REPORT 3

THE NATIONAL INSTITUTE OF INDUSTRIAL PSYCHOLOGY

FOUNDED IN 1921 FOR THE APPLICATION OF PSYCHOLOGY AND PHYSIOLOGY TO INDUSTRY AND COMMERCE

TESTS OF MECHANICAL ABILITY

By F. M. EARLE, M.ED., B.Sc., A. MACRAE, M.A., M.B., CH.B., and other Members of the Institute's Staff.

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THE National Institute of Industrial Psychology was founded in 1921 as a scientific association for the study of Industrial Psychology and the application of its results in practice. The Institute is non-political and is supported both by leading industrialists and by trade unions.

The aim of the Institute is to reduce waste of human energy throughout industry. It aims at eliminating all possible causes of needless strain or friction, whether these causes be *physical*—bad lighting, ventilation or posture, bad movements or methods of work, bad organization, lay-out or arrangement of material, or *mental*—irritation, discontent or anxiety, especially in relation to monotony, fatigue, ignorance, inadequate incentives or defective management. One hundred and fifty investigations have now been carried out in different industries.

The Institute employs psychological tests in the selection of the most suitable employees for particular occupations. In this work it has received the co-operation of the Ministries of Labour and Agriculture, the Board of Education, the War Office, the Home Office, the Post Office and other Government Departments, as well as of the Trades Union Congress.

Psychological tests are also used for guiding adolescents and others in the CHOICE OF A CAREER. Extensive experiments have been carried out in London schools with the co-operation of the London County Council, and an increasing number of private individuals are being tested and advised at the Institute.

Studies in Vocational Guidance

III. Tests of Mechanical Ability

By F. M. EARLE, M.ED., B.SC., A. MACRAE, M.A., M.B., CH.B.,
and other Members of the Institute's Staff

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PREFACE

THE investigations which have been carried out during the past five years by the Institute in a London school area into the problems of Vocational Guidance have given rise to several side-researches. Accounts of two of these, (*a*) on the aptitudes and attainments necessary for success in different kinds of employment, and (*b*) on the use of Performance Tests of Intelligence at school leaving age, have already been published.[1] Another is described in the following Report. The expenses of the research have been met by a grant received by the Institute from the Laura Spelman Rockefeller Memorial.

This Report has been prepared by Mr. F. M. Earle, M.Ed., B.Sc., and Mr. A. Macrae, M.A., M.B., Ch.B., who are jointly responsible for the experimental work from which the results here described have been derived. In the earlier stages of the work all the tests were given by Mr. Macrae, and decisions as to their probable vocational value were based upon observations made by him as well as upon the interim analyses of the data obtained. The application of the tests to secondary school boys has also been carried out by Mr. Macrae. In the later stages of the Vocational Guidance Experiment the revised individual test has been used by several investigators of the Institute's staff—namely, by Mr. D. E. R. Hughes, Mrs. Milner, B.Sc., Miss G. Roberts, B.Sc., Miss M. B. Stott, B.A., Mr. M. Munro, M.A., B.Ed.

'Mechanical ability' may be defined as the ability to grasp and to employ the mechanical principles involved in the use of machines and implements. It is often popularly known as 'machine-sense,' and, as is well known, it is possessed in widely different degrees by different persons. To devise a vocational test which will disclose and estimate this ability satisfactorily, and to examine the psychological and other factors entering into and affecting such a test, are the essential objects of this investigation. Incidentally, light is thrown on the nature of mechanical ability.

The tests hereinafter considered all consist in putting together the parts of simple mechanisms. Successive improvements in method are described; and in its final form the test has been standardized, after being applied to over 600 adolescents and young adults individually. The influence of age and the varying difficulties involved in the assembly of the different test-objects receive due consideration.

