REPORT 11

THE NATIONAL INSTITUTE OF INDUSTRIAL PSYCHOLOGY

SPEED AND PRECISION IN MANUAL SKILL

BY

D. F. VINCENT

PUBLISHED IN LONDON BY THE
NATIONAL INSTITUTE OF INDUSTRIAL PSYCHOLOGY
14, WELBECK STREET, W.1

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FOREWORD

THE investigation described in this report was undertaken as the result of the study of Women's Attitudes to Repetitive Work, described in N.I.I.P. Report No. 9. One of the points emerging from that study was that some people seemed to welcome, while others resented, the kind of job about which the recurring remark was " There's no skill in this job except doing it fast". It seemed desirable to attempt to discover whether there were two distinct aspects of manual skill, namely the capacity to do a simple job quickly and the capacity to do a more complex job requiring a high degree of precision and dexterity. If the existence of such aptitudes could be demonstrated, they might offer a partial explanation of the different views expressed by different workers, and if convenient measures of them could be devised they would have a practical value in the selection and allocation of recruits to the different kinds of work.

Several members of the Institute's staff participated in this investigation. Mr. D. Cox, Dr. O. Porebski and Mr. D. F. Vincent were responsible for the design of the special tests devised and the apparatus was made by Mr. Cox and Mr. Vincent. The tests were tried out and the test programme was planned by Dr. O. Porebski who, with Mrs. C. M. Miller, carried out the test administration. Mr. D. F. Vincent undertook the statistical analysis with assistance from Mrs. R. D. Lancashire, and wrote the report.

The cost of the investigation was met from funds provided by the Medical Research Council.

C. B. FRISBY.

14, Welbeck Street,
London, W.1.
September, 1955

SPEED AND PRECISION IN MANUAL SKILL

THE ORIGIN OF THE INVESTIGATION

In a former research on repetitive work*, an analysis was made of the attitudes of women engaged upon it. Industrial repetitive tasks can be classified in many ways, for example according to the attention demanded of an operator. One way in which tasks differ is in regard to skill and speed; at one end of a continuum are tasks for which weeks or months of training are needed before a novice can do them at all, at the other end are tasks which almost anyone can do after a few minutes of practice. Yet often tasks of this latter type require days or weeks of practice before a new operator can work at a speed which is commonplace among experienced workers. As many of the latter expressed it, " There is no skill in this job except doing it quickly". There is evidence that some people gain a satisfaction from being able to work fast; and also that some workers prefer a not-so-fast job which makes more demands on what is generally thought of as skill or dexterity—being able to do the type of job which is really difficult. The question that presents itself is " Are these differences of preference related to inherent psychological or physiological differences?"

Before this question can be answered it is necessary to determine whether there actually are differences in ability that make it easier for one person to acquire the capacity for speed in simple tasks and another to acquire the skill to perform complicated operations with accuracy and precision. Is there an aptitude for " skill of speed " that is inherently different from an aptitude to acquire " skill of precision "? The investigation described in this report was planned to throw light on this question.

THE FACTORIAL APPROACH

The method of factor analysis has been employed mainly for disentangling mental characteristics. If there is any characteristic so marked as to affect the scoring of a test, then if a suitable battery of tests is employed, and the scores subjected to a factor analysis, the characteristic will appear as a factor. If there really are different inherent aptitudes for acquiring the two kinds of skill, then if the scores of a suitable battery of tests of skill are analysed, the two aptitudes should show up as two separate factors. The problem was to devise a suitable battery of tests.

A primary requirement for a battery of tests for a factor analysis is that in the case of each factor there shall be some of the tests whose scores are not affected by that factor, or in practice, tests whose scores are only affected to a minor extent by the factor.

As the present investigation was a search for evidence of a skill of speed factor and skill of precision factor, it was necessary to have tests whose scores would depend upon dexterity alone, and

*N.I.I.P. Report No. 9. *Women's Attitudes to Repetitive Work*. Cox, Dyce-Sharp and Irvine. 1953.

which were not affected by speed of working, and tests whose scores would depend entirely upon the speed at which some simple task could be performed—some task that required little or no dexterity.

It was decided to employ three separate groups of tests. The tests of the first group were to consist of very simple operations involving the movement of one set of muscles, such as those of a finger or of the wrist, which were to be scored by the time taken for a given number of repetitions. The tests of the second group were to consist of simple tasks requiring a small amount of dexterity and were also to be scored by the time taken. The tests of the third group were to consist of comparatively difficult tasks which the subject could perform at any speed he wished and which were to be scored by the success with which he performed them.

If there are two quite separate inherent aptitudes, one of which makes for the acquisition of skill of speed and the other which makes for the acquisition of the skill of precision, then two factors should emerge from the analysis. The first group of tests should have loadings of the speed factor only, the third group of tests should have loadings of the dexterity factor only, while the second group of tests should all certainly have loadings of the speed factor, and some should have loadings of the dexterity factor.

Previous research on manual dexterity has been done under the auspices of the Institute by F. M. Earle† and by J. W. Cox‡. Both developed tests, but they were all tests for skill of speed; tests of the type that it was proposed to use in the second group of our battery. It is interesting that J. W. Cox found evidence of a group factor in his tests which he called the 'routine' factor. He used the term 'routine work' for repetitive work in which the skill involved is the skill to do the work quickly.

THE THREE GROUPS OF TESTS

The first group of tests was for operations involving the muscles of the fingers, wrist and forearm, and not requiring dexterity. They were scored by the speed at which the operations were performed and will be referred to as the 'speed' group.

The second group of tests was for operations involving the muscles of the fingers, wrist and forearm, but for which a certain amount of dexterity would be required. These, too, were scored by the speed at which the operations could be performed, and will be referred to as the 'speed-dexterity' group.

The third group of tests was for operations requiring a considerable amount of dexterity; the subject was allowed to perform them as slowly as he wished and the scoring was made by the success with which the operation was performed. They will be referred to as the 'precision-dexterity' group.

THE 'SPEED' GROUP OF TESTS

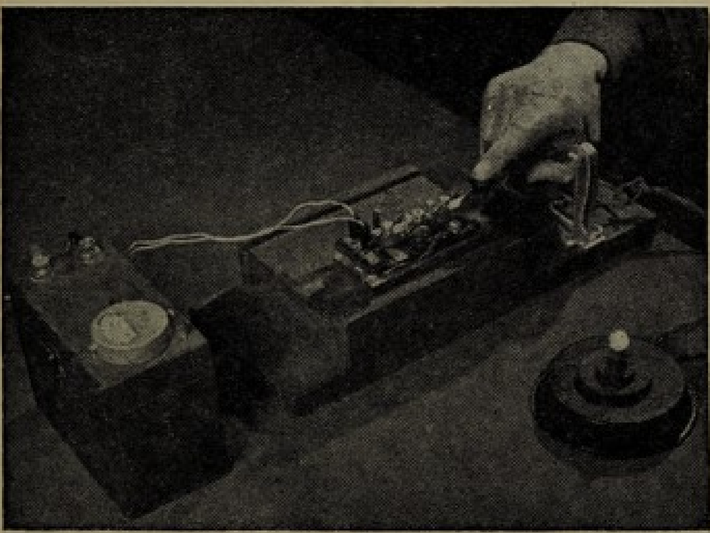
Our aim was to employ a test in which mainly the finger muscles were used, a test in which mainly the wrist muscles were used, a test in which most of the work was done by the muscles of the forearm and other tests in which more than one set of muscles was used.

Since operations that require no special dexterity can usually be performed very quickly, some form of mechanical counting device was required for the scoring, and our first difficulty was to find a suitable device. Drum counters of the Veeder and similar types have two disadvantages. Firstly, they are operated by moving an arm through an arc of forty-five degrees or more, and they do not operate unless the arm is moved through the whole of the arc. Secondly, if they are operated at too high a speed or too violently the units drum is liable to move forward more than one division. We had to experiment with different types of counter and eventually found a high-speed electrically operated counter, a piece of automatic telephone exchange equipment, that was sufficiently reliable for our purpose.

†N.I.I.P. Report No. 4. *The Measurement of Manual Dexterity*. F. M. Earle, F. Gaw and others. 1930.
‡Manual Skill. *Its Organisation and Development*. J. W. Cox. Cambridge University Press. 1934.

In all the tests of the speed-dexterity group the subjects were given a trial run in which speed was not emphasised. When the test was made they were told to make the movements as quickly as possible.

