A PURSUIT PENDULUM[1]

BY WALTER R. MILES

Nutrition Laboratory of the Carnegie Institution of Washington. Boston, Mass.

One of the measurements used at the Nutrition Laboratory on the aviation candidates in the spring of 1917 was to record the adequacy of ocular-pursuit movements in following the swing of a pendulum. The subject was seated at a head-rest with the left eye covered. A polished metal bead suspended by an invisible cord was arranged to swing through a visual angle of about 40°. The pendulum made a double swing in 2 seconds. Its release was synchronous with exposure of the eye to the recording beam of light, after the manner of Dodge's photographic technique.[2] The repeated instruction was to watch the bead intently every moment of its swing. Six or more successive trials by a subject were photographed side by side on one plate. These records do not easily provide an exact quantitative score for accuracy of pursuit. However, it is convenient to rank these photographic records showing the reaction time occurring at the start of the pendulum's swing, together with the number and size of abrupt horizontal movements by which the subject supplements his inadequate pursuit, into five grades or groups of excellence. Such grouping gave a positive correlation of 0.40 with the subsequent progress of these men in learning to fly.[3]

[1] In abbreviated form this paper was read before the American Psychological Association, Cambridge, December 30, 1919.

[2] Diefendorf and Dodge, Brain, 1908, 31, pp. 451–489. See Plate II for illustrative records showing fully the characteristics of this type of eye-movements. For a description of the eye-movement recording apparatus as used on the aviation candidates, see Benedict, Miles, Roth, and Smith, 'Human Vitality and Efficiency under Prolonged Restricted Diet,' Carnegie Inst. Wash. Pub. No. 280, 1919, pp. 159 ff. and pp. 184 ff.

[3] Our subjects, the first groups of candidates to attend the Aviation Ground School of the Massachusetts Institute of Technology, were a very superior lot of men. Nearly all graduates of our best universities, these men had been prominent in athletics and many of them on their own initiative and at their own expense had taken some

At the time this result was found hardly any single test indicated a higher correlation with flying. Officials advised, however, that the ocular-pursuit measurement, as carried out photographically, was too complex for any general use in the preliminary selection of candidates for pilot training.

These details have been recited as they account for the simplicity of the device described below. The pursuit pendulum was an effort to meet a definite situation. Care was exercised to exclude all electrical and photographic or other graphic features, to make the apparatus its own gravity-operated chronometer and such that it could be used nearly anywhere and would give an immediate quantitative score for the accuracy of the eye-hand coördination in pursuit movement. Although an opportunity never came after the development of the test to try it on a group of aviators or men who were in this training, the possible general usefulness of the measurement to other laboratory workers and in industry may warrant the description of the pursuit pendulum, together with illustrative data for initial performance, improvement with practice, and changes in efficiency, *e.g.*, as produced by a superimposed nutritional factor such as alcohol.

From a suitable wall bracket a pendulum carrying a reservoir is arranged to swing over a sink or table, a small stream of water flowing from the lower extremity as the pendulum swings. The individual under test, seated before the sink, attempts to catch the water in a cup of limited diameter. A separate cup is used for each double swing and the volume of liquid collected represents quantitatively the adequacy of pursuit.

The bracket, *A* (see Fig. 1), extends from the wall about 45 cm. and is fairly rigid. The pendulum, *B*, 140 cm. long,

training in aviation. They were keenly interested in aviation problems and coöperated whole-heartedly, as did also the officials at the ground school. Although about 65 men were measured, the government found it imperative to send many of these to Europe immediately upon their having finished at the ground school, and they therefore received the flying training abroad. Most energetic efforts were made by Professor E. L. Thorndike to secure the flying scores for these men on whom Drs. H. E. Burtt, L. T. Troland, and myself had worked. Scores for 26 were finally obtained and it is for these that the correlation mentioned was found.

