning is heard with a tendency to react." And so it is with all sounds. All sounds tend to produce motion in some part of the body. We notice it in the case of loud sounds, in the case of sounds which startle us and especially in the case of rhythmic musical sounds. In the same way reaction is a

[1] See the article cited above.

brain reflex. Therefore the difference between sensorial and muscular reactions is not to be found by deciding whether or not they are brain reflexes.

The key-note to much of the confusion about the different kinds of reaction lies in the indefinite use of the word attention and in a lack of careful introspective analysis of what actually takes place in consciousness.

The word attention is most commonly used in the sense of ideational attention. This kind of attention is described by such expressions as: "Having a clear idea of the object of attention;" "keeping the object in the foreground of consciousness;" "thinking about an object calmly and quietly, yet clearly." It is passive as distinguished from the two following varieties of attention. There is little feeling of effort. What there is, is largely devoted to the inhibition of other ideas. Doubtless there is a slight innervation and muscular contraction but they are not prominent in consciousness.

This kind of attention can be directed to any part of the body, to any motion to be made or stimulus to be perceived, or to something entirely disconnected from the experiment. For instance, in one series, 96, the reactor fixed his attention on a lecture which he had just attended. The time for one ear was 200^{σ} M.V. 27^{σ}, for two ears 179^{σ} M.V. 24^{σ}. This exceptionally long time was not due entirely to voluntary diversion of the attention; the series was also taken without a warning to tell when the signal was to be expected.

As a rule this kind of attention does not shorten reaction-time. So far as distinct thought forms are concerned, the nearer a blank the mind can be kept the more satisfactory seems the reaction.

Often, turning the attention to another object seems to facilitate the movement, just as in writing the hand moves more freely when the attention is directed to the word being written than when it is directed to the muscular effort involved. It seems to drain off the surplus ideational force and leave the field clear for the reaction.

Using the word in this sense MARTIUS is right in criticizing MÜNSTERBERG when he speaks of the idea of the sound as fusing with the idea of a movement to be made. There is no fusing together of these ideas. Association is the word which describes their relation to one another, and the association is always a temporal succession, so far as the ideas themselves are concerned. It is impossible to keep two of these ideas in consciousness for any length of time. When the effort is made, it results in a rapid passing from one to the other. First one comes into the foreground of consciousness, then the other.

A second sense in which the word is used is that of neural attention. Were it not for the fact that the word usually implies an increase in the muscular tension this might be called innervation. It results in bringing into consciousness the neural sensations. Sometimes it seems like a voluntary control of the nerve-force similar to the involuntary change which is produced by a severe strain when an increase in nervous excitement for the time being counterbalances physical fatigue. Closely combined with it there may be more or less of the feeling of outgoing will force as experienced in willing-games where one person wills another to do some particular thing.

This is closely connected with a third meaning of the word attention, namely, feeling-attention, i. e. the becoming immediately conscious of different parts of the body, which may be expressed either as bringing those parts into consciousness or as extending consciousness into them.

Using the word attention in either of these meanings it is possible to turn the attention to different parts of the body at the same time and to speak of ideas melting together. But the ideas here are quite different from those which we found in the first division.

In one case, 136, this attention was directed to all parts of the body at the same time. It seemed to increase the nerve-force and to result in a general excitement of the whole system. The average time of this series was 148^{σ} M.V. 17^{σ}, that of the series just before and just after, under the same conditions was 129^{σ} M.V. 10^{σ}. But a single experiment is hardly sufficient to show the effect of this kind of attention. No experiments were taken in which this kind of attention was directed to one or two parts of the body during a whole series.

A fourth sense in which the word attention is used is that of muscular attention. Involuntary changes in the condition of the muscles take place in response to various psychical changes; for example, they become tense in a fit of anger. To a large extent a similar change may be produced by voluntary effort. Something similar to this is usually meant by the expression "innervate the muscles." We can keep the muscles of the hand or arm relaxed or in a state of tension independent of the three kinds of attention already mentioned. Record 100 is an example of this; the first half was taken in the usual way and had a time of 146^{σ} M.V. 33^{σ}, the second half was taken with tense muscles and had a time of 120^{σ} M.V. 16^{σ}. In one of the experiments in this series the motor impulse for reaction was not strong enough to overcome the pressure on the key.