Finger Tapping. For finger movements only we used speed of tapping. It would have been possible to eliminate wrist movement by clamping the subject's wrist, but this would have prevented him from getting his finger into the most comfortable position. We found the most satisfactory way of preventing wrist movement was to make the subject grip a handle with the thumb and three fingers and to tap with the fore-finger. To ensure that he did not relax his grip, a split handle was used incorporating a switch which was wired up with a lamp and a dry battery. If he relaxed his grip the lamp went out. The object tapped was a telegraphic morse key, fitted with a flat topped 'knob'. The morse key was wired up to the electric counter.

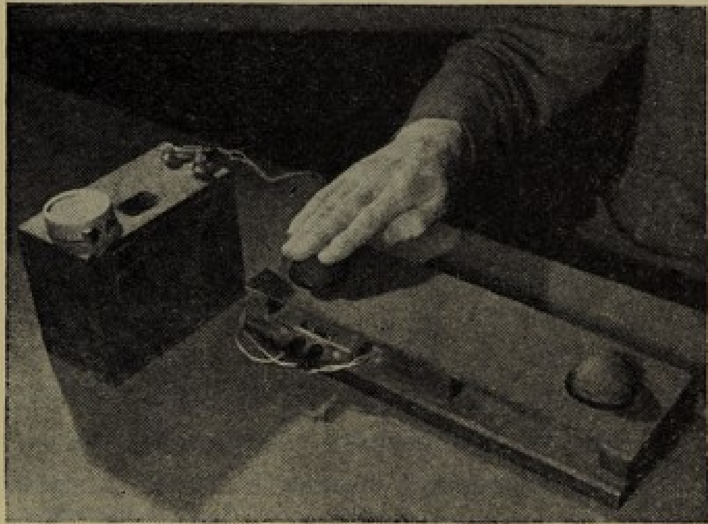


The scoring was by the time in seconds required by the subject to make fifty taps. Timing was done with a stop watch. The score was the total time taken for five separate runs of fifty taps.

Wrist Tapping. For wrist movements we also employed tapping. The subject held the normal knob of a morse key between thumb and fingers, the usual position adopted by a telegraphist, in which all the movement is made with the wrist.

Scoring was by the time in seconds required by the subject to make one hundred taps. The final score was the total time taken for five separate runs of one hundred taps.

Double Tapping. For arm movements we had two keys spaced ten inches apart, which had to be tapped alternately. To do this at speed it was necessary to bang the keys and there was the risk that a subject would slacken his speed if he found that it hurt him. To avoid this we constructed a special piece of apparatus in which the 'knobs' to be tapped were covered with two inch hemispheres of soft sponge rubber.

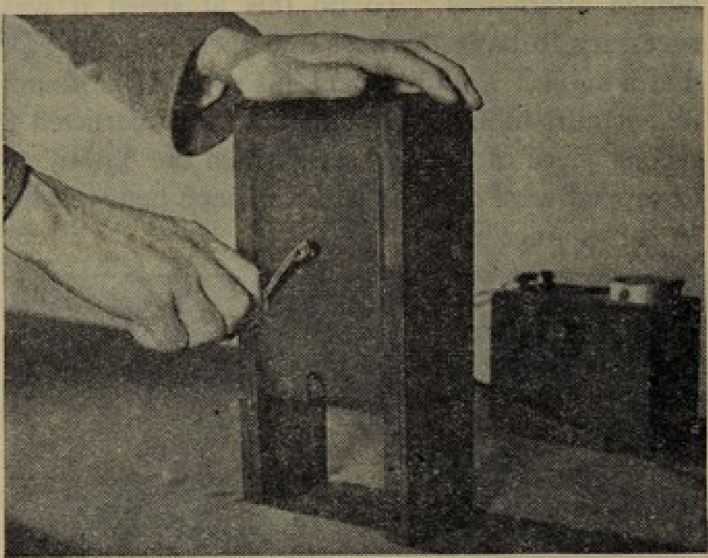


Scoring was by the time in seconds for the subject to make fifty double taps; one hundred taps in all. The final score was the total time required for four runs of fifty double taps.

Twisting. For more complicated movements we used twisting and cranking. The twisting test consisted of a handle that could be rocked through an arc of about sixty degrees. The rotation was limited by a light metal rod with a bob at the end which banged against stops. The subject was required to grasp the handle with the fore-arm extended and to rock it as fast as he could, so that the bob banged against the stops. A switch device was incorporated which actuated the counter and recorded the number of to-and-fro movements. *(Photograph on page 4.)*

Scoring was by the time in seconds required to make fifty to-and-fro movements. The final score was the total time taken for four runs of fifty to-and-fro movements.

Cranking. The cranking test was a box, clamped to the bench, carrying a crank arm with a four-inch throw, fitted with a handle that was grasped with the thumb and fore-finger. Inside the box, a light rubbing contact, which did not introduce any appreciable drag, actuated the counter.

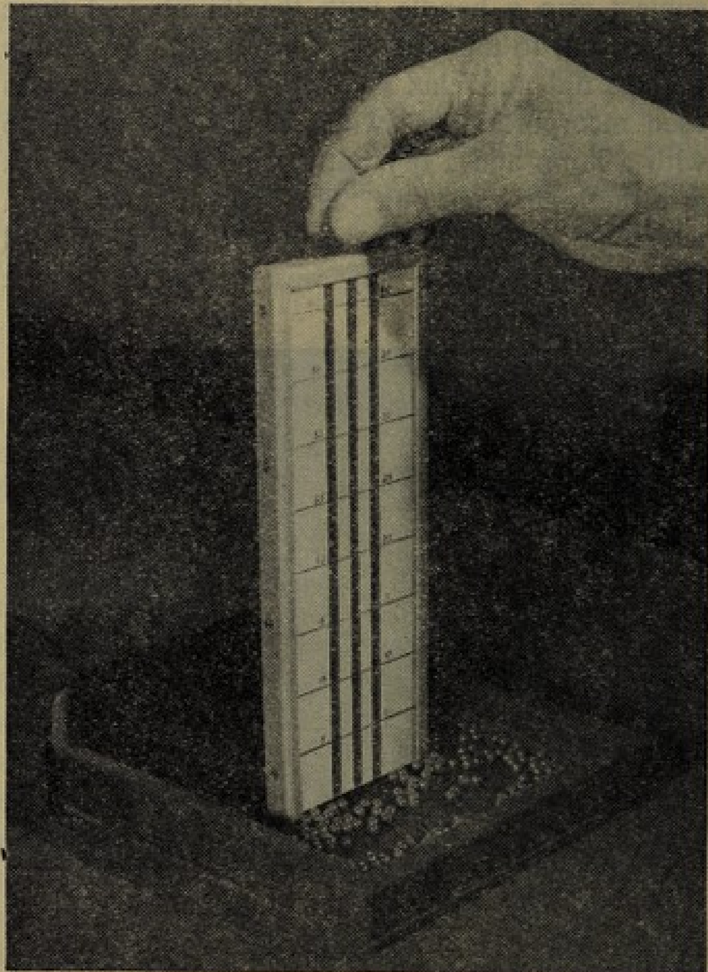


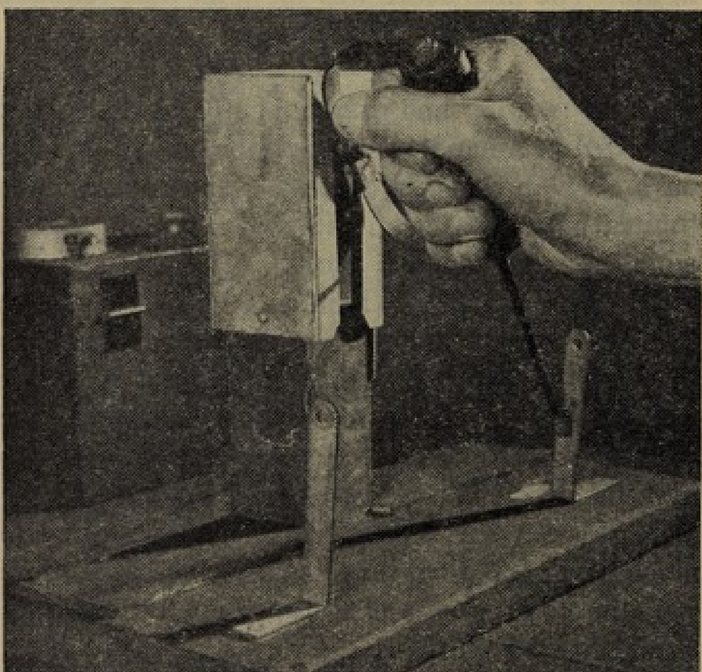
The scoring was by the time in seconds required to make fifty revolutions. The final score was the total time required for four runs of fifty revolutions.