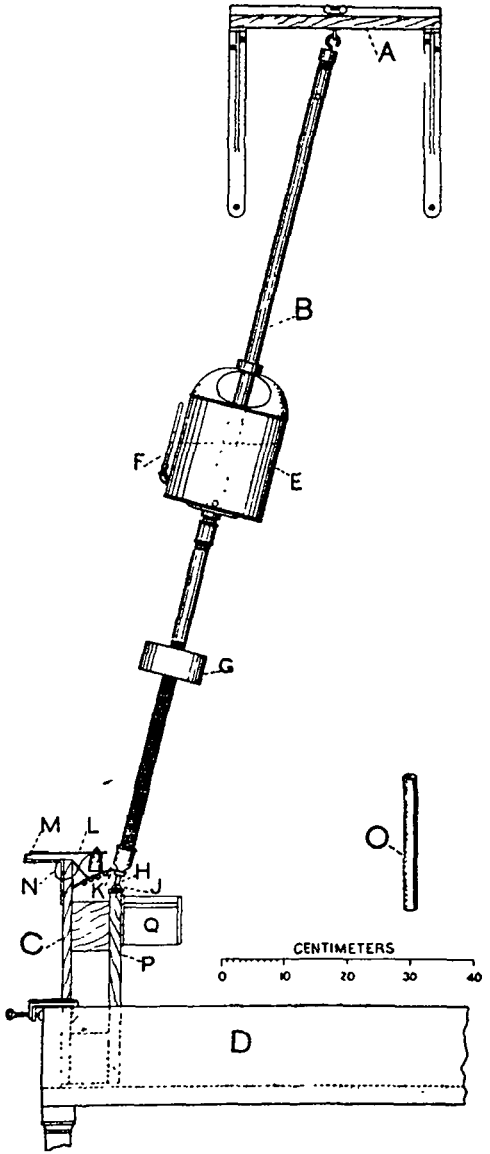

FIG. 1. Diagram of the pursuit pendulum. *A*, wall bracket; *B*, pendulum carrying reservoir, *E*. Gauge, *F*, determines volume of liquid in reservoir. *G*, adjustable weight regulating pendulum's period. *C*, wooden frame clamped to sink, *D*. Nozzle, *H*, of pendulum held by catch, *K*, against rubber tubing, *J*, until released by fall of hammer, *L*, hinged at *M*. Short section of chain, *N*, determines lift of hammer. *O*, cup of limited diameter, in which the expelled liquid is to be collected by the subject under test. *P*, position at which cup, *O*, is held at start. *Q*, short-stop for ending the catch.

is suspended by two screw eyes. Its shaft is continuous through the reservoir and is very stiff, being made of sections of galvanized-iron pipe (regular $\frac{1}{2}$-inch inside diameter). The reservoir, *E*, a 1-gallon galvanized-iron oil can, surrounds the shaft and is firmly secured and made leak-tight by the use of a "railing flange" soldered to its bottom. As the reservoir is located about midway the length of the pendulum, the head of water changes but little with the decreasing level in the can. An adjustable weight, *G*, of about 4 kilograms allows for regulation of the pendulum's period and makes the position of the center of mass much less dependent upon the exact amount of liquid in the reservoir. Openings are arranged in the pipe shaft on a level with the floor of the can and air vents are placed above. The water flows very freely from the reservoir, and at the lower end of the shaft is reduced to a stream 3 mm. in diameter by the nozzle, *H*.

A simple arrangement for retaining and releasing the pendulum is shown in Fig. 1 and separately illustrated by a top view in Fig. 2. The wooden frame, *C*, is clamped to one end of the sink, *D*, at such a height that when the orifice, *H*, is slipped up on a cushion, made of a short horizontal section of rubber tubing, *J*, a closure is made which is practically leak-tight. A catch at *K* retains the pendulum in this position until the fall of the rubber-headed hammer, *L*, hinged at *M*. The hammer is lifted by the operator and held in a nearly upright position, determined by a short section of chain (see *N*, Fig. 1). It is released on verbal signal from the subject and requires 0.3 second to fall and start the pendulum. This method of release corresponds to common industrial operation and the reactor, especially a subject without psychological training, likes it better than having the start occur at some arbitrary and more or less unexpected time beyond his control.