A fifth way in which attention can be directed is best expressed as a preparation of the path for the motor impulse from the brain. This consists of a moderate innervation of the whole nerve tract, a small muscular tension and an effort to get a clear idea of the sound and the movement to be made, resulting in a rapid passing of the thought from one to the other. The last experiment of series 113 was made in this way; the time was 127^{σ}, that of the whole half-series 156^{σ} M.V. 15^{σ}.

A sixth state of the attention, one which requires as much effort of a certain kind as any, is that of inattention. All ideational attention, all neural attention and muscular attention are withdrawn leaving the reaction mechanism as far as possible to work automatically. This reduces the circulation, the nervous and muscular tension and with that the whole energy of the system. The tension of the muscles becomes so weak that they sometimes fail to move the very light spring in the reaction-key. By this means many persons are able to put themselves to sleep in a short time. Series 210 was taken in this condition; the time was, in the dark 141^{σ} M.V. 13^{σ} with a steady light in the field of vision 140^{σ} M.V. 8^{σ}.

None of these six descriptions accurately state the condition of the attention in the majority of our experiments. The most prominent feature was always an expectant attention, a strain in the muscles of the ear and a waiting for the sound. There was no attempt to form an idea of what the sound was to be, but simply an effort to hear it as quickly as possible. At the same time there was an under-current of neural and muscular attention directed to the hand and arm. If it is proper to use the terms primary and secondary consciousness, the primary was engaged with the sound, the secondary with the motor apparatus.

Aside from these seven phases of attention numerous other combinations of the three elements are possible. The dividing line between the classes is not a sharp one. All three or any one can be given especial prominence. Certainly the expressions muscular reaction and sensory reaction are of themselves very indefinite and give no accurate descriptions of the distribution of psychic energy.

With these different kinds of attention in mind it would be impossible to agree with James when he says,[1] in speaking of Wundt's and Exner's experiments, "The preparation to react consists of

[1] Principles of Psychology, I 438.

nothing but the anticipatory imagination of what the impressions or the reactions are to be" and "It is impossible to read Wundt's and Exner's pages and not to interpret the 'Apperception' and 'Spannung' and other terms as equivalent to imagination." A little practice will enable one to become master of all the different phases of attention here mentioned and many others more difficult to describe.

The remarks thus far have referred to voluntary attention. On the other hand there is a large involuntary element always present in the state of attention at any given time. This changes with practice and with the mental and physical condition. One naturally falls into a habit of reaction. The attention in that case is largely involuntary and resists all efforts of attention in other directions but co-operates with additional voluntary attention in the same direction. When a person is sleepy he has little control over the attention. The same is true when he is wrought up to a high state of nervous excitement.

The mass of bodily feelings varies with changing physical conditions; when one is fresh and vigorous they are large and massive and the motor impulse to reaction seems to meet more or less resistance in passing through them. After prolonged bodily or nervous strain these feelings tend to grow less and their center gradually rises. The extremities drop out of consciousness and the reaction seems to take place with less resistance. The background of all these various forms of attention is the constant play of psychic life. Waves and ripples of feeling and conation are incessantly passing through the mind. More clear cut and easily recognized are the ideas and images of the memory or imagination which follow each other at their own fancy. Now they pass along lightly like fleecy clouds over a summer sky. At the sound of the warning they vanish from consciousness and all the energies of the mind are bent to catch the coming stimulus and make the reaction. At another time the thoughts roll along like heavy irresistible storm-clouds. They heed not the faint warning or even the signal itself. Throughout a whole series the mind will be busily engaged inventing new apparatus, improving the old or struggling with some great problem of life. The reaction, so far as consciousness is concerned, goes on automatically. No amount of effort at the end of the series can call into consciousness a single fact connected with the reaction, nothing save the elements of this dream-like stream of consciousness. But during such a series let there be a break in the regularity in the recurrence of warning or signal and the mind is instantly alert to inquire into the matter. Though apparently absorbed in other matters, yet there is a kind of unconscious attention being directed to the reaction.