The investigators show that success in this test is influenced (i) by the ability to perceive relations of shape or form and, to a less extent, (ii) by general intelligence and (iii) by manual dexterity. They also point out that apparently these three factors operate in different degrees according to the kind of mechanical ability required for different trades, *e.g.* for those of the fitter, carpenter, electrician and smith. Hence, although the test here studied is of useful prognostic value for lads up to the age of 15 or 16 who have not yet received any specialized training, the conclusion is reached that for older boys

[1] "Occupation Analysis," *Nat. Inst. Industr. Psychol.* Report, No. 1. "The Use of Performance Tests of Intelligence in Vocational Guidance," *Industr. Fat. Res. Bd.* Report, No. 53.

about to enter particular trades additional tests will need to be employed, which yield more detailed information about the component factors just mentioned, or in which these factors are balanced in approximately the same way as they are in the trade under consideration. Lines of future research are thus clearly indicated.

Thanks are due to Professor C. W. Valentine for kindly revising the Report before it was sent to press.

CHARLES S. MYERS (*Director*)

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November 1929

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I. INTRODUCTION

(1) *Nature of the Problem*

THE last twenty years have seen a remarkable development in the use of psychological tests. Not only has there been considerable expansion in the practical work of 'intelligence' testing, but new tests, intended to measure the more specialized of human abilities, have been devised from time to time. Thus, Seashore has devoted a great deal of care to the work of perfecting a series of tests of musical ability; Burt, Thorndike, Thurstone and others have investigated various scholastic abilities. From these and similar researches have been developed numerous standardized tests intended as aids to the practical measurement of the abilities of any given person.

The need for such measurement has been increasingly felt as modern life has become more highly specialized, and as, at length, the problems of vocational guidance are beginning to receive the attention they deserve. In particular, the problem of choosing a career wisely is being examined to discover how a satisfactory choice may best be made. It seems essential that a person who chooses to embark upon a particular career should possess at least the more important of the abilities needed for the successful performance of the duties he will eventually have to undertake. How are these abilities to be ascertained? Herein lies the task of the vocational psychologist—to devise measures by which the degree of ability for a specific occupation possessed by a prospective candidate may be adequately explored.

Among these measures may be mentioned that of the ability to understand and to deal with problems of a mechanical kind, *i.e.* problems in which some principle of mechanics is applied. Certain people are notoriously clumsy and bungling in dealing with machinery, because they lack, not dexterity of hands, but rather the ability to grasp the mechanical principles involved; others, again, seem 'born' to the successful management of complex mechanisms. What are the origins of these commonly observable differences, and how may such abilities be detected and measured without long apprenticeships or periods of training?

Psychological analysis discloses the fact that a mechanical problem is usually twofold. There is necessarily first of all apprehension of the *relations* between the parts of the machine which arise from their shape or form; such apprehension, in the simpler problem of constructing an object from its component parts, is often sufficient to enable anyone to solve it easily. But there is also necessary a perception of the *function* both of the component parts and of the mechanism as a whole, and this second aspect of the problem may be the more important. It is possible to put together (or 'assemble') the parts of many mechanisms in a number of different ways; but only one of them will allow the completed mechanism to perform its proper function. Many an amateur mechanic has found to his cost that it is easier to take a mechanism to pieces than to assemble it properly again!

It may be thought that abilities of this sort depend largely upon instruction or training and upon experience gained in the workshop and elsewhere. But there is good ground for believing that success depends as much upon innate ability as upon training. Not only are there good mechanics and bad mechanics, but no amount of experience or instruction seems sufficient to change a bad mechanic into a good one. This being the case, the psychologist may confidently attempt the measurement of innate mechanical abilities in the belief that, however difficult the measurement may be, such abilities undoubtedly exist.

(2) *Previous Researches into this Problem*

The earliest work on tests of mechanical ability was carried out by Stenquist[1] at Columbia University. Acting on a suggestion originally made by Thorndike, Stenquist experimented with 'assembling' tests in which the subject is required to put together the parts of simple mechanisms encountered in everyday life, such as a lock and a bicycle bell. After much research directed to the discovery of suitable material and to the refinement of the method of presenting the tests, he finally prepared three series of practical assembling problems. Series I and II are approximately equal in difficulty, while Series III contains simpler problems suitable for use with younger children. In each case the test is intended to be used in group form, the procedure being as follows. Ten assembled articles are arranged, roughly in order of difficulty, in a specially constructed box in which each article occupies a separate compartment. A small screwdriver is included ; and the hinged lid of the box, when opened towards the subject, forms a working tray. Each member of the group is given one of these boxes and is required to attempt the problems in a standard order, proceeding from the easier to the more difficult. He is allowed thirty minutes in which to complete the task, and he is advised to spend not more than three minutes on any one problem. In scoring the test, 10 points are given for each model perfectly assembled, while for incomplete successes partial scores are allotted according to an arbitrary scale of values ranging from 1 to 9. If the work is completed in less than the standard time, a speed bonus of one half-mark for each unused minute is added to the score.