THE 'SPEED-DEXTERITY' GROUP OF TESTS

There are a number of suitable tests in existence and it was not necessary to devise new tests. Three were chosen involving different degrees of complexity of finger movement. In each test of this group a preliminary trial run was made in which speed was not emphasised.

R.V. Manual Dexterity Test. A modified version of the R.V. Manual Dexterity test was used. In this test the subject is required to pick up three-sixteenth-inch ball bearings from a tray with the thumb and forefinger and to drop them through a hole in a plate. The balls drop into grooves behind a sheet of glass and there is a scale attached for rapid counting. Each of the grooves will hold forty-five balls. In this case the scoring was by



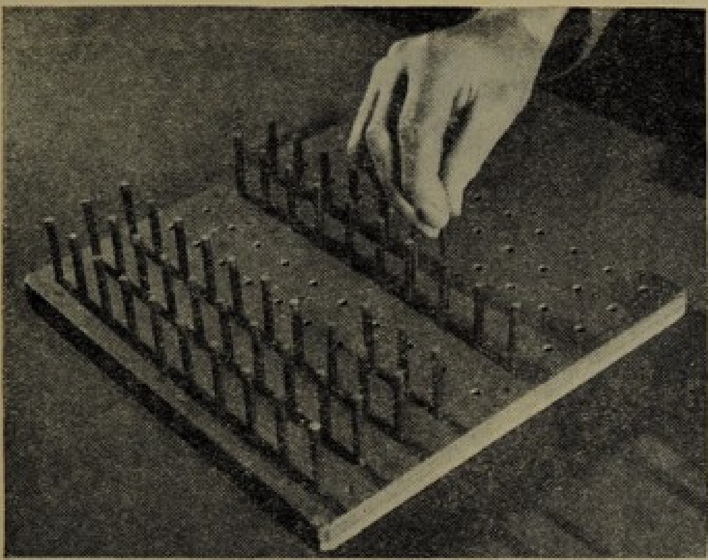


Twisting Test

the time in seconds taken to fill one of the grooves. The final score was the time taken to fill five grooves.

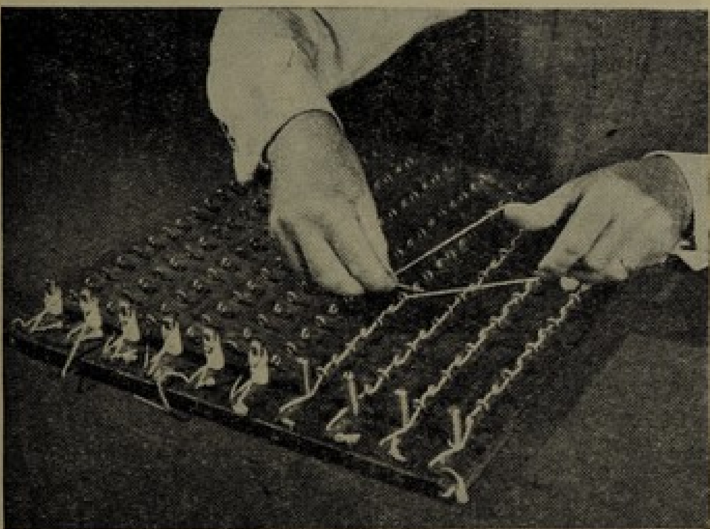
Peg Board. A well known design of peg-board was used, in which the board consists of one hundred holes arranged in square formation, and spaced one inch apart. In the apparatus used the top of the board is faced with a hard plastic and the holes are three eighths of an inch deep. The pegs are of hard plastic, two inches long and three sixteenths of an inch in diameter.

A peg-board is a versatile piece of apparatus and can form the basis of a variety of manipulative



tests. In this study the upper fifty holes of the board were filled with pegs and the task was to move them one by one to the lower fifty holes. To make the task a little more difficult it was required that each peg should be turned upside down before being placed in one of the lower holes.

The scoring was by the time in seconds to perform this task. The final score was the total time required for five runs.



Cox Eye-board. The third test used was the (J.W.) Cox Eye-board. In this test there are ten laces fastened at one end to the board and with a tag at the other. Each lace has to be threaded successively through a row of twenty screw-eyes. It requires rather more complicated manipulation with the fingers than the other two tests of this group. In this case, each run consisted of threading two of the laces. The scoring was by the time in seconds for each run. The final score was the total time required for five runs.

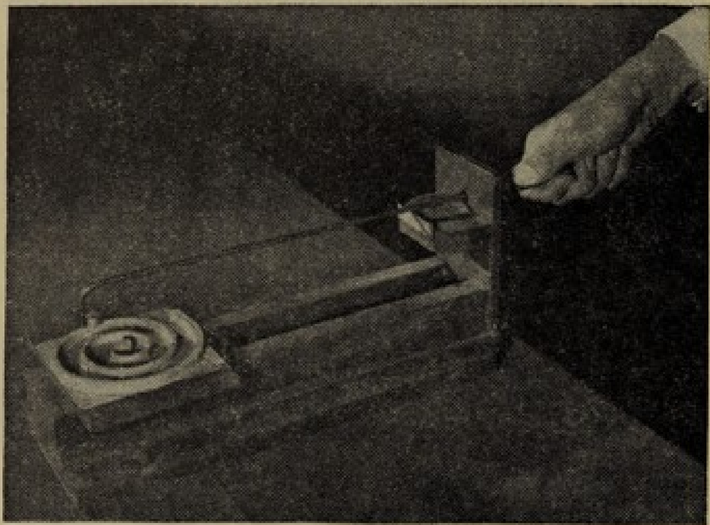
THE 'PRECISION-DEXTERITY' GROUP OF TESTS

There were no suitable tests in existence and a certain amount of experimental work had to be done to devise tests.

The Tracking Tests. The aim was to produce a test that would present a difficult manipulative task to be performed with one hand. The general idea was to perform some operation on a small object with an implement arranged so that a small movement at the manipulating end produced a large movement at the operating end. For the task we used a cylinder of brass three-eighths of an inch high and half-an-inch diameter, which had to be pushed along the top of a miniature wall, without being knocked off. In the preliminary experimental work, we used three types of miniature wall. One was of a zig-zag formation with a uniform width of a quarter of an inch. Another was an hexagonal spiral, also of a uniform width of a quarter of an inch. The third, the one finally adopted, was in the form of a true spiral of three turns, four inches external diameter, and with the wall varying in width from a quarter of an inch at the outside to one eighth of an inch at the inside. The wall was marked off into sections radially and the scoring was by the number of sections over which the cylinder was pushed before it was knocked off.

A considerable amount of experimental work was necessary before a suitable device for pushing the cylinder along the wall was found. The first two devices were discarded because they were found to be too complicated. The difficulty of the task depended to some extent on the adjustment of the device and there was no certainty that the adjustment could be kept constant.

The device finally adopted consisted of a handle fitted with a length of three-sixteenth inch diameter steel rod, the last inch of which was bent over at a right angle. This was passed through a quarter inch diameter hole in a brass plate fixed in a vertical plane. To reach the cylinder on the minia-

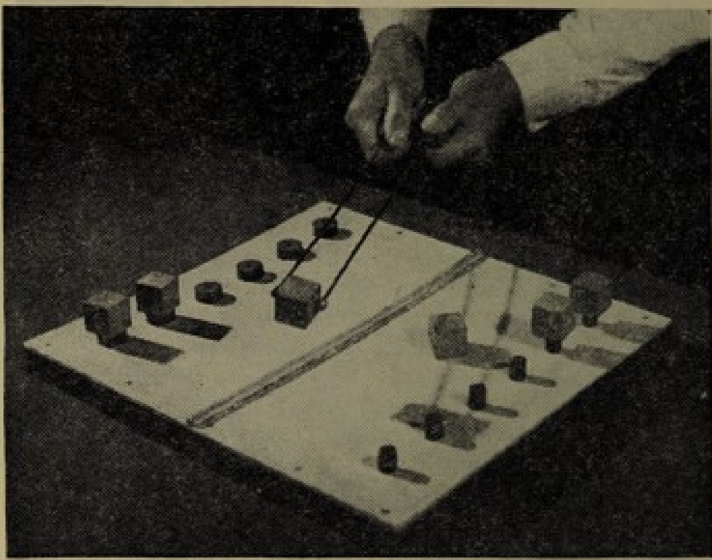


ture wall the rod had to be pushed through the hole almost up to the handle. The rod was eighteen inches long and to avoid the muscular effort required to balance the rod, the handle was weighted. The movement at the operating end was three or four times as great as at the handle end, depending upon the position of the rod, and the combination of a sliding and a rocking movement that was required made the operation sufficiently difficult.