Again, when the mind is apparently wholly engaged in the matter of reacting, an idea will suddenly come into the mind from some mysterious quarter with force enough to carry away for the moment all the attention, unconscious as well as conscious. In series 127 there was such an instance. An idea suddenly flashed upon the mind just as the signal was heard and the motor impulse being started; the whole force of the attention was diverted and the only impulse which reached the hand was a tremor too weak to raise the finger.

These observations and others suggested by the summary of the notes taken during the course of the experiments show that there is still much which can be learned about the mind and its processes from the study of reaction-time. They suggest a large number of experiments which might be carried out along the different lines of attention. Most of all they emphasize the great value of introspection. For the rougher work in reaction-time this may not be necessary. We can easily detect differences in reaction-time due to the presence of very distracting influences, to the effect of practice, to changes in intensity of the stimulus, to a change in the quality of the stimulus, and to many similar changes. But as soon as we inquire into the nature of reaction, and try to make quantitative estimates of these changes and to learn more about the nature of the mind's activities, then introspection is necessary.

Some will criticise these reaction-experiments because they were all made upon one person, and therefore can give no idea of what would be the result in another case. They say that results to be of value must be made upon a great many persons and the average computed as has been done in the case of physical measurements.

In reply it may be said of physical measurements that while statistical results from one point of view are of great value yet all the important discoveries in physiology have been made upon individuals. Statistics would never have discovered the circulation of the blood or the constituent parts of the brain. The human body is for the most part the same the world over and a discovery in anatomy in one body holds good in all others. The same thing is true in psychology. Nearly all the results thus far obtained have been gained from the study of individuals. The human mind like the human body is for the most part the same in its workings everywhere and a discovery in one mind will hold good for other minds. Though important results will be reached along statistical lines yet the greatest advance in the future as in the past will in all probability be made by discoveries in investigating individuals.

EXPERIMENTS SHOWING THE EFFECT OF CHANGES IN THE STATE OF ATTENTION UPON THE MAXIMUM RATE OF VOLUNTARY MOVEMENT.

In a series of experiments carried on at Clark University, DRESSLAR found that the time required to make 300 taps varies with different individuals and with a change in the mental and physical condition of the same individual. Increased central activity favored an increase in the rate of voluntary movement.[1] BRYAN continuing the investigations upon a large number of school children found that the rate of tapping for the different joints of the hand and arm varied with children of different ages in accordance with their physical and mental development.[2] Many interesting points were brought out as to the effect of fatigue and the relative development of the different joints. But with the apparatus which they used it was impossible to show the relation between the individual taps of the series. The most that could be done in that line was to detect a slight decrease in rapidity due to fatigue when more than 300 taps were taken at a time. Otherwise it was taken for granted that the rate was uniform throughout the series.

The following experiments were taken with the purpose of investigating this question of the uniformity of rate. Our reaction-time apparatus offered the best possible means for measuring the interval between each successive tap. The taps were made upon the reaction-key in the dark room, and recorded by the electric sparks on the smoked paper of the drum. About 300 taps could be recorded on one paper by turning the drum slowly. An electro-magnetic time-marker was placed beside the tuning-fork and connected with a pendulum which beat seconds. This enabled one to tell at a glance the number of taps in a second in any part of the curve while, without it, it was necessary, in order to find the number of taps in a second, to add up the successive intervals, given in thousandths of a second, until they amounted to a second, and so on throughout the series.

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[1] *Some influences which affect the rapidity of voluntary movements,* Am. Jour. Psych., 1891 IV 514.