These tests were 'tried out' on large numbers of American school children (mainly boys) and on men in the American army. The scores of various groups of subjects were compared with the results obtained by the same subjects in verbal intelligence tests and also with the rankings of manual instructors. The correlations with intelligence were low, rarely exceeding 0·4. The correlations with shop instructors' ranks, on the other hand, were high, in some cases even as high as 0·9 ! It was found that the tests brought to light enormous variations in ability among individuals of the same age and the same scholastic

[1] J. L. Stenquist, *Measurements of Mechanical Ability* (New York: Teachers College, Columbia University. 1923).

level. We shall consider the reasons for this at a later stage. Meanwhile it is sufficient to say that Stenquist believed that the tests provide a valuable means of detecting those who possess mechanical aptitude, since other methods of examination fail to disclose differences in abilities of this kind. It was in this belief that the Stenquist tests were used in the preliminary Vocational Guidance experiment carried out in 1923 by the Institute and the Industrial Fatigue Research Board jointly.[1]

Influenced partly by Stenquist's results and partly by the use of the tests in the above inquiry, we accepted this general statement of the position and adopted in the Institute's subsequent investigation the principle of using simple objects which could be taken to pieces, the problem in each case being to discover how to assemble the parts of the object correctly. But some of the objects that were included in Stenquist's series proved unsuitable for use with English children—unsuitable because the mechanisms chosen were not familiar to the subjects tested. For example, the more difficult of the two bottle stoppers was of a pattern never used in this country, so that in the absence of any clue as to the function of the object the child would be compelled to resort to crude 'trial and error' methods of attack on the problem. In the case of certain other objects, notably the mouse-trap, imperfections from the mechanical point of view were discovered. Consequently a more satisfactory collection of mechanical objects had to be found.

It was also thought desirable to use the Stenquist collection of objects (suitably adapted) as an *individual* test rather than as a *group* test, so that more detailed observations of the child's method of working could be made. But, in order to save time over these individual examinations, it was thought worth while to experiment with a group test of a somewhat different kind which, it was hoped, would serve to eliminate those who were hopelessly incapable of dealing with mechanical problems. The results of these experimental inquiries are given in the next section.

While these experiments were being carried out by the Institute, J. W. Cox was independently investigating similar problems. His results have been published recently.[2]

II. EXPERIMENTAL WORK ON A GROUP TEST OF MECHANICAL ABILITY

In the experimental work on a group test suitable for eliminating those who would be quite incapable of gaining a satisfactory score at the subsequent individual examinations, the following articles were used :

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[1] "A Study in Vocational Guidance," *Industr. Fat. Res. Bd.* Report, No. 33.

[2] J. W. Cox, *Mechanical Aptitude* (London : Methuen and Co. 1928). It is convenient to postpone discussion of this book until a later stage (see p. 32). Dr. Cox is now a Research Fellow of the Institute, and is continuing there his experimental analysis of mechanical and motor abilities.

1. Penholder and Nib (two components).
2. Safety Razor without Blade (three components).
3. Spring Paper Clip (three components).
4. Gas Tap with Washer and Screw (four components).
5. Safety Chain (four components).

(1) *Procedure*

The test was given to four children simultaneously, the method of presenting it being as follows. Five parts—the penholder, the razor handle, the gas tap lever, one jaw of the clip, and one link of the chain—were arranged in a row (in the above order from left to right) on the table in front of each child, and all the remaining parts of the five models were mixed together in a pool on the farther side of the row. The subject was required to take the parts from the row in turn, beginning with the penholder, to discover the corresponding parts in the pool, to put the parts together and to drop the models when completed into a small cardboard box. The time allowed for the test was ten minutes, and the children were told to work as quickly as possible.