The cups in which the subject is to catch the expelled liquid (see *O*, Fig. 1) are made of thin-walled brass tubing, 19 mm. (regular $\frac{3}{4}$-inch tube) inside diameter and nearly 22 cm. long. At the start a cup is held at position *P*, against the wooden frame, nearly vertical from and about 2 cm. lower

than the orifice, *H*. No water leaks into the cup and it is possible to begin the hand movement almost in register with the pendulum. While the subject follows the pendulum to the right, the operator turns the short-stop, *Q*, from position 1 into position 2. (See Fig. 2.) This metal screen stops the return movement of the cup at a distance of 2 cm. in front of position *P* and thus gives the operator a little space within which to catch the pendulum and replace it on *J* without spilling liquid into the cup, as otherwise an error would be introduced in the result.[1]

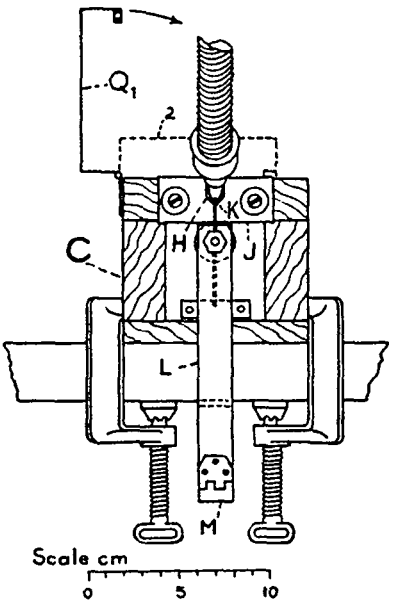

FIG. 2. Top view of the arrangement for retaining and releasing the pendulum. *H*, pendulum nozzle pressed by the rubber tube, *J*, to form leak-tight closure; *K*, hook by which pendulum is held in position until *K* is depressed by the hammer, *L*, which is hinged at *M*; short-stop, *Q*, at an appropriate time is turned into position 2 in order to cut the return pursuit slightly short and allow space in which the experimenter may catch the pendulum.

With two liters of water in the reservoir the period of the pendulum for a double swing is just 2 seconds. Naturally this time will increase somewhat as water is lost and the center of gravity lowered. Practically, the change is of no consequence to the test, as we find that with two liters of water 20 v. d. require 40 seconds, while with one liter 40.3 seconds are required, and when the reservoir and shaft are empty 40.9 seconds are required. Thus, for testing purposes the period of swing may be regarded as independent of the

[1] Another source of error must be guarded against with the coöperation of the subject. He should be cautioned not to slip the cup up over the nozzle of the pendulum or, indeed, to bump the cup against the nozzle and thus interfere with its motion. The stream of liquid does not spray out and there is no advantage, from this standpoint, in having the mouth of the cup very near the pendulum. This requirement not to touch the pendulum with the cup is a part of the coördination, but unfortunately does not show in the objective results.

amount of liquid in the tank. The amount of head of the liquid and the size of the orifice were arranged with the idea that 50 c.c. should be the possible catch per double swing. With 2 liters in the reservoir at the start, it is found that at the first double swing the subject can catch, possibly, 50.4 c.c. and at the tenth succeeding catch 49.7 c.c. For eight successive trials the amount delivered is thus within 1 per cent. of 50 c.c. It has seemed satisfactory to replenish the water every five or ten trials. If the subject is catching nearly all the liquid expelled, the opening in the cup should be reduced. A gauge, *F* (Fig. 1), on the side of the tank makes it a simple matter, when introducing water at the opening in the top of the reservoir, to determine that the volume of water shall be up to 2 liters. During the swing the orifice of the pendulum, as used in the collection of the data presented below, moved a horizontal distance to the right of 70 cm. This is a fairly large excursion, but most adults can follow the movement without swaying of the body, if they so desire.

More complex arrangements of such pursuit apparatus naturally suggested themselves, for example, the pendulum might be made the long arm of a siphon. An orifice, not a part of a pendulum, might be carried on a belt and given a complicated series of movements, prolonging the pursuit and requiring coördination for forward and backward as well as for lateral displacements.[1] After the experience with the ocular-pursuit measurement it was assumed, however, that in trying to contribute to the problem of selecting aviation pilot material the simpler the test apparatus the more serviceable it might possibly become. Therefore this model was made independent of electrical features, did not require running water or a sink, could be filled by hand from a pitcher and could be arranged over a table or inclined trough, as the operator's conveniences might permit.[2]

[1] In a personal communication Professor Carl E. Seashore informs me that, after trying the original test at the Nutrition Laboratory, he has arranged a very successful combination for testing motor ability to perform circular pursuit movements, by using a phonograph motor, a time-interrupted circuit, and an electric counter.