[2] *On the development of voluntary motor ability,* Am. Jour. Psych., 1893 V 1.

As a matter of fact this longer process was gone through in the preparation of the curves described below because there was a slight irregularity in the successive spaces marked off by the pendulum, due to the fact that the mercury contact was not made exactly in the middle of the arc of oscillation.

A click on the bell was the signal to begin tapping and the instructions were to tap as rapidly as possible until a second click announced that the record was complete.

TABLE VIII.

No.	A	MV	M V′	No.	A	M V	M V′
1	139	15	12	11	139	11	9
2	134	9	9	12	144	11	3
3	135	7	7	13	147	14	3
4	130	7	6	14	147	14	7
5	130	4	4	15	138	7	6
6	133	6	7	16	143	9	5
7	130	9	7	17	114	15	6
8	133	4	4	18	148	19	5
9	138	6	3	19	143	16	5
10	138	6	4	20	139	10	5

No., number of group.
A, average time.

Table VIII gives a summary of the figures for one experiment. There were 180 taps, or rather intervals between successive taps, recorded in this experiment. They were collected into groups of nine for the purpose of showing the gradual changes in the rate during the series; instead of finding that the intervals are all the same, we found a continual variation. During the 180 taps there were only four cases where successive intervals were recorded as the same. The intervals were collected into groups of nine for the purpose of showing the gradual changes in the rate during the series; only the averages of these successive groups are given in the table. The deviation of the individual intervals was computed in two ways. The first deviation-column represents the average deviation of each

TABLE IX.

Name	Date	A	MV	T	S
W. I. C.	Feb. 25.	133	9.3	7.5	39.9
"	Feb. 28.	147	9.5	6.8	44.1
"	"	145	9.	6.9	43.5
"	"	147	10.	6.9	44.1
"	"	138	9.	7.2	49.4
Average		142	9.3	7.1	44.2
C. B. B.	Mar. 24.	175	11.	5.7	52.5
Dresslar		117		8.5	35.3
"	Av. of 20 visitors	167		6.0	50.4

A, average time.
T, number of taps per second.
S, number of seconds for 300 taps.

interval of the group from the total average of the 180 intervals. The second column represents its deviation from the average of its own group of nine. The difference between the two is due to the gradual change in rate. Looking at the first column one would say that the irregularity of tapping increased very fast toward the end of the series but a glance at the second column shows that this was not the case. On the contrary there is a steady increase in the regularity of the intervals in the different groups but, owing to the rapid increase in the intervals themselves, the deviation of the later groups from the total average is greater than that of the earlier ones.

Six of these experiments or sets of taps, were taken and they all show the same general results. The average for the successive groups of nine taps for the six experiments were 140^σ, 137^σ, 136^σ, 134^σ, 139^σ, 144^σ, 146^σ, 147^σ, 148^σ, 150^σ, 145^σ, 150^σ, 150^σ, 154^σ, 154^σ, 154^σ, 153^σ, 152^σ and 150^σ. These averages show an increase in the rapidity of tapping for the first four groups of nine. After that there is a gradual falling off for five groups then a slight recovery during two groups followed by a still greater slowing up for four groups and then another slight recovery. The average of the first set of groups is 140^σ, that of the nineteenth, which is the last to contain records from all the six experiments, is 150^σ.

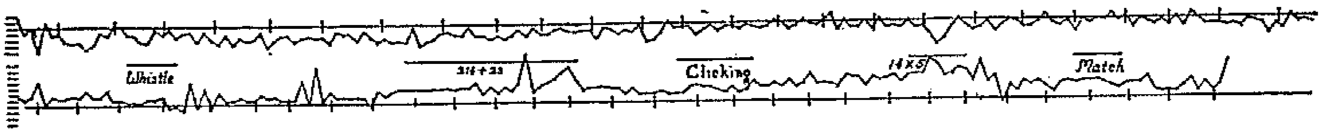

Fig. 14.