One minute of practice was allowed, after which three trials were made. The score was the distance that the cylinder was pushed along the wall before it was knocked off.

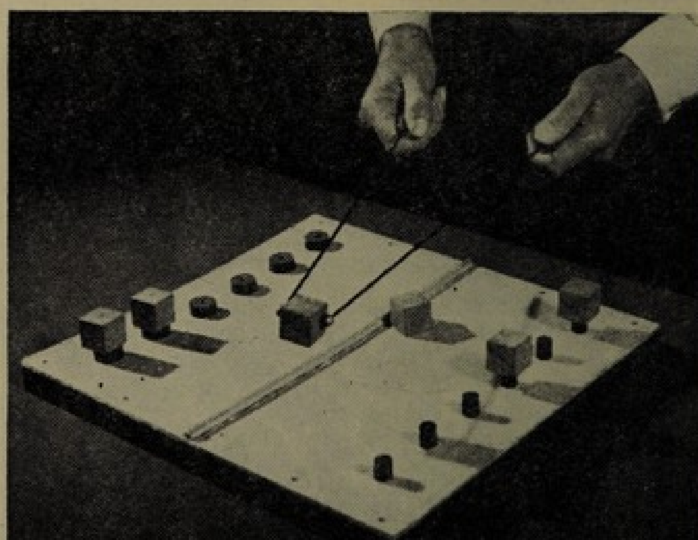
Placing Tests. The object of these tests was to provide a difficult manipulative task to be performed with both hands. The general idea was that each hand should hold some sort of implement and the operation to be performed should be such as to need the simultaneous manipulation of both implements.

The implements used were lengths of one-eighth inch diameter steel rod, fitted into a handle at one end and with a three-eighths inch diameter brass ball at the other. The rods were thirteen inches long between the ferrule of the handle and centre of the ball. The task was to lift a one-inch wooden cube, by gripping it between the brass balls, from a 'stand' and to place it on a 'pedestal' a short distance away. The subject was allowed to take his own time at this operation. The brass balls at the end of the implements ensured that the cube was touched at one point only; the task was too easy without them. The 'stands' were cylinders one inch in diameter and five-eighths of an inch high. A board was constructed with six stands



and six pedestals, the distance between stand and pedestal being eleven inches. It was found, however, that it was more convenient to use one stand and one pedestal only and for the administrator to replace the cube after each trial.

This apparatus was used for two tests. In the first the subject was allowed to place his hands

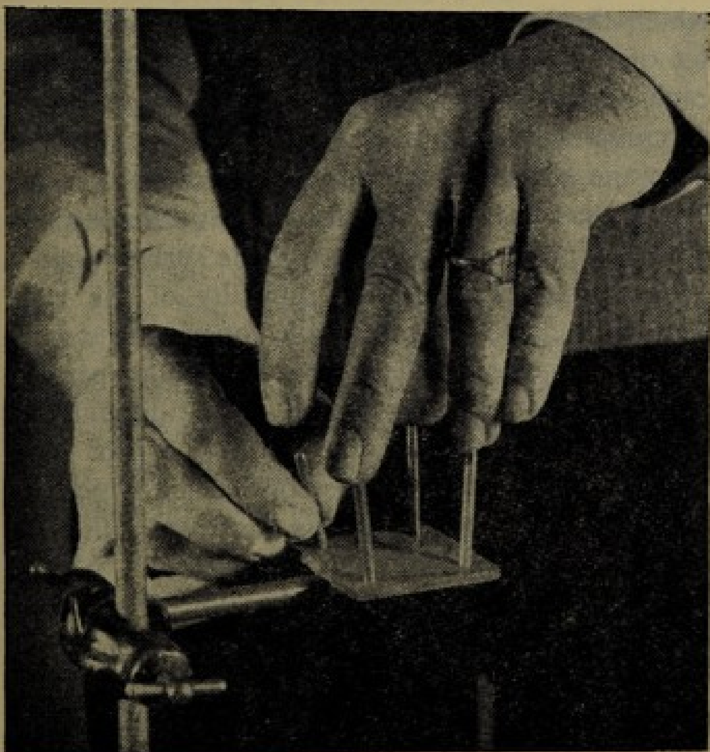


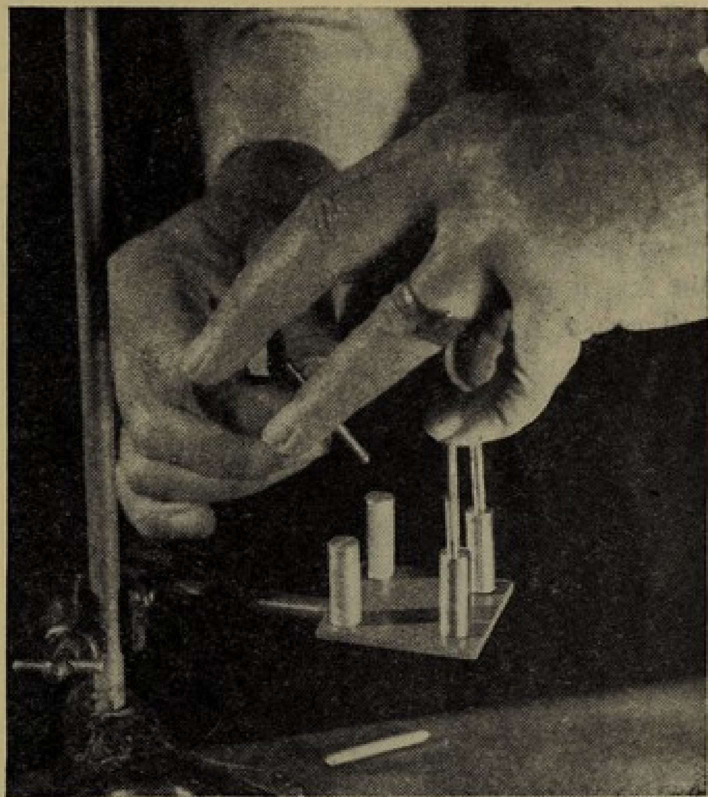
together. In the second he had to keep his hands apart. This made the task considerably harder as well as making it essentially a different operation, since a considerable degree of bi-manual co-ordination was required which was not involved in the first test.

In the first test each subject was given one minute for practice and then a run of five trials. Two points were given each time a block was placed on the pedestal and one point if the block was carried successfully across not less than half the board but dropped before it was placed on the pedestal. If the block was dropped before it was carried half way across the board it was counted as a failure and no points given. A narrow strip of wood, rounded at the top, was fixed across the centre of the board. With this device the block had to fall on one half of the board or the other, it could not rest on the rounded top of the strip, so there was no doubt whether the block had been carried halfway across the board.

The second test was much more difficult and there was a far higher proportion of failures. The subject was given two runs of five trials after one minute of practice. After the first run the board was turned round so that five blocks were moved from right to left and five from left to right. The scoring was made in the same way as for the first test.

Peg Balancing Tests. The object of these tests was to provide a difficult manipulative task to be performed mainly with the fingers. A plastic plate, rigidly fixed in a horizontal plane, had four depressions arranged in a square formation. There were four pegs to be balanced, consisting of a one and three-quarter inch length of five-thirty-second inch diameter mild steel, rounded at the ends. In the first test one end of each peg was placed in one of the depressions in the metal plate and it had to be held in a vertical position by the tip of one finger placed on the other end. The thumb and three fingers of one hand were used for supporting the four pegs which were placed in position one at a





time by the other hand. After that, they had to be removed one by one. In the second test four brass cylinders, three-eighths of an inch diameter and one inch long, were placed on the plastic plate. Each cylinder had a depression at the top similar to the depressions in the plate. The pegs had to be placed in position again and held vertical with the fingertips, but in this case their lower ends rested in the depressions on the tops of the cylinders. After that they had to be removed again, one by one. In each of these tests a trial was considered as finished when a peg was dropped or when all four had been placed and removed.