[2] A criticism which may be raised against the quantitative score which the apparatus makes possible is that this score is not a sufficiently graduated result. Prac-

In practice successive catches can follow each other rather rapidly, their speed being largely determined by the quickness of the subject's motions in replacing and taking up the cups and the promptness of his verbal signals for release of the pendulum. Twenty-five trials are easily made in five minutes. The 25 cups stand in order, as at *R* in Fig. 3, being conveniently held in a box frame, *S*. Each fifth cup has a black band near the top serving in the test as a signal to the operator to replenish the water in the tank. If there is no time immediately after the test to measure the results, the cover, *V*, is placed over the open ends of the cups, the name, date and hour are noted at *U*, and the box is set aside.

In measuring the results it is tedious to empty each cup separately into a small graduate and so determine the volume of liquid. Since the cups are all of the same inside diameter (as nearly so as brass tubing is commercially made) and all have the same inside depth, a graduated scale, *W*, cut from thin aluminum sheet attached to a cork float can be introduced into the mouth of each cup as these are held conveniently side by side in the box frame, *S*, and the volume of liquid can thus be very quickly determined for the successive catches. After the catches have been individually measured, provided that such analytical data are desired for securing a measure of variability, the frame, *S*, is grasped in such a way that the rubber tube, *T*, attached to the hinged door on the front, presses against all 25 cups so that their contents may be emptied and drained at once into the inclined V-shaped trough, *X*, and so into the large graduate, *Y*. The total score is in this way very readily secured.

If a good subject reaches such a degree of skill that, for example, he regularly catches more than 80 or 90 per cent.

tically, it makes no difference whether the pursuit is so accurate that the stream of water goes in at the center of the opening in the cup or over at one side, just so long as the whole stream is collected. Since the edge of the cup is sharp, tapered from the outside, if the stream strikes here it will be divided, part collected and part lost. With a slower-moving pendulum, a somewhat larger orifice, and a cup with the mouth the same size as the orifice, probably an arrangement could be made so that the subject could always catch a part of the liquid and thus small inaccuracies of pursuit would more properly be represented in the result.