Table IX contains the final averages of the six experiments. Besides the average interval between successive taps, and the average deviation from it, the number of taps per second has been computed, and also the time required to make 300 taps. This was done for the purpose of comparing the results with those obtained by Dresslar and Bryan. The time required for 300 taps is naturally somewhat less than it would have been if that number of taps had actually been made; for the experiments show that the last taps of a series are much slower than the first owing to fatigue.

However, we are not so much concerned with the number of taps in a series as with the regularity of the intervals between the successive taps. This can be studied much more satisfactorily by means of graphic representation than by tables. Accordingly the records of two series have been plotted. The resulting curves are given in fig. 14.

The curves represent the intervals between the successive taps of each series. The abscissas show the place of each tap in the series while the ordinates represent the length of the interval between two adjacent taps, each vertical division on the paper representing 10^σ and the horizontal line being taken to represent 150^σ. Thus the high parts of the curve correspond to slow and the low parts to rapid rates of tapping. The short vertical lines mark off the seconds.

A glance at these curves shows how the interval between the taps is constantly varying. Only in a very few instances does it remain the same for two successive intervals. For two, three or even four successive taps there will be a gradual increase in the rate until the mind is satisfied with its work or until it is unable to keep up this high strain of attention, when the rate again falls off. This effect can be seen in the second and third seconds of the first curve. Again as in the fourth and fifth seconds of this same series the process of change is more rapid. The rate alternately rises and falls with each successive tap. In the sixth second the rate falls off for three intervals, gains in the next what was lost in the last two, and again loses the same in the two following. Most of these changes pass unnoticed by the person while he is tapping. He is, however, at times conscious of a falling off in the concentration of attention and tries to correct it by a special effort.

The second curve, corresponding to the record of C. B. B. in table IX, is almost entirely above the 150^σ line, showing a slower rate of tapping than the other experiments. The explanation of this is the fact that the experimenter had learned of the great irregularity of the intervals and in this case aimed to tap as regularly as possible rather than as fast as possible. The result shows a slower rate but also the same irregularity, the same increase and falling off in the rate, now rapid, now gradual.

In all of these records aside from the usual variation in rate there are a few unusually long or short intervals. In the nature of the case there are more long ones than short ones. In one case there seems to have been a momentary break in the series, due very likely to a condition sometimes experienced by other persons in similar experiments. All of a sudden in the midst of a series of taps the arm seems to be momentarily paralyzed.

Over and above this variation in the rate from one tap to another there are larger gradual changes from second to second. During the first second there is always a general increase in the rate. After the middle of each curve there is a gradual slowing up. Dresslar detected signs of fatigue after 300 taps. My experiments show a decrease in the rate soon after 100 taps.

But aside from these two changes in the rate, an alternate increase and decrease of the successive intervals and a gradual slowing up toward the end, there is a third change brought out by these curves, which is of great interest. If we turn the curves around and look at them from the end so that the line of vision makes a small angle with the plane of the paper we notice a gradual rise and fall of the curve every two or three seconds. This is doubtless due to the gradual rise and fall of the attention and corresponds to the alternate appearance and disappearance in consciousness of a sound just loud enough to be heard, as for example the ticking of a watch held at just the right distance, and with the alternate appearance and disappearance of faint rings on a rapidly rotating disk.[1] The chief point of difference is that in those cases the phenomenon is a matter of consciousness whereas in this case the person is entirely unconscious of the rise and fall in the rate. This fact shows that the rise and fall are not confined to ideational attention but are also characteristic of the subconscious muscular attention. These results agree with those recently obtained in the field of sight and hearing[2] in not showing any regular period of rise and fall. In general it occurs every three or four seconds.

In the second, third, fourth and fifth experiments an effort was made to distract the attention of the person tapping. The warning and signal used in reaction-experiments were sounded several times and the tuning-fork sound described in one of the experiments in reaction-time was turned on while the ear was at the telephone. In some cases there may have been slight changes in the rate of tapping owing to their influence, but that was by no means clear. In fact such weak sounds would hardly be expected to produce much disturbance in such heavy work.