The group was limited to four subjects, and the above procedure was followed in order to enable the examiner to record the exact time spent by each child on each of the five problems. It was found possible to record the time at which each object was completed by each child, and subsequent calculation gave the length of time spent on each object. To obtain further information about each child a brief individual examination was then given. Two new objects (concerning which information was desired) were used—a patent key-ring and key, and a hypodermic syringe. The child was first given the ‘ disassembled ’ key and ring ; and when he had solved this problem or had attempted it unsuccessfully for two minutes, he was made to begin work on the syringe. Two minutes were also allowed for this part of the test, and the exact time spent on each of the models was noted.

In the scoring of these tests, marks were assigned for complete or partial success in each of the seven models, with the exception of the pen which was employed mainly as a ‘ trial ’ test (a ‘ shock-absorber ’). The maximum number of marks obtainable was 20—twelve for the four group tests and eight for the two individual tests. No marks were given for method or for speed ; but it was thought desirable to take these factors into consideration if the test results were to be really valuable in giving an estimate of each child's ability. Thus a score of 15 might be grade B in a case in which the work is quickly and methodically performed, but grade C in another case in which the result is achieved by methods which show less practical judgment.

The group tests were given to 54 boys and to 36 girls. The individual tests were given to the same boys (54) and to 19 of the girls. Table I and Figs. 1–4 show the distribution of the total scores and the percentage frequency of the various marks obtained for the separate objects.