In the first test the subject was allowed one minute for practice. One point was given if three pegs were balanced before one was dropped and two points if all four pegs were balanced and then removed without any being dropped.

Five trials were made and the final score was the total number of points gained on all five trials.

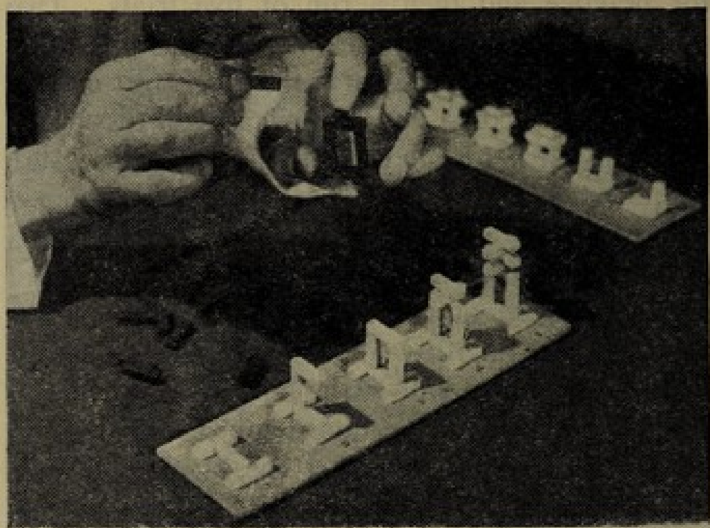
In the second test two minutes were allowed for practice. Three points were allowed for balancing three pegs, four points for four pegs and five points if all four pegs were balanced and then removed without any being dropped.

Rolling. The aim of this test was to provide a difficult manipulative task for which the fingers of both hands would need to be used simultaneously. It was based on the operation of rolling cigarettes. In place of paper, sheets of thin plastic of about the same dimensions as cigarette paper were used. Six three-sixteenth inch ball bearings were used in place of tobacco. During the preliminary trial of the test it was found to be rather too difficult to roll up six ball bearings at the same time. The test was modified so that the subject rolled up three ball bearings cigarette-wise at first, and then afterwards dropped three more ball bearings into the

roll. An attempt was considered to have failed when any of the balls was dropped.

Each subject was allowed two minutes practice and then made three trials. One point was allowed if the three balls were successfully rolled up, and two points if the additional three balls were inserted successfully.

Models. The object of this test was, again, to provide a difficult manipulative task requiring the use of the fingers of both hands. The basis of this test was the toy 'bricks' with which children build fantastic buildings or porticos. The 'bricks' used were of a square section of one quarter of an inch,



and one inch long. The little 'buildings' that had to be made were too unstable to stand unsupported; the bricks had to be held in position by the fingers of one hand. The bricks had to be placed in position, one by one, by the fingers of the other hand. A range of ten little 'buildings' was devised, the easiest being such that anyone could construct it, and the hardest being such that most people failed after repeated attempts. As the difficulty of these tasks varied with the order in which the little bricks were placed in position, a set of demonstration models was constructed for each of the little buildings, showing the stages of its construction, brick by brick.

In the experimental stage of this test wooden bricks were used. It was found that differences in the roughness or smoothness of the surfaces had a considerable effect on the difficulty of the task. Also, a brick that was not quite square at the ends, or whose opposite sides were not quite parallel planes, could add considerably to the difficulty of the test. To ensure that all the bricks were accurately shaped, jigs were constructed which enabled slightly oversized bricks, cut from a sheet of ebonite, to be filed to exact dimensions. All the surfaces were finished with a fine file. The sets of demonstration models were of wood, the bricks being cemented in position with 'balsa' cement. To ensure that they were presented in the same way to each subject the set of demonstration models for each building was cemented in position on a strip of strawboard.

During the trials of this test, it was found that to use the whole set of ten buildings would take more time than could be spared for one test. It was therefore decided to reduce this test to two of the buildings of medium difficulty.

The subjects were allowed two minutes practice on each building. Three attempts were allowed at each. The operation was divided into five stages and one point was allowed for each stage completed. When a brick was dropped or when the building collapsed in the subject's hand, the attempt was considered to have ended.

In the second group tested (the girls) it was found that a little more time could be given to this test and the number of attempts was increased to five for each building. The final score was the average number of points gained at all the attempts.

OTHER MEASUREMENTS

In addition to the test scores, measurements were made of hand width and finger length, and muscular strength of the hand was measured with a dynamometer.

SUBJECTS

The group consisted of 52 boys and 50 girls, all between the ages of 15 and 16½ years; the choice of subjects was made on practical considerations. The battery of tests took far too long to be given on odd occasions, and the apparatus was such that it could not easily be transported to different localities. It was necessary to secure groups of subjects who could attend at one point on the same day. Pupils in their last year at school who could be persuaded to give up a day of their holiday were therefore an obvious choice.

The proposition was made as attractive as possible to the young people, by paying them a small fee, providing lunch and refreshments and arranging the programme so that it became for them an interesting first hand experience of test work. Their interest was kept going by explaining the purpose of the investigation and by stimulating a competitive spirit to do well at the various tests.

This sample was, of course, self selected since only those who thought that it was worth while attended. It was thought that such selection would not be of any significance as far as the test results were concerned, for there was no reason why these pupils who felt interested should be any better or any worse at these tests than those who were not interested. Since most of the tests were new and those not new were used with a modified technique it was not possible to obtain any positive evidence from the tests themselves that such selection as there might be with this group had no effect on the scores. It was possible, however, to make a check by giving all the subjects an existing and standardised test not too dissimilar from those of the speed-dexterity tests of the battery. For this purpose we used the normal version of the R.V. Manual Dexterity test which has been in use at the N.I.I.P. for many years. The mean score of the group tested was 70.3 and the standard deviation 8.7; the mean for this age is 70.8 with a standard deviation of 8.6. This is as close an agreement as could be expected from a group of 102; there was no evidence for any selection for manual dexterity as measured by the R.V. test.

As in an experiment such as this, the question of the level of intelligence of the group may arise in any discussion of the results, they were given a non-verbal intelligence test, N.I.I.P. Group Test 72. The mean score of the group tested was 30.8 and the standard deviation was 6.8. The mean score for this age is 26.1 with a standard deviation of 10.0. It seems that the group was slightly selected for intelligence, the mean being about half a standard deviation higher than that of the general population.

TESTING PROCEDURE

All the apparatus was set up permanently in a test room. A check of the functioning of all tests was made before the commencement of a session. The high speed electric counter assembly was made up in duplicate; each was in a separate case with self-contained dry cells, with a check circuit built in, operated by a press switch, which showed the voltage of the dry cells under load.

The testing was done by two administrators each testing approximately half the subjects. Each administrator was able to test two subjects each day, allocation of the subjects being made beforehand from the list of volunteers. Normally four subjects were tested each day, but there were days when only two volunteers were available, on which occasions they were tested by only one of the administrators.

It was explained to the volunteers on arrival what they were required to do, when they would have a break for coffee, for lunch and for tea, how long each session would last, who would be partners and to which administrator they would be allocated. They were also told that in addition to the agreed fee there would be small monetary prizes for high but obtainable scores, but that they would not know the prize winning score till after each test was completed.

After the preliminary explanations the subjects were given the non-verbal intelligence test, Group Test 72, and the standard version of the R.V. Manual Dexterity test; next measurements of finger length and hand width were made, and muscular strength of the hand was measured with a dynamometer. Then measurements of elbow height were made both when standing and when sitting; a chair was adjusted for each subject so that elbow height when sitting should be constant. When necessary each subject was allocated a platform to stand on so that at all the tests for which the subjects stood, the elbow height would be constant to the nearest inch.

The time allowance for the various tests was arranged so that the total time required for tests of the speed group and speed-dexterity group was about equal to the time required for the tests of the precision-dexterity group. The speed and speed-dexterity tests were set up in one room and the precision-dexterity tests in another. Each of the administrators took two subjects into one of the rooms and testing proceeded till midday, with a fifteen minute break for coffee. There was an interval of one hour for lunch, after which the two administrators and their subjects changed rooms for the afternoon session, in which there was a fifteen minute break for tea and biscuits.

