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PENDULUM CHRONOSCOPES AND ACCESSORIES FOR PSYCHOLOGICAL EXPERIMENTATION.

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In connection with his work as director of the psychological laboratory of Indiana University, which position was held till August 1, 1908, the writer had occasion to attempt to develop chronometric apparatus both for research and for the student practice course. Partial notices of these attempts have occasionally appeared, but no complete account such as is here given. In the *PSYCHOLOGICAL REVIEW*, Vol. 7, No. 5, 1900, the writer described 'A Type of Pendulum Chronoscope and its Motion Apparatus,' the construction of which was suggested particularly by accounts of the Fitz pendulum chronoscope. The chief difference between this and the model constructed by the writer lay in the mode of carrying and clamping the index. In this first model, the axis of the pendulum was so cut that its knife edges were exactly in line and in the middle of the axis so that a further extension of the axis, which carried the index, rotated as if the axis were in circular bearings when the pendulum moved. The index was attached to a soft iron disc, which could rotate on the extension of the axis and was pushed by a spring against a friction disc attached to the end of this extension. A magnet fixed to the bracket, on which the axis of the pendulum rotated, could be made to attract the soft iron disc carrying the index, and fix it in position. When the disc of the index rested against the friction disc of the axis, it was held in place sufficiently firmly to follow the movements of the pendulum accurately. On the attraction of the index disc from the fric-

tion disc to the magnet, the friction keeping the index moving with the pendulum was greatly reduced and the index disc was held firmly in position against the magnet, with its point against the scale. The pendulum could swing on fairly freely and was caught at the end of the return swing by teeth on the escapement armature. The interval measured was the interval between the release of the pendulum by the escapement and the arresting of the index. The first chronoscope had mercury cup arrangements for intervals and a movable bob for securing different rates. In the later models these have been replaced by devices both more nearly accurate and more convenient. In the first model the release of the pendulum was not noiseless and was therefore defective. However, from the point of view of accuracy, aside from the work of the two devices just mentioned, the work of the first pendulum chronoscope seems to have been as good as that of later models.

To remedy the defects of the first model and to produce a more finished piece of apparatus, a second model was designed. This is the most complete form yet constructed, as the third is only a simplification of the second. Of this second model no detailed description has been published till this present article. It was constructed from the writer's designs by Stoelting and Co. of Chicago and formed a part of this firm's exhibit at the St. Louis Fair in 1904. A cut of model No. 2 appeared in the Indiana University book, published for the same fair.

In model No. 2, the release and catch of the pendulum is of the same sort as in model No. 1 except that it has been made silent by preventing the armature from touching the magnet of the escapement. As in the first model, the release and catch has several notches so that the pendulum may be caught on the return swing by some one of them, according to its retardation. In some, perhaps all other, pendulum chronoscopes, the holding and release of the pendulum for a record is secured by having a magnet hold the pendulum directly at the beginning of its swing, the pendulum beginning its swing when the current is broken. That this last form of release is also good seems evident, and which of the two types of release will be adopted in the construction of pendulum chronoscopes cannot be pre-

dicted with certainty. Both are silent, which is essential, if the experimenter would avoid unnecessary trouble and inaccuracy. However, in case the pendulum is held directly by a magnet some variation may be expected from differences in its retardation, due to differences in the duration of the current and differences in the weight of the pendulum for fast and slow rates, as well as differences in annealing. These effects are largely avoided in the escapement used. The pendulum is released by the making of the circuit of the escapement magnet which may therefore be supposed to be in the same condition for every record, and a current is used which is twice as great as is necessary to release the pendulum for the fastest rate, when it bears most heavily on the tooth of the escapement. Only the form of escapement peculiar to this instrument has been used with these chronoscopes so the writer has made no experimental comparison of the two types. However, in testing chronoscopes 1, 2 and 3 with the simple falling ball apparatus, in which the falling of the ball is comparable with the falling of the pendulum with the simple magnet escape, the chronoscopes seemed to be more accurate than the testing device, because of variations in the hysteresis of the ball and the magnet holding it. Systematic rotation of the ball, which was probably not so well annealed as it should have been, and the use of a current barely sufficient to hold the ball gave the best results.

For rapid action of the magnets, the cores must be comparatively large with few windings of wire. A convenient size of the magnets both of the escape and the index is one that will require the use of the same or of equal currents to make the chronoscope give the correct time. In the first models of chronoscope No. 2 an error was made with regard to this matter so that a stronger current was required for the escapement than for the index.