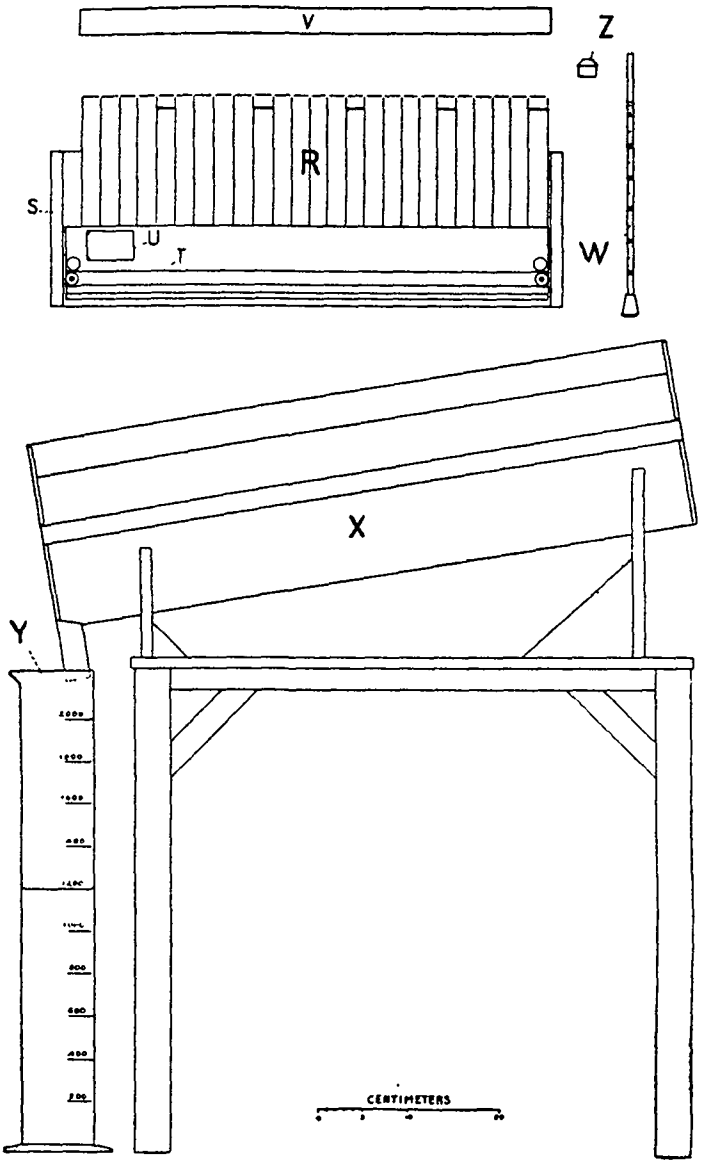

FIG. 3. Arrangement of the cups in a way convenient for measuring the quantity of liquid, by simple accessory apparatus. *R*, bank of cups in carrying frame, *S*; *V*, cover for cups; *U*, pad for noting name, date, and hour; *T*, rubber tube attached to hinged door of frame, *S*, which is pressed against cups in emptying; *W*, measuring float graduated in c.c.; *X* and *Y*, inclined trough and large graduate for receiving the contents of a whole bank of cups emptied at once; *Z*, collar to reduce the opening at the mouth of the cups, for especially expert subjects.

of the possible catch, the task may of course be made more difficult by decreasing the effective opening in the cups. A collar, Z, can be slipped into and withdrawn from each cup by the subject as he uses them in turn and thus the opening may be reduced to 10 mm. or to whatever size is deemed desirable to make the task satisfactorily difficult.

It is probable that any investigator who arranges such an apparatus as is here described will not make it an exact duplicate. Nevertheless illustrative data are of value in supplementing the description of the apparatus, as they give an idea of the type of results that may be expected from its use. In December, 1918, and January, 1919, considerable data for this test were obtained on a group of staff members of the Nutrition Laboratory, including ten women and eight men.[1] The pursuit test was given on 35 days, usually successive except for Sundays, and the amount of practice was 20 catches per day. At that time the equipment of cups consisted of two banks of ten each. It was hardly feasible that each individual should be tested at exactly the same time on each day, but care was taken not to measure subjects when they were fatigued or otherwise indisposed.[2]

The average results for a group of 18 adults are shown graphically in Fig. 4. Each plotted point on the curves represents 360 catches, *i.e.*, 20 catches by each of 18 subjects. Each of the two groups of ten catches made by a subject on a single day was dealt with separately when obtaining the average and standard deviation. This was done to show the progress made during the day. As might be expected, the second ten catches almost invariably averaged 1 or 2 c.c. higher than the first ten and the variability was usually smaller. For this brief paper we have averaged the two means

[1] The collection of these data, including its tabulation and elaboration, was successfully accomplished by an assistant, Mr. E. S. Mills, whose care and cooperation are gratefully acknowledged.

[2] In this early practice experiment it was thought that the subject should execute the pursuit by an arm movement not supplemented by a body movement. Therefore two rods were arranged to extend from the sink and to be brought in contact with the individual on both sides, somewhat above the waist. These rods, while not hindering the trunk from twisting, obviated the subject's swaying from side to side. Probably this restriction is unnecessary. It has not been used in later measurements.

and the two coefficients of variability secured for each of the 18 individuals on each day and have employed these 18 quantities to obtain the average represented by each plotted point on the curves shown in Fig. 4.