Rest pauses were automatic, as one subject was watching or resting while the other was being tested. In addition, a pause of about two minutes was introduced between each test for comments and explanations. Everything was done to encourage the competitive spirit, and sweet-stuff was provided to help to maintain a friendly atmosphere.

THE RELIABILITIES OF THE TESTS

All the tests had been previously given a trial run on a small group made up of members of the N.I.I.P. staff, and from the experience gained modifications of both apparatus and test procedure had been made. These trials gave a rough idea of the reliability of each test and provided the basis for planning the testing timetable. For practical reasons the battery had to be such that it would not take longer than a day to administer. It was not practicable to allow a very long time for each test to ensure a high reliability.

A final check of the reliabilities was made on the scores of the 102 subjects, as a result of which it was decided to discard two of the tests. The reliabilities were as follows:—

TEST	RELIABILITY
Finger Tapping	.88
Wrist Tapping	.96
Double Tapping	.92
Twisting	.89
Cranking	.87
R.V. Manual (modified technique)	.96
Peg Board (modified technique)	.88
Cox Eyeboard (modified technique)	.85
Tracking	.45 (discarded)
Placing (Hands together)	.75
Placing (Hands apart)	.84
Peg Balancing (Pegs only)	.71
Peg Balancing (Pegs and Cylinders)	.82
Rolling	.32 (discarded)
Models	.60

In tests consisting of an even number of trials, the reliabilities were calculated by correlating the first half of the test with the second half. In tests consisting of an odd number of trials, the middle trial was omitted from the calculation. In each case the reliability of the full length test was calculated by the Spearman-Brown formula. Some of the reliabilities are rather lower than would be acceptable in a test intended for use in a selection procedure. If these tests were to be used for that purpose some of them would need to be lengthened to bring the reliability up to an acceptable level. However, for the purpose for which the tests were intended, the reliabilities were high enough.

THE FACTOR ANALYSIS

Table 1 shows the inter-correlations of all the tests in the battery.

It can be seen from an inspection of this table that the dynamometer measurements introduce a new factor, and the measurements of hand-width and finger-length introduce another. These, with the two expected factors of the tests, bring the number of possible factors up to four. There is, of course, the possibility that there may be so much overlap of the hand-size and hand-strength (dynamometer) factors that most of the variance of these three measurements can be accounted for by a single 'hand-size-and-strength' factor. The hand-size factor appears to be bi-polar, that is to say large hands are advantageous in some tests and disadvantageous in others. There seems to be a similar bi-polar nature in the factor associated with the dynamometer measurements. There is nothing very surprising about this, in fact it is what might have been anticipated, but it is very inconvenient from the point of view of a factor analysis. Negative values in the original table increase the

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Finger Tapping		·408	·472	·425	·611	·042	·323	·169	·193	·046	·149	·091	·025	–·022	·061	·262
2. Wrist Tapping	·408		·276	·478	·333	–·059	·174	·106	–·027	·058	·139	·121	·160	·164	·144	·265
3. Double Tapping	·472	·276		·372	·383	–·177	·286	·136	–·114	·055	·069	·092	·117	·024	–·030	·305
4. Twisting ..	·425	·478	·372		·395	–·135	·109	–·013	·075	·076	·219	·111	·439	·064	·158	·412
5. Cranking ..	·611	·333	·383	·395		·060	·384	·121	·393	·177	·114	–·017	·070	–·074	–·056	·191
6. R.V. Manual Dexterity	·042	–·059	–·177	–·135	·060		·488	·441	·198	·299	–·152	·043	–·116	–·372	–·676	–·566
7. Pegboard ..	·323	·174	·286	·109	·384	·488		·446	·233	·149	·017	·045	·100	–·271	–·359	–·140
8. Cox Eyeboard	·169	·106	·136	–·013	·121	·441	·446		·286	·242	·033	·095	–·040	–·234	–·440	–·322
9. Placing (Hands together) ..	·193	–·027	–·114	·075	·393	·198	·233	·286		·422	·092	·028	·116	–·122	–·105	·013
10. Placing (Hands apart) ..	·046	·058	·055	·076	·177	·299	·149	·242	·422		·115	·001	·221	–·119	–·378	–·202
11. Peg Balancing (Pegs only)	·149	·139	·069	·219	·114	–·152	·017	·033	·092	·115		·432	·159	·256	·282	·253
12. Peg Balancing (Pegs and Cylinders)	·091	·121	·092	·111	–·017	·043	·045	·095	·028	·001	·432		·163	·024	·133	·215
13. Models ..	·025	·160	·117	·439	·070	–·116	·100	–·040	·116	·221	·159	·163		·209	·244	·245
14. Finger Length	–·022	·164	·024	·064	–·074	–·372	–·271	–·234	–·122	–·119	·256	·024	·209		·564	·503
15. Hand Width	·061	·144	–·030	·158	–·056	–·676	–·359	–·440	–·105	–·378	·282	·133	·244	·564		·694
16. Dynamometer	·262	·265	·305	·412	·191	–·566	–·140	–·322	·013	–·202	·253	·215	·245	·503	·694	

TABLE 1

number of negative values in the first table of residuals which cannot be removed by changing the signs of the row and column, and they in turn increase the number of negative values that cannot be removed from the second table of residuals, and so on. Although it is theoretically possible to carry out an analysis by the centroid or a similar technique when there are a large number of unreflectable negative values, their presence reduces the accuracy with which a factor can be extracted.

Since it was likely that four factors might be present an attempt was made to extract four factors. An iterative technique was employed to find the best fitting values for the communalities, in place of the usual method of using the highest value in each column. This adds somewhat to the amount of computational work, and adds little to the accuracy when there are a large number of tests in the battery, but with a battery of sixteen tests it was thought worthwhile.

It was found that the four factors obtained could not be rotated to form any configuration which had any meaning. The attempt to factorize the sixteen tests was a failure. There are two probable reasons. Firstly, the large number of negative coefficients in the original table. Secondly, the limited number of subjects (102) to whom the tests had been given and the low values of many of the coefficients; both tended to make the standard errors of the correlation coefficients high. In techniques of the centroid type there is a progressive increase in the error of each factor extracted; the number of factors than can be extracted with reasonable accuracy, always assuming that they are there to be extracted, depends upon the standard errors of the original correlation coefficients.

The battery was re-factorized with the hand-size and dynamometer measurements omitted. Again an iterative method was used to find the best fitting values for the communalities. Three factors were taken out and the loadings both before and after the rotation are shown in Table 2, below.

As a check on the results obtained, the correlations were re-factorized by the Holzinger Bi-factor and also by the Burt Group-Factor methods. The results obtained are shown in Table 3,

To avoid computational errors, calculations were made to three decimal places, but the third figure has no significance. To clarify the resulting factor pattern, it is necessary to prune away the dead wood. This has been done in Table 4. As

Tests	Factor Loadings (Before rotation)			Factor Loadings (After rotation)		
	I	II	III	I	II	III
1. Finger Tapping	·622	·244	·310	·702	·140	·174
2. Wrist Tapping	·441	·318	·084	·495	–·067	·225
3. Double Tapping	·397	·300	·295	·577	·000	·037
4. Twisting	·530	·520	–·122	·542	–·276	·442
5. Cranking	·640	·118	·310	·680	·201	·186
6. R.V. Manual Dexterity	·180	–·630	·155	–·120	·665	·000
7. Peg Board	·575	–·282	·371	·430	·596	·097
8. Cox Eyeboard	·390	–·444	·216	·138	·604	·092
9. Placing (Hands together)	·380	–·375	–·135	–·024	·423	·350
10. Placing (Hands apart)	·374	–·345	–·092	·010	·408	·318
11. Peg Balancing (Pegs only)	·273	·240	–·295	·136	–·196	·402
12. Peg Balancing (Pegs and Cylinders)	·236	·116	–·233	·082	–·085	·332
13. Models...	·278	·186	–·314	·100	–·154	·420

Table 2

	Bi-factor				Group Factor			
	I	II	III	IV	I	II	III	IV
1. Finger Tapping…	·182	·759			·380	·670		
2. Wrist Tapping …	·066	·555			·290	·535		
3. Double Tapping	·035	·564			·174	·550		
4. Twisting …	–·079	·677			·294	·508		
5. Cranking …	·275	·654			·488	·510		
6. R.V. Manual Dexterity …	·026		·702		·001		·856	
7. Peg Board …	·244		·682		·498		·572	
8. Cox Eyeboard …	·105		·622		·302		·549	
9. Placing (Hands together) …	·260			·368	·477			·116
10. Placing (Hands apart) … …	·198			·427	·417			·195
11. Peg Balancing (Pegs only) …	–·049			·531	·306			·385
12. Peg Balancing (Pegs and Cylinders)	·051			·371	·225			·270
13. Models … …	·014			·382	·326			·281