In the sixth series the distractions were greater and show themselves plainly in the second curve. They were produced by an assistant in the reaction-room. A second electro-magnetic marker was placed on the drum and connected with another key in the reaction-room ; by means of this key the assistant could register by the side of the time curve the beginning and the end of each disturbance.

The nature and place of the disturbances are noted just above the curve; their duration is indicated by the length of the short lines above the curves. In every case it will be seen that the disturbance produced marked changes in the rate. The blowing of a loud whistle was followed by a great irregularity. The mental addition of 214 and 23 at first made the rate very regular, more so than at any other point in all the series. This was during the period

[1] LANGE, *Beiträge zur Theorie der sinnlichen Aufmerksamkeit und der activen Apperception*, Phil. Stud. 1888 IV 390.

[2] MARBE, *Die Schwankungen der Gesichtsempfindungen*, Phil. Stud. 1892 VIII 614.

between hearing the problem and beginning to solve it. At first the person was reluctant to undertake the problem. He felt that all his energies should be directed to the tapping but finally realizing that the problem must be solved he went at it. The first attempt at solution produced marked irregularly and real work was accompanied by a steady falling off in the rate. As soon as the answer was reached the attention returned to the tapping and the rate rapidly recovered.

A clicking with the tongue, such as is used to make a horse go faster, owing to this association seemed accompanied by irresistible impulse on the part of the person tapping to accelerate his movements. There was a slight falling off in the rate at the first surprise and then a gradual increase for four taps. But to the great surprise of the person who did the tapping, the rate did not exceed that which had been maintained since the last disturbance. The mental multiplication of 14 by 5 produced great irregularity as well as a general decrease of the rate. The sight of a lighted match, however, produced great regularity and a steady increase in the rate.

This sudden increase in the regularity of tapping without a marked change in the rate, when the attention is attracted by some other object, is similar to the fact noticed in some of the experiments in reaction-time, namely, that more regular results were sometimes obtained when the mind was partially absorbed in other things. The more superficial, ideational attention is directed to them while the unconscious muscular attention which is largely a matter of habit runs along more smoothly and automatically. As the mind is absorbed in the secondary problem, the more substantial subconscious attention gradually withdraws from the muscular effort and reinforces the mental effort.

On the other hand, as was also shown in the reaction experiments, some sudden surprise, in this case a clicking sound or a lighted match, at once draws away the deeper as well as the more superficial attention. But as soon as the surprise is over there is no strong intellectual effort required to watch the light and the subconscious attention returns unhindered to its habitual task, while the more fickle ideational attention remains captivated by the new sensation.

There can be no question that these last changes in the rate of tapping are due to disturbances of the attention. There can also be no question that the second change mentioned, namely the gradual slowing up after the first ten seconds, is due to fatigue. This fatigue may be psychical, muscular or neural. Judging from the results obtained by LOMBARD in his investigation of the amount of work which can be done by a person under different conditions,[1] it is probable that the fatigue is in the nerve centres.

In the case of the change first described, namely the variation from tap to tap, the cause is not so evident. The fact that a partial withdrawal of the attention stops it and makes the intervals regular indicates a psychical cause. Under the additional strain of conscious voluntary attention the nerve mechanism acts more irregularly. Irregularity seems to be a characteristic of the higher forms of psychic life. The usual explanation is that there are two sets of nerve centres involved, the higher more unstable brain-centres and the lower more automatic ones of the smaller brain and spinal cord. A disturbance of the attention is supposed to cut off the higher centres from the circuit engaged in the muscular action. Yet both in the tapping and the reacting it was seen that further central activity was accompanied by further decline in the muscular rate. Therefore it seems proper to speak of a subconscious attention in this connection.