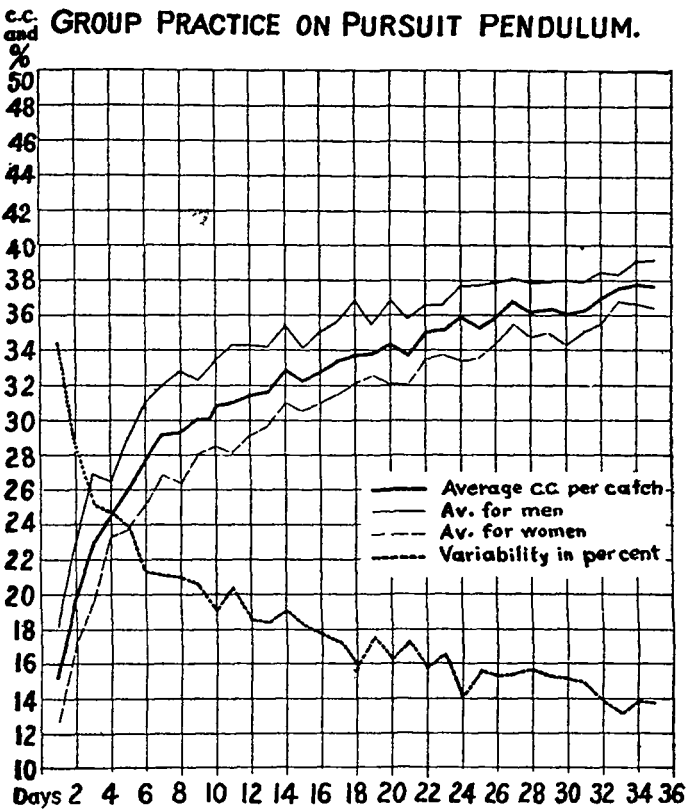

FIG. 4. Curves showing average results for ten women and eight men tested on 35 days with 20 catches per day practice.

The heavy broken line in the figure indicates the coefficient of variability (standard deviation divided by mean) in terms of per cent. The heavy solid line gives the average catch in cubic centimeters per day. On the first day the individual averages ranged from 8 to 29 c.c. per catch with a grand average of 15 c.c., which represents 30 per cent. of the possible catch. First trials by a number of other adults confirm this figure as about what may be expected for an initial per-

formance, when the subject seriously tries the test and consistently makes 20 or 25 catches. The curve showing the average catch per day rises rapidly on successive days to 20, 23, 25, 26, 28, and, on the tenth day, to 31 c.c. representing 62 per cent. of the possible catch. Thus, on the tenth day of 20 trials the average efficiency has doubled over what it was at the start. After 25 days more of such practice the average increase above this level is only 7 c.c., bringing the figure to 38 c.c., which is about 75 per cent. of the possible catch. The practice curve is very regular in form and shows no definite indication of orthodox plateaux, and it is evident that the chief part of the rise due to practice can be quickly worked off by 200 or 300 catches, if it is desirable to bring the individual up toward the stage of a practice level. The curve for the coefficient of variability is practically an exact counterpart in form to that for the average catch. At the beginning the variation between catches equals about 34 per cent. and at the tenth day, when the average catch has doubled, the variability has decreased to 19 per cent. or not far from one half, and by the end of the series has decreased to about 14 per cent.[1]

It is recognized that the group of subjects employed in this experiment was relatively small and it is hardly justifiable to draw conclusions regarding such matters as the difference between men and women in their efficiency in executing such a pursuit movement. If the individuals are ranked on the basis of their total average catch per day, it is found that of the better nine there were six men and three women, while in the poorer half of the group there were two men and seven women. There were three women poorer than the poorest man, but only one man did better than the most efficient woman. The average difference between the groups of eight men and ten women is shown in Fig. 4 in the light line curves, which are above and below the curve for the general average

[1] The coefficient of variability for other neuro-muscular tests may be found by referring to Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, pp. 551 et seq. Examples which may be mentioned are: eye-movement speed, 9 per cent.; eye reactions, 19 per cent.; word reactions, 9 per cent.; and electrical threshold about 6 per cent.

catch (heavy solid line). The curves for the men and for the women are fairly smooth, and maintain about a uniform distance apart, the men on the average catching 4 cc. more than the women.[1]

Individual practice curves, such as illustrated in Fig. 5, are naturally less smooth than the average for the whole group. In Fig. 5 results for one of the most efficient and also for one of the least capable subjects have been combined. Subject *C* made very rapid progress, starting with 21 c.c. and rising to 28, 30, 32.4, 35.8, and 36.7 c.c. on the next six successive days. (See Curve 1.) There is a slight decline on the seventh and eighth days and quite a definite decrease on the ninth day. The fluctuations usually range from 1 to 3 c.c. Undoubtedly these variations in the average would have been smaller had the number of trials on each day been larger. For a fairly long period, that is, from the tenth to the twenty-ninth day, the average for Subject *C* is very close to 37 c.c., which is 74 per cent. of the possible catch. The performance during this period may conceivably be classed as a plateau, for there is undoubtedly an indication of a definite stage of improvement following it, during the last six days. The coefficient of variability for Subject *C* (Curve 2) shows rapid improvement at first, corresponding to his improvement in the amount of the catch up to the seventh day. Beyond this time there are fluctuations, some of them quite large. From the seventh to the twentieth day, inclusive, the average variability is about 14 per cent., while from the twenty-first to the thirty-sixth day, although there are several instances as low as 8 or 10 per cent., the average is 12.5 per cent.