Table 3

	Rotated Centroid				Bi-Factor			Group Factor			
	A	B	C	X	A	B	C	X	A	B	C
1. Finger Tapping	·70	·	·	·	·76			·38	·67		
2. Wrist Tapping	·50	·	·	·	·56			·	·54		
3. Double Tapping	·58	·	·	·	·56			·	·55		
4. Twisting …	·54	·	·44	·	·68			·	·51		
5. Cranking …	·68	·	·	·	·65			·49	·51		
6. R.V. Manual Dexterity	·	·67	·	·		·70		·		·86	
7. Peg Board …	·43	·60	·	·		·68		·50		·57	
8. Cox Eye-Board	·	·60	·	·		·62		·30		·55	
9. Placing (Hands together) …	·	·42	·35	·			·37	·48			·
10. Placing (Hands apart) …	·	·41	·32	·			·43	·42			·
11. Peg Balancing (Pegs only)	·	·	·40	·			·53	·31			·39
12. Peg Balancing (Pegs and Cylinders)	·	·	·33	·			·37	·			·
13. Models …	·	·	·42	·			·38	·33			·

Table 4

all loadings below .3 are of doubtful significance they have been omitted. (Loadings of *less than* .316 account for *less than* ten per cent of the variance of a test, so that they are relatively unimportant).

A dot indicates the omission of a loading not significant or of doubtful significance. The blank spaces in the second two analyses do not mean that there are no loadings on these factors, it is simply that these methods of factorizing do not detect them if they are present.

In the case of the Bi-factor analysis, it will be seen that almost all the loadings obtained are slightly higher than those of the centroid analysis. The group factors obtained by this method are not necessarily orthogonal with respect to one another, though they are orthogonal with respect to the general factor X; usually they are slightly oblique. With oblique factors it is possible to get a better 'fit' than with orthogonal factors, and for that reason the loadings are usually slightly higher.

In the case of the Group Factor analysis the loadings on the general factor X are rather higher than those of the Bi-factor analysis. A larger proportion of the variance is attributed to the general factor and less of it to the group factors. The general pattern as regards the A and B factors is very much the same as in the other analyses; but all but one of the loadings on the C factor have shrunk below the level of significance.

There is not a very close agreement between the three analyses, but in view of the fact that the correlations were obtained from only 102 sets of scores, a very close agreement is not to be expected.

THE SIGNIFICANCE OF THE FACTORS

A table of inter-correlations such as the present can be resolved into a very large number of different factor configurations, though many of them are likely to be merely artifacts of the method. Most of them can be discarded from theoretical considerations, but with a single analysis there is always the risk that a configuration that is actually spurious may be accepted because it conforms with some hypothesis. There is much less rick in accepting a factor pattern that has emerged from several independent analyses. In the present case the A and B factors have emerged in three analyses, and there is as much agreement in their loadings as can be expected from analyses based on the scores of 102 persons.

The general factor and the C factor are less certain. In considering them it must be remembered that all methods of factorizing involve approximations and they all involve assumptions that are rarely strictly true. One method may fail to detect a factor with small loadings and another may exaggerate it. The C factor has appeared in all three analyses though in one of them its loadings are small. There is no justification for rejecting it, the uncertainty is about its magnitude. The general factor does not appear at all in the first analysis, but an analysis of the centroid type, made on the scores of a small group, normally does not detect a very small factor when other larger factors are present. In the second analysis there is an indication that a general factor is there, but the loadings are not significant. In the third analysis eight out of the thirteen loadings are significant. It would be unwise to reject the general factor as spurious, but there is considerable doubt about its magnitude.

The final test of the results of a factorization is whether there is any reasonable explanation of the factor pattern that has emerged. In the present study the A, B and C factors are reasonable enough, but it is difficult to find any interpretation of a significant general factor. There does not appear to be anything in common between all the tests, except that they were all operations performed with the hands. There is nothing unreasonable in a *small* general factor. It could arise from the reaction of the persons tested to the test situation, or alternatively, it could be of a composite nature. A number of small factors, each too small to be detected individually and not necessarily having loadings on all the tests, could, with some methods of analysis, appear collectively as a small general factor.

On the whole the most probable state of affairs is an A and a B factor with moderately large loadings in many of the tests, a C factor with smaller and more uncertain loadings, with the possibility of a small unidentifiable general factor. The presence of a general factor has little bearing on the object of the present study, the conclusions would be the same whether it were there or not.

In an analysis such as the present, in which the group tested was small, the numerical values of the loadings must be taken with caution. Of the three methods used, the centroid method makes the fewest assumptions and is generally the more accurate, so that the loadings obtained by it are likely to be nearest to the values that would have been obtained with a much larger group. In all that follows they will be accepted as the best estimates.

The factor pattern that has emerged is not quite what was expected. The analysis has shown that apart from a possible general factor the scores of these dexterity tests are consistent with the assumption that three and not two variables are involved. They have been designated A, B and C. Factors are merely mathematical entities. The fact that a factor has emerged does not imply that it necessarily represents any definable physiological or psychological trait. It may, but the proof that it does must always rest on other evidence. Three group factors have emerged in this analysis and it is possible that there are three distinct traits affecting tasks requiring dexterity, each identifiable with some physiological or psychological characteristic, but it is not safe to assume that this must be so. If this is taken as a working hypothesis, it is possible to make a guess at their nature, but for the purposes of the present study it is quite unnecessary to do so. The A factor, for instance, is with one exception confined to the speed group of tests. A possible guess is that it represents something of a physiological nature that is associated with rapidity of movement of the muscles. Actually, it does not matter whether these three factors can be identified with physiological or psychological characteristics or not. What matters is that peoples' performance at tasks such as those involved in these tests *seems to be as though there were three separate abilities that they possess in varying degrees.*

Although the tests were designed as three separate groups, it was expected that there would be some overlapping. The analysis shows that in fact there is. It is not unexpected that the Pegboard test has something in common with tests of the speed group. Part of the operation performed requires rapidity of movement rather than dexterity.

The two Placing tests have loadings on both the B (speed-dexterity) and C (precision-dexterity) factors. The inference is that actually these two

Tests	Proportion of Variance		
	A	B	C
Finger Tapping	55%	—	—
Wrist Tapping	26%	—	—
Double Tapping	36%	—	—
Twisting	33%	—	22%
Cranking	41%	—	—
R.V. Manual Dexterity	—	45%	—
Peg Board	21%	41%	—
Cox Eye Board	—	42%	—
Placing (Hands together)	—	23%	16%
Placing (Hands apart)	—	20%	12%
Peg Balancing (Pegs only)	—	—	23%
Peg Balancing (Pegs and Cylinders)	—	—	13%
Models	—	—	29%

Table 5

tests are intermediate between those of the speed-dexterity group and the other tests of the precision-dexterity group. It was not intended when the tests were devised that they should be, but there is nothing irrational in the fact that they are.

It is certainly unexpected that the Twisting test has something in common with the precision-dexterity group.

Something can be learned from the magnitude of the factor loadings. For the present purpose the most convenient measure of the scatter of the scores of a test is the variance, since the square of a factor loading shows what proportion of the variance is due to that factor. No test of the types used in this experiment is ever perfect, for the score has to be made on a limited number of trials which may not be truly representative of a person's performance. It will be seen from the table of reliabilities quoted earlier that some of the tests would need to be lengthened considerably if they were to be used in guidance or selection procedures. For the purposes of this experiment this is unimportant, since the contribution of each factor to the total variance of a perfect test can be estimated from the reliability. The proportion of the variance of a perfect test due to each factor (i.e., the square of the factor loading divided by the reliability) is shown in Table 5.