The explanation of the third change in the rate, namely the gradual rise and fall, is still more uncertain. Many persons will object to the use of the word attention in this connection. They would claim that it is a purely muscular phenomenon and regard it as supporting MÜNSTERBERG's explanation of the appearance and disappearance of faint visual images. The disappearance, he thinks, is due to fatigue of the muscles of the eye. As soon as the image disappears they relax and begin to recover; when they have regained their strength the object comes into consciousness again.[2]

It seems certain that this rise and fall in the rate must be closely connected with the appearance and disappearance in consciousness of faint sensations but it seems equally certain that they are not due to muscular fatigue. In the first place, it must be remembered that this rapid tapping is not a mere muscular operation; we have seen that the rate changes with changing psychic states. In the second place, there is no chance for the muscles to recover while the tapping continues. In the case of the eye there is a possibility that the muscles relax when the image disappears. Not so here. In the third place, the real fatigue shows itself in the general slowing up of the rate.

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[1] *Some of the influences which affect the power of voluntary muscular contractions*, Jour. Physiol. 1892 XIII Pts. 1 and 2.

[2] MÜNSTERBERG, *Beiträge zur experimentellen Psychologie* 1889 II 69.

Conclusions from the introspective observations.

1. Reaction-time is constantly affected by irregular disturbances a large part of which may be detected by introspection.
2. Introspection is not to be trusted in estimating results.
3. Exercise shortens reaction-time.
4. Reactions to the wrong signal, reactions before the signal is heard and the reflex nature of reactions are not sufficient criteria to distinguish muscular from sensorial reactions.
5. There are at least six distinct kinds of voluntary attention; ideational attention, neural attention, feeling attention, muscular attention, preparatory attention and inattention.
6. The involuntary attention is constantly changing.

Experiments showing the influence of disturbances of the attention upon the voluntary control of muscles.

There have been various devices invented to show the effect upon the body of various psychical disturbances. Some of the effects which have been pointed out are a rise in the temperature of the brain, a change in the circulation, a contraction of involuntary muscles, increased activity in the various glands, and a change in the force with which the muscles can be contracted. Lombard found that the knee-jerk showed marked changes in the case of mental disturbances. We have seen that the reaction-time and rate of tapping are influenced in a similar way. Jastrow[1] describes a piece of apparatus which he calls the automatograph, constructed for the purpose of registering involuntary movements of the hand. The hand is placed on a freely moving table to which there is attached a marker that records every movement upon a smoked paper. It was found that when the apparatus is screened from the eyes of the person experimented upon that the hand involuntarily follows in the direction toward which the attention is turned.

During the course of my experiments Dr. Scripture suggested that the accuracy with which a person could steadily point to a given spot would be a measure of the amount of attention he could direct toward the work. In accordance with that suggestion the apparatus shown in fig. 15 was arranged to measure this accuracy. It differed fundamentally from Jastrow's automatograph. In his case

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[1] Jastrow, *Studies from the University of Wisconsin*, Am. Jour. Psych. 1891 IV 398; 1892 V 223.

the pointer was concealed from the person performing the experiment; here the pointer was in full view and every effort was made to keep it steadily opposite a given mark.

A receiving tambour was fixed to a standard in a horizontal position, face upward, so that the lever moved in a vertical plane. A light pointer eight inches long was attached to the lever. Back of the tip of this pointer a piece of card-board was fixed in a vertical position parallel to the plane of the lever. A dot was made on this card-board just below the end of the pointer. The recording tambour was adjusted to register the movements of this lever upon the smoked paper on the drum. An electro-magnetic time-marker was placed by the side of the recording tambour and connected with a pendulum which beat seconds.

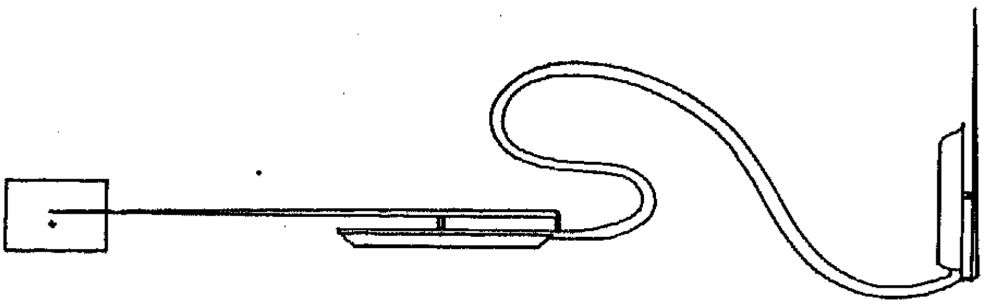

Fig. 15.