Subject *R* did poorly at the start, with an average catch of 8.5 c.c. (see Curve 3) and a variability of 54 per cent. (see Curve 4). Furthermore, poor learning ability is demonstrated by the results for the third and fifth days, when the

[1] Nothing extensive has been done with children. Probably in working with them the excursion of the pendulum should be reduced somewhat from the 70-centimeter swing employed with adults. However, preliminary trials with the apparatus as arranged for adults indicate that a nine-year-old child can catch at the beginning from 10 to 12 c.c. and a six-year-old child from 5 to 6 c.c.

average was in each case slightly lower than on the preceding days. The results show considerable progress between the fifth and the twentieth days, a change from 15.5 to 29 c.c. with some decrease in the variability, although the fluctuations here are quite large. The average for the last five days

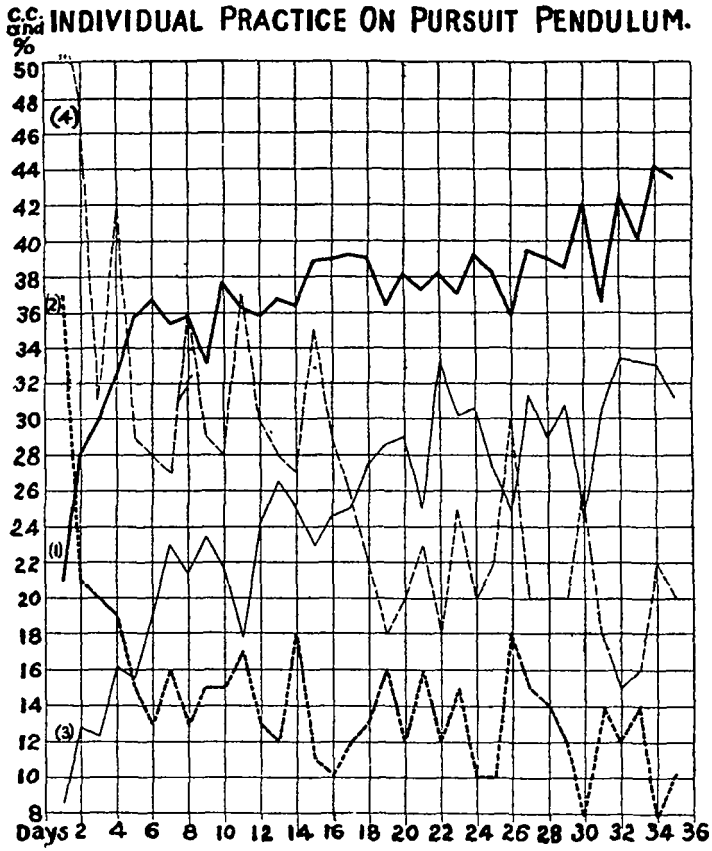

FIG. 5. Individual practice curves showing comparison between two subjects. Curve 1 shows the average catch per day and Curve 2 the average variability per day for one of the most skilful subjects. Curves 3 and 4 show the average catch and variability per day, respectively, for one of the least capable subjects.

is 32.3 c.c., or approximately 65 per cent. of the possible catch, with an average coefficient of variability for these same days of about 18 per cent., in contrast to the 75 per cent. catch and 14 per cent. variability for the total group of adults.

To illustrate a series of measurements made on an individual for the purpose of investigating the effect of some introduced factor on neuro-muscular efficiency the data in Table I are given. The pursuit-pendulum test was one of a number of measurements used in a recent alcohol experiment. This fragment of data is introduced for the sole purpose of illustrating the pursuit pendulum results and in no sense as a contribution to alcohol literature. The complete data are being elaborated for later publication as an alcohol research. The series of eight tests required 30 minutes. Following a light lunch, the subject carried through this series two times in succession. At the end of the second period he drank 1