The different rates of swing of the pendulum are secured by screwing on the necessary counterpoises. In model No. 1 these rates were secured by raising and lowering an eccentric bob, which also permitted the experimenter to adjust the pendulum so that it would hang vertically. The plan of detachable counterpoises, which has usually been employed in pendulum chronoscopes, seems to be the more convenient.

Instead of the semicircular mercury cups for securing intervals, as in No. 1, a system of one fixed and two movable keys on a curved slide is employed. These are both more accurate and more convenient than the mercury cups. They can be used for definite intervals for any purpose. In the laboratory of Indiana University they have been used especially for giving the time of

FIG. 1. Model No. 2.

exposure in tachistoscopic experiments, and in standardizing the smaller pendulum chronoscopes of model 3. A laboratory equipment consisting of one chronoscope of the type of model 2 and several of the type of model 3, especially for student use, seems to meet most actual needs.

The contacts in the small movable keys are kept together by having a pointed projection of the lever making the contact just slip over a triangular tooth on a short spring. When the lever

is struck by the pendulum and is moved a short distance, perhaps less than half a millimeter, the projection slips over the tooth,

FIG. 2 Pendulum of Model No. 2.

which then throws it out of the way. By this means sufficient pressure at the contacts is secured and the resistance to the pendulum is made small.

The pendulum is so constructed that with its three counterpoises it will swing at three different rates, namely, at one half, one and two seconds for the half swing. Fig. 2 gives the proportions of the different parts of the pendulum graphically. The distance $X-Y$ is 20 cm.; $Y-OP$ is 5 cm.; OH is 6 mm.; the thickness of V is 1 cm.; of W 1 cm. at the top and 0.8 cm. near I . J ; IJ is 4 cm., JL 5 cm.; and HG is 4 cm.; HF is 3.4 cm.; HD is 6.5 cm.; and HA is 8 cm.; $HFEG$ is hollow with a .75 mm. wall, except at HG where the thickness on each side of the screw is 1 mm., though when it is fully screwed on, $HGPO$ is to be practically solid. Parts $HFEG$, $HDCG$ and $HABG$ may be changed to give respectively half swings of .5, 1 and 2 seconds. M represents the index and N a cross-section of one of the movable keys.

The length of the scale arc is about 29 cm.

To secure correct proportions in the construction of this pendulum requires considerable time and skill; and in the simplified form, No. 3, only an approximation is attempted. The calibration of the scale is done in essentially the same way in all cases, except that the procedure was somewhat simplified in connection with the construction of model 3. The calibration is both easy and accurate and consists essentially of letting the sparks from an induction coil actuated by an electric tuning fork of 100 vibrations a second run over the piece from which the scale is to be made, after it has been smoked. Not all tuning forks even by the best makers give the correct number of vibrations; different conditions must also be taken into account. Some correction of the tuning fork may therefore be necessary. The method of securing the spark records for the scale has been the same throughout, though a couple of minor improvements have been introduced. A very fine wire is run down the index and the end turned toward the scale. The upper end has a hook at the level of the axis and rests in a mercury cup. The formation of the spark circuit can easily be imagined. To make the pendulum start at a certain point between the sparks, a rather complicated system of wiring and balancing of currents was at first arranged, so that when the escape was gently shaken by the primary giving rise to a spark another current

would be switched in to pull the escape down. This plan gives good results and the spark can be run over the same record several times with coincidence. The pendulum will by this plan also start at corresponding points for different rates. However, the method is complicated and a very simple device has been introduced which serves fully as well.

With both methods the escapement is so placed as barely to hold the pendulum. With the new plan, a good-sized permanent magnet is placed over the back projection of the escapement lever so that this will fly up to the magnet when the escapement is given a very slight shake. This shake is given to it by the interrupted current of the primary and usually in the same way on the closing of the primary circuit, at least so that several coincident spark records may be obtained. The second change in the making of the spark records was that of omitting smoked paper and smoking directly the piece intended for the scale, which seems to give better results.

Two points should be noted in levelling the chronoscope. Each instrument has a universal level attached. By the aid of this it can be approximately levelled, but this procedure should be supplemented by seeing that the index runs the full length of the scale. With the combination of these two ways errors from levelling should be very small.