This apparatus having been arranged in a convenient position, a person placed his finger on the lever of the receiving tambour and, with the whole arm free, kept the end of the pointer as steadily as possible opposite the dot on the paper. It was found impossible to keep the point exactly opposite the dot; there was a constant vibration above and below. Within certain limits the movements of the point increased or decreased inversely with the amount of attention given to the work.

Figs. 16–19 contain sections cut from the record of one of these experiments. The upper curve was drawn by the lever of the registering tambour and shows the vertical movement of the finger. The heavy broken line was made by the time-marker and each section represents one second. The fact that some are longer than others shows that the drum was not turned with uniform speed; this fact must be kept in mind while examining the records.

The irregular shape of the curve shows the constant movement of the finger. In the centre of each of these sections there is a still greater irregularity. These disturbances all correspond to disturbances of the attention at the time the record was made.

A mark shows the point where the disturbance began, the white mark toward the right marks the point where the disturbance ceased.

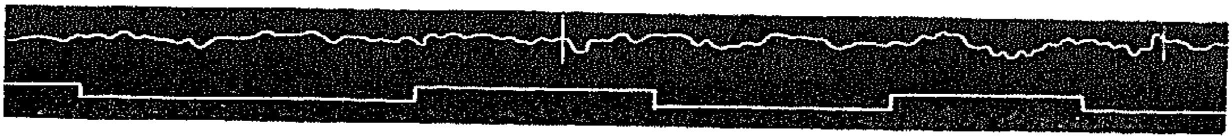

Fig. 16.

Fig. 17.

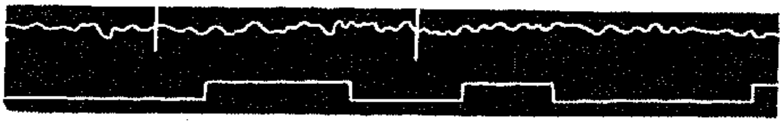

Fig. 18.

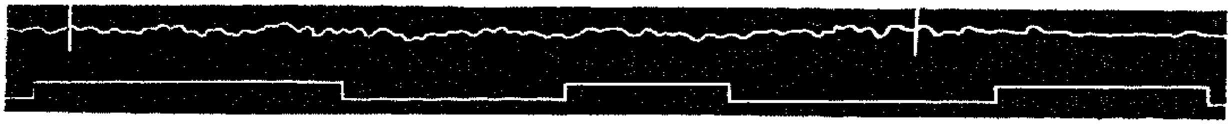

Fig. 19.

Fig. 16 shows the effect of an accidental distraction. There is great irregularity just at the time when another person happened to leave the room. The first half of fig. 17 indicates the effect of a sound which originated in another room. The distraction seemed to steady the hand; great irregularity occurs about the time of return of attention. Fig. 18 shows the effect of the mental subtraction of 88 from 89. In this case the problem was so simple that the answer was given immediately, yet the disturbance is very marked. In fig. 19 the attention was drawn away from the work in hand by a person walking around the room.

These are only a few of the instances in this one experiment which show the inability of the mind to resist the smallest influences even when the will is set resolutely against them. It seems that in cases where the attention is distracted in a way such as to cause a tendency to move the eyes or when mental work is being done, the control of the muscles is uncertain. When the disturbance is a slight one, such as noticing a noise in another room, the distraction seems to aid the regularity. This latter case seems to be analogous to the well-known fact that we can perform numerous actions much better when only half attending to them.