TABLE I

THE PURSUIT PENDULUM AS A TEST OF NEURO-MUSCULAR EFFICIENCY. RESULTS SHOWING THE EFFECT OF ALCOHOL

Date	Successive Half-hour Periods					
	1	2	Drink	3	4	5
1919	c.c.	c.c.		c.c.	c.c.	c.c.
Nov. 5	1,142	1,120	1 liter water	1,115	1,145	1,120
Nov. 8	1,170	1,152	" " "	1,176	1,191	1,185
Nov. 19	1,190	1,184	" " "	1,192	1,200	1,190
Nov. 21	1,190	1,178	" " "	1,178	1,140	1,148
Nov. 22	1,200	1,180	" " "	1,200	1,193	1,192
Av.	1,178	1,163		1,172	1,174	1,167
	1,170			+2	+4	−3
Nov. 6	1,178	1,150	1 liter	1,092	1,108	1,096
Nov. 7	1,156	1,166	2.75 alc.	1,137	1,122	1,066
Nov. 10	1,172	1,185	27.5 grams	1,146	1,130	1,096
Nov. 17	1,173	1,173	" "	1,130	1,043	1,065
Nov. 18	1,172	1,208	" "	1,107	1,102	1,135
Av.	1,170	1,176		1,122	1,101	1,092
	1,173			−51	−72	−81
				53	76	78
				1,172	1,172	1,172
Av. loss, 5.9 per cent.				4.5	6.5	6.7

liter of water, or 1 liter of water in which 27.5 grams of ethyl alcohol had been diluted. The quantity and temperature of the liquid were not varied. Fifteen minutes were quite sufficient in which to drink the liquid. After the liquid was taken,

the series of measurements was repeated three times, that is, periods 3, 4, and 5 of the day. Table I shows data for five normal days, on which only water was taken, and for five other days on each of which 1 liter of a 2.75 per cent. alcohol mixture was consumed. No effort was made to disguise the taste of the alcohol. The subject, an abstainer by habit, was in the best of physical condition. The values in Table I give the total catch in cubic centimeters for 25 cups, as measured by the method of emptying the whole bank of cups at once. (See Fig. 3.) The two preliminary periods for the five days on which water only was taken show total averages of 1,178 c.c. and 1,163 c.c., or a combined preliminary average of 1,170 c.c. (46.8 c.c. per catch), which compare favorably with the two preliminary values, *i.e.*, before alcohol was taken, on the alcohol days, namely, 1,170 c.c. and 1,176 c.c., or a combined average of 1,173 c.c. (46.9 c.c. per catch). Periods 3, 4, and 5 show only minor differences (+ 2 c.c., + 4 c.c., and − 3 c.c.) from the combined preliminary average in the case of normal days. On the alcohol days the differences are all minus, that is, less water was caught after the alcohol was taken by − 51 c.c., − 72 c.c., and − 81 c.c. for the total averages. Subtracting the alcohol differences from those for normal days, it is found that 53 c.c., 76 c.c., and 78 c.c. represent the alcohol effect for periods 3, 4, and 5, respectively. These decrements between normal and alcohol performance, on the basis of 1172 (the grand average for all preliminary trials on both groups of days), equal 4.5, 6.5, and 6.7 per cent., or an average loss of 5.9 per cent., which represents the alcohol effect on this test of coördination. The subject improved somewhat between November 5 and 22, but since there is only slight improvement within the day and the water and alcohol experiments alternate with each other, this practice change is not troublesome. Indeed, the data are very consistent, *e.g.*, at no time following ingestion of alcohol was the subject able to catch as much as he had in the poorer preliminary period for the same day.

A pursuit coördination test, such as has been here described, not only possesses the advantages of requiring very

simple apparatus and of securing quantitative results which are immediately available without the painstaking reading of records, but it appears to have elements comparable to many industrial operations where the task not only requires quick reaction but also that a movement or movements be executed according to a fairly definite pattern. A reaction is usually only the beginning of coördinated movement towards some end or of a series of such coördinations, and probably in most instances in practical life the adequacy with which the series of coördinations is carried through is fully as important, if not more so, than the mere matter of speed in initiating them. Especially would this appear to be the case in movements for compensating, directing, aiming, or otherwise tending any moving object, where the pace and pattern are not set entirely by the subject himself. Quickness, precision, and steadiness of movement have long been tested in reference to stationary objects. The pursuit pendulum provides a simple means of measuring these factors in reference to a moving object and thus supplements the general psychological measurement of motor control and capacity. The pursuit test invariably challenges a subject's interest, but practically every one finds it more difficult than he at first expects.