Nearly all the different time measurements fall conveniently within the limits of the forward swing one scale or the other. Occasionally a record is longer, in which case the time is ascertained by noting the point at which the index stops on the return or subsequent swings.

The three scales are not equally valuable, the half second and two second scale being more serviceable. In model No. 3 only these two are used and the one second scale could be omitted in model No. 2, but it seems sufficiently useful to be retained in the complete instrument.

Fig. 3 represents model No. 3 with all the accessories, that is, with a complete outfit for the usual chronometric experiments of the laboratory. Model No. 3 was designed not so much for research as for the student practice course, though it can serve for either as far as accuracy is concerned. It differs from No. 2

chiefly in being smaller, much simplified, and in having the especially expensive features eliminated so as to make it possible for a laboratory to have a considerable number of duplicates for general student practice. The base is 25 by 15 cm., while the base of no. 2 is 38 by 21 cm. Other parts are proportionally reduced. The base is made of cast iron, left without planing. The pendulum bracket, which is 15 cm. high, is cast solid and the rests for the knife edges of the pendulum, which in model 2 are separate pieces of hardened steel, are planed out with a properly shaped tool and left without hardening. The pendulum instead of being made from a solid piece, as in model 2, is a composite. A half inch brass rod is selected and a screw thread cut at one end. Pieces of the proper shape for the lower bob and the expansion to hold the axis are soldered on. The upper bob with its detachable part, to be used to secure the slow swing, is screwed on, the fixed part being soldered. The pendulum is then adjusted so as to give a half swing in from 450 to 500 σ and a slow swing of about 2000 σ or more. The scales for the two swings are made on opposite sides of the same piece of brass; and either side can, of course, be presented by lifting the brass piece out of its guides and putting it in the required way. As these scales are then made from a spark record in the way indicated, theoretically no part needs to be constructed with special accuracy, unless it should develop some irregularity of motion. Among the things needing most care in construction are the axis with its knife edges, the knife edge rests, the hole in the pendulum for the axis, the index armature, the armature of the escapement, and the scales; but for this ordinary good workmanship will probably do.

To make it possible to use the return swing accurately, it is necessary to make the measurement of some known interval longer than the first half swing so that the index will be stopped on the return. With this as a point of reference, the return swing can be read with sufficient accuracy and the proper values can better be assigned to the more thickly crowded divisions at the end.

The difference in the usefulness of models 2 and 3 is represented chiefly by the omission in model 3 of the sliding keys and

FIG. 3. Model 3 with Accessories.

so of the possibility of using it for securing intervals for tachistoscopic exposure, standardizing other instruments, giving the second signal in complication attention experiments, and for other purposes requiring intervals.

It is, of course, possible to conceive of other types of pendulum chronoscopes, which yet retain the essential features of those here described, especially a fourth, that would have the features of model 3 for reducing cost of construction and at the same time the sliding keys of model 2 for intervals. With such an instrument almost everything could be done that can be done with this line of chronoscopes, and the cost should be much less than for model 2. In size this instrument might be the same as model 2 or between model 2 and model 3, which would perhaps be preferable. The pendulum would need to be somewhat heavier than that in model 3, for the operation of the keys. With one instrument like model 2 and several like model 3, there is, of course, no special occasion for the construction of an instrument of this type and none has been made. But if there were to be but one instrument and model 2 would appear to be too expensive, then the proposed model 4 would seem to meet the requirements.

The accessory apparatus for signals and reactions has been devised to secure accuracy of experimental conditions and at the same time simplicity and convenience. Figure 3 shows the entire outfit. It consists of a board about four feet long, with the various pieces of the accessory apparatus attached. As has been stated, chronoscopes of types 2 and 3 start silently and operate silently till the index is clamped in the reaction. Apparatus for touch and visual stimulation must also operate silently, while the specific function of apparatus for auditory stimulation is to give a regulable noise at the instant of the closure of the circuit for starting the chronoscope. As is well known, reactions for auditory stimulations are shorter than for visual stimulation and for touch stimulation in certain localities, and all reactions are likely to be reduced to auditory reactions, if there is any sound in connection with the different stimulations. It is not safe to trust the reactor's statement as to which stimulation is being followed. He may not be aware that he

is reacting to certain clicks of the chronoscope when he should be reacting to visual stimulation. If the reactor is near the Hipp chronoscope, for example, visual reactions are quite likely to be in reality auditory, due to the sound connected with the beginning of recording by the chronoscope, even though this is so muffled as to be only slightly audible and the reactor himself is not aware that it plays any part in his work.