DISCUSSION OF THE RESULTS

THE A FACTOR

To ensure that a clear cut factor pattern shall emerge from an analysis, it is essential that for every expected factor there shall be some tests that have high loadings of that factor and zero or very low loadings of any other factors. It was expected that two factors, a speed factor and a dexterity factor, would emerge, and the speed group tests were put into the battery to meet with this requirement and to "pull out" the assumed speed factor, which it was expected would also appear in the speed-dexterity group of tests. Unexpectedly, three factors have appeared. The A factor is confined almost entirely to the speed group of tests. Industrial repetitive tasks are not as simple as those of the speed group. There are many tasks of about the order of difficulty of those of the speed-dexterity group, and it is possible that the A factor will be involved in some of them. As, however, in the present study this factor has appeared in only one test out of these three and in this case it accounts for only 21 per cent of the variance, it does not seem likely that it is of much importance in industrial repetitive work. The A factor may be of theoretical interest but it has little or no bearing on the inquiry into the fundamental nature of preferences for different kinds of repetitive work.

THE B FACTOR

This factor appears in all the tests of the speed-dexterity group, and to a lesser extent in two of the tests of the precision-dexterity group. Some of the tests employed by J. W. Cox were a little more complicated than those used for the speed-dexterity group. The 'routine' factor that he found may be identical with the B factor which also appears in two of the tests of the precision-dexterity group. If tasks similar to those of the tests of the speed-dexterity group were involved in industrial repetitive work they would be of the kind which anyone can learn to do in a short time but in which the skill lies in the ability to do them quickly; they would evoke among some of the workers such remarks as "There is no skill in this job except doing it quickly". The B factor appears in each of the tests and to about the same extent (41% to 45%) presumably it would be involved in industrial repetitive work of the "skill of speed" type.

THE C FACTOR

This factor appears in all the tests of the precision-dexterity group. It is not suggested that five tasks are anything like an adequate sample of all kinds of industrial repetitive work of the skill of precision type. However, since this factor does appear in all of the tests, though in very varying degrees, it is a safe assumption that it will be involved to some extent in most industrial work of this kind.

THE ANSWER TO THE ORIGINAL QUESTION

The purpose for which this study was planned was to provide an answer to the question whether there were two different sorts of ability associated with two different sorts of skill. It has been a pilot study only, and it is not safe to draw any far-reaching conclusions from the performance of only one hundred and two persons at only thirteen tasks; any deductions made must be taken as tentative. So far as this study goes it seems extremely likely that the answer is "Yes". Whether the B and the C factors represent definable unitary traits, or whether they are each the resultant of a complex of psychological and physiological characteristics does not matter; people's performance at tasks of the degree of complexity to be found in industrial repetitive work is as though there were two separate abilities represented by these factors which they possess in varying degrees.

THE RELEVANCE OF THE B AND C FACTORS

The question remains as to whether these two abilities, or apparent abilities, have any bearing upon the attitudes expressed concerning one or other of the two types of repetitive work. Of the three tests of the speed-dexterity group, the B factor accounts in each case for a little more than forty per cent of the total variance. It is interesting that although these three tests are very different, the contribution of the B factor is about the same in each case. It would be unsafe to assume that in the case of repetitive work requiring the skill of speed the B factor is likely always to account for about forty per cent of the variance of people's performance; there is too much variety in such work to justify any such assumption. However, in the case of repetitive work of about the same level of difficulty as that of the three tests of the speed-dexterity group, it is probable that the B factor does account for about forty per cent of the variance. In work of greater difficulty it may account for more or less. So far as the evidence of the two Placing tests go, it seems likely that it accounts for less.

Very roughly this means that in some kinds of repetitive work requiring the skill of speed, a person's success depends to about forty per cent on the extent to which he possesses some inherent 'ability' and to about sixty per cent on something else. Since most people prefer to do work at which they feel they can be successful, it is possible that a 'B' type worker (a person with a high endowment of the B factor) would be more likely to find 'B' type work congenial. Whether the effect of a high endowment of the 'B' ability is enough to make a worker express a strong preference for 'B' type work and a low endowment of the 'B' ability is enough to make him express a strong distaste for it, is another matter. Since success at 'B' type work appears to depend to a much greater extent on other influences than a high endowment of the B factor, it is not likely that this ability is more than a minor cause for preference or dislike. When a worker says " There is no skill in this job except . . ." a lack of 'B' ability may have something to do with his implied disapproval, but in most cases it is more likely that the major cause is something else.

In the case of the second type of repetitive work, that in which the skills required are complex, success is certainly due to some extent to the apparent inherent ability that is represented by the C factor. Of the five tests in the precision-dexterity group the C factor accounts for from twelve to twenty-nine per cent of the variance. Since industrial work will vary very much more than these five tests, it is likely that in some jobs the C factor will account for less than twelve per cent of the variance, and in some for more than twenty-nine per cent. In some industrial work of this type the C factor may have an influence as great as the B factor has in skill of speed jobs, but so far as it is safe to trust the evidence of these five tests, it looks as though in most jobs the influence of this factor will be considerably less. When in the case of some jobs a strong preference or distaste is expressed, a high endowment or a lack of the C factor may be a contributory cause, but so far as the evidence of this study goes, there is no reason to suppose that it will ever be more than a contributory cause. In very many jobs, and probably most jobs, the evidence suggests that the influence of the C factor is more likely to be negligible. When strong views are expressed about such work, it is likely that the causes will be found to lie in the personality or circumstances of the worker.

SUMMARY

The object of this inquiry, as previously stated, was two-fold; firstly, it was to look for evidence of the existence of a separate inherent ability that makes for success at work demanding skill of speed and another inherent ability that makes for success at work demanding skill of precision; secondly, it was to see whether these abilities, if they existed, were likely to have any bearing on the preferences that are sometimes expressed by workers.

It has been emphasised that this has been a pilot study and that any conclusions reached must be accepted as tentative, but so far as the evidence of this investigation can be trusted it seems that there are three separate groups of personal characteristics which operate as though there were three separate abilities. One of these apparent abilities does not appear to be of anything more than minor importance, if of any importance at all, in industrial repetitive work; of the other two, one appears to be associated mainly with aptitude for skill of speed and the other with skill of precision. Of the two latter, the one associated with skill of speed may sometimes be one cause for preference, but it does not seem likely that it is ever the sole cause or even a major cause. The other may sometimes in some kinds of work demanding skill of precision be a minor cause for preference but it seems likely that in many or most cases its effect will be negligible.

It seems that in any future research on the causes of preferences it would be unwise to neglect these abilities entirely, but major causes will need to be sought in differences in personality or circumstances.

It is not suggested that further work on the apparent abilities represented by the B and C factors is unnecessary in the study of the problems of repetitive work, but in view of the smallness of the contribution they seem likely to make to the variances of workers' performance, the conclusion is that in the present incomplete state of our knowledge they are not the most profitable field for future research.

POSTSCRIPT

The results of this investigation have a bearing on the use of manual dexterity tests as part of any procedure for the selection and allocation of workers for employment on repetitive tasks. The results suggest that, since the C factor accounted for only a small part of the variance of the scores of the precision-dexterity tests, it is likely that it will account for an equally small part of the variance of the performance of people engaged in work demanding skill of precision. C factor tests of the kind used in this study are, therefore, unlikely to be of very much value in selection and allocation procedures and it does not seem that it is worth while to attempt to develop a larger battery of this type of test.

It should be noted, however, that the inquiry does not provide any evidence on the value of more complex, analogous type, tests in selection for operations involving skill of precision. The capacity of such tests to forecast performance at this kind of work must be determined for every task for which it is proposed to use them.

In the case of B factor tests it is a different matter. There are likely to be some repetitive tasks in which the B factor does account for as much as forty per cent of the variance, and in such cases 'B' tests would have a small but useful prognostic value. There is some field for the development of really effective 'B' tests. The indication of this study is that any test which employs only one type of task is not likely to have a B factor loading of more than about .6 to .7. To be really useful such a test ought to have a B loading of .9 or more. To achieve this, a test would need to consist of a number of quite different tasks, that is, it would need to consist of a number of different tests whose scores were pooled. If the scores of three tests each having a B loading of .65 were pooled with suitable weighting, the B loading of the compound test would be about .85. If the scores of five separate tests were pooled, the B loading of the compound test would be about .90. There is a possibility of useful research in the design of such tests. These are two difficulties. The tests used on this occasion required five minutes or more of testing time for each. A compound test taking half an hour would often be rather too long to be of practical use. Research is needed on tests that can be given quickly. The other difficulty is the apparatus required. Five pieces of apparatus similar to that used in the tests of this study would be costly and difficult to transport. What is needed is some versatile piece of apparatus which can be used to provide five quite different tasks of a suitable level of difficulty.

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