In the first place, an effort has been made to avoid most of the trouble connected with the setting up of the chronometric apparatus, and especially the trouble connected with changing from one form of reaction to another. The labor of changing is likely to fall on the assistant in the laboratory or on the instructor, rather than on the student; and with a large number of students this introduces a very considerable and unnecessary burden. There is usually not sufficient time for the extended study of the physics of the problem and learning merely to imitate the manipulation of the wiring has probably not sufficient educational value for the time expended. Apparatus for the different forms of stimulation can be ready for use, and in circuit with the chronoscope at the same time, requiring only that a card be slipped in to separate the contacts of the apparatus for touch stimulation in case it is of the break circuit form and is not in use, and for visual exposures of words or figures, that the mirror key be moved from one end of the four foot board to the other and a card holder be substituted for the lens. A card would also need to be slipped between the contacts of the face key, if the break circuit form were used. These changes are slight, however, compared with the labor of setting up separate forms of apparatus for these purposes, especially if correct experimental conditions are to be observed.

While practically all the accessory apparatus is somewhat different from that in use with other instruments, only the device for light stimulation and the exposure of letters, words, figures, colors, etc., is so different that it could not easily be replaced by apparatus of the usual type. For mere light or color stimulation, the mirror key, large lens, and shield with circular opening are required. The circular opening is covered with one or more thicknesses of tissue paper. When the mirror key is

pressed down, at a certain point in its movement, an image of the light will be thrown on the circular opening and the chronoscope will be started at the same instant. This coincidence of the image and the starting of the chronoscope is secured by adjustment. The mirror keys actually in use have an arc at the end of the lever against which a contact spring rests. It is partly insulated so that for a certain distance it can bear against it without starting the pendulum, while this is started when it reaches a certain point in the arc. It is at this point that the image of the light is to be thrown on the circular opening, which occurs without its appearing to come in from below. The purpose of the arrangement, aside from securing contact at a certain point of the movement, is to reduce the sound of the contact so that it will be inaudible to the reactor. If the

FIG. 4 Mirror Key.

key is well made this is the case, but might not be so after it has become worn. On the whole it seems more convenient than a silent key of the mercury type, as it has to be moved about, even though it will require occasional care. However, the latter might be preferred by others and one could be more certain that it would be sufficiently silent. The source of light for the mirror key shown in Fig. 3 is an electric light placed a little to the left of the middle of the board. This position is not a necessary one and for some reasons a position above the

board would be preferable. Stimulation by different colored light is secured by putting different colored glasses before the source of light. In doing this care must be taken that the illumination of the surroundings be not sufficient to betray the color.

To arrange for the exposure apparatus, the mirror key is transferred to the other end of the board directly under the shield. Two metal posts at either end of the board make this change of position easy and at the same time secure the necessary connection with the chronoscope. The exposure apparatus is shown in Fig. 5. It will be seen that a mirror is placed a

FIG. 5. Exposure Apparatus.

little to the left of the key and that a card holder is substituted for the lens. The subject sees the words or figures in the fixed mirror. When the mirror key is pressed down so as to bring the words or figures into position, it is impossible to tell what they are during the movement, but it becomes possible as soon as the mirror key is arrested, as it is by striking a fixed contact, which has been substituted for the arc contact. The conditions for visual accommodation and fixation seem satisfactory. The words or figures disappear when the mirror key is allowed to move away from contact. If the mirror key were moved by an electric magnet and the current regulated by an interval apparatus, such as that of model 2, this exposure apparatus could be used accurately as a tachistoscope. By some practice, it is possible to press the key down so as to make contact to from one tenth to one twentieth of a second and most of the im-

portant facts of tachistoscopic work can thus be demonstrated, without the attachment of the electro magnet, though, of course, not with satisfactory precision. The position of the card holder is such as to require care in securing its proper illumination. What is seen is seen after double reflection. On the whole good

FIG. 6. Face Key.

mirrors of the usual sort, with the silvering on the back will probably in the long run be more convenient, but much better results for a time are obtained by silvering the front surfaces both of the fixed mirror and the mirror of the key, for which glass with an even surface should have been secured. How-

ever, front silvering tarnishes and would have to be repeated every few months to keep the mirrors ready for constant use, but the results are so much better that the trouble is at least worth while for the enthusiast.

The face key, Fig. 6, for showing that there has been the beginning of a movement of the lower jaw, as in beginning to speak a word, is probably next in the degree of difference from apparatus ordinarily in use. The recording of this reaction accurately is difficult and a little practice is necessary to secure good results. As has been stated, the key records merely the time of opening the mouth. Some subjects will open the mouth before they are ready to react. If this occurs, they must be trained to wait until they begin to express a word by this movement. The key has been made only in the break circuit form, but can, of course, also be made in the make circuit form. In the pendulum chronoscopes here described, all the circuits are make circuits, which in case break circuit keys are used, requires that they be used as short circuits. In the case of the break circuit keys of the interval apparatus, they must also sometimes be used as short circuits to secure a make circuit connection in the main line. The break circuit face key must therefore be used as a short circuit, which involves no great difficulties, if there is sufficient power.

In constructing the face key spectacle rims are taken and arranged as shown in the cut. The nose piece contains the springs for keeping the contacts together. The key must stay rather firmly in place, so it may respond accurately to the beginnings of movements. For this purpose the key is tied with a band behind the head. Rather heavy frames, or light frames reenforced by copper wire, are best for carrying sufficient current. With good construction, the durability ought not to differ greatly from that of any other pair of spectacle frames. The subject feels more at ease and the hygienic features are more convenient, if not better, than they are in the case of keys held between the teeth. The touch stimulation key, represented in Fig. 7, does not differ in any important respect from the usual. The rate of separation of the contacts, however, is not less but greater than the rate of motion of the point touching the skin.

The sounder, represented in Fig. 8, for sound stimulation is somewhat different from the usual dropping ball apparatus. It consists of a small hammer held down against the surface it strikes by a spring. The contact of the hammer with this surface starts the chronoscope. The spring holding the hammer

FIG. 7. Touch Key.

down should be under sufficient tension to prevent any rebound. The scale enables the experimenter to use the same or different intensities of sound stimulation, as he may wish. An attempt to arrange the scale for equal audible or equal physical units of intensity has not been made. In this respect the dropping ball apparatus has the advantage of having the ball drop with kinetic energy proportional to the height of the fall, though it is not certain that the complex sound caused by the ball striking the bridge and the bridge in turn the base is precisely proportional to the kinetic energy. For accurate work, the intensity both audible and physical of the sound from the falling ball apparatus would probably also need to be determined. The sound from the falling ball apparatus is dull, while that from the sounder here described is relatively sharp. It is proposed chiefly because of its convenience, as it furnishes accurate conditions in a small compass, except for experiments upon the

effects of varying intensities, for which it would require further graduation.

With regard to the accuracy of this type of chronoscope, the writer has made several tests at different times. Some results are reported in the article describing model no. 1. Instead of adding to these, some results kindly lent by Professor W. D. Scott, of Northwestern University, will be summarized. The

FIG. 8. Sounder.

tests were made on a chronoscope of model 2, constructed by Stoelting & Co., and were executed by Mr. Gordon Fulcher. The account of the tests points out that variations in the record may be produced by varying the current either in the escape-ment or the index coils; and the records giving the absolute time are obtained only with a certain adjustment of the escape-ment and index.

The testing apparatus consisted of two falling weights, one striking a lever starting the chronoscope, the other striking a lever and arresting the index. The possible errors of the testing apparatus appear to have been very small.

Under circumstances most favorable to the chronoscope, he obtained readings for intervals of 200σ and 100σ 'as closely identical as could be determined by the eye.' His general conclusion is that the chronoscope could be made to read to $1/5\sigma$. By special care in construction or by adding a certain constant to the averages, this adjustment of the chronoscope which gives the best results could be made permanent. In adjusting it so as to

secure absolute records directly, however, somewhat less uniform results were obtained. For an interval of 200σ he obtained records of 199.9, 200, 199.8, 200.1 and 200σ and for 100σ he obtained 100.5, 100, 100.1 and 100.5σ .

In dealing with records as small as a fraction of σ , the utmost precaution must be taken to avoid any disturbance. For example, the slight jar given the chronoscope by having the key of the testing apparatus on the same table with it had a determinable effect, when it was brought down sharply, and the accuracy attained in practice will doubtless be somewhat less than in these tests in which the utmost care was taken.