GROUP TESTS

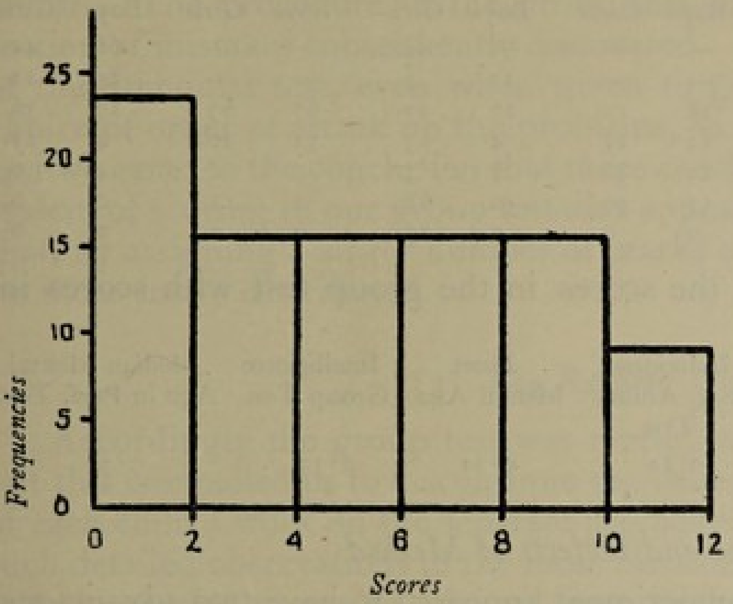

FIG. 1—BOYS

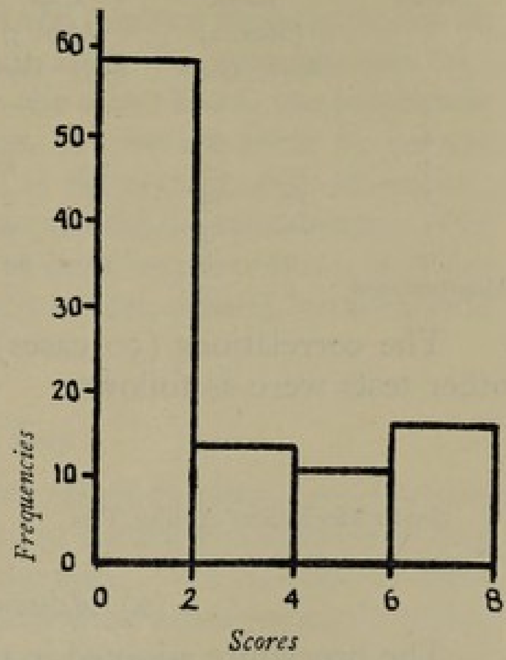

FIG. 2—GIRLS

COMBINED TESTS

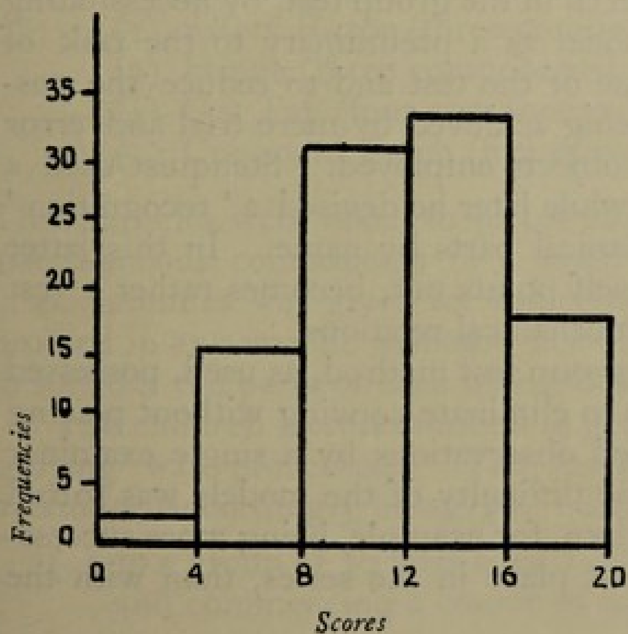

FIG. 3—BOYS

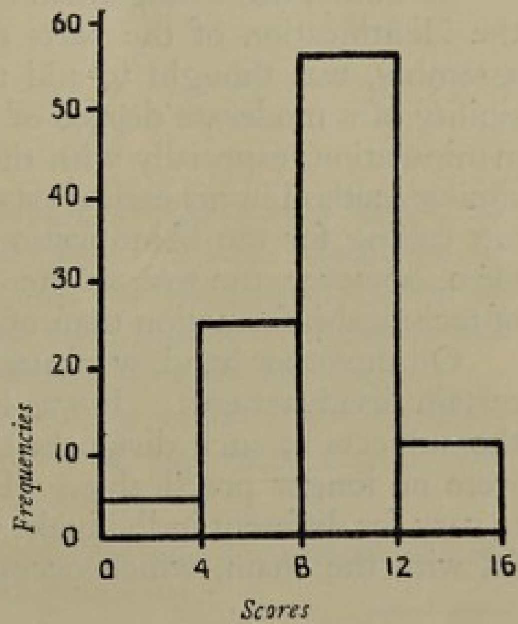

FIG. 4—GIRLS

TABLE I

PERCENTAGE FREQUENCY OF EACH MARK FOR EACH OBJECT

Score	Razor (*Max.* 2)		Clip (*Max.* 3)		Tap (*Max.* 3)		Chain (*Max.* 4)		Key & Ring (*Max.* 3)		Syringe (*Max.* 5)	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
5	—	—	—	—	—	—	—	—	—	—	68	42
4	—	—	—	—	—	—	13	3	—	—	11	11
3	—	—	33	6	28	11	26	11	67	63	13	36
2	72	69	9	0	15	17	4	3	31	26	4	11
1	28	25	2	0	22	22	7	3	0	0	4	0
0	0	6	56	94	35	50	50	61	2	11	0	0
Unattempted	0	0	0	0	0	0	0	19	0	0	0	0

The correlations (50 cases) of the scores in the group test with scores in other tests were as follows :

	Individual Mech. Ability Test	Binet Mental Age	Intelligence Group Test	Median Mental Age in Perf. Test
Group Mechanical Ability Test .	0·41	0·21	0·33	0·32

(2) *Advantages and Defects of Method*

The procedure adopted in this experiment appeared to have two advantages not possessed by the Stenquist method. In the first place, the recording of the actual time spent on each article and the personal observations which were possible in the case of the tests given individually enabled the examiner to obtain a truer assessment of the child's performance, in respect of both speed and quality, than would otherwise have been possible.[1]

Secondly, the arrangement of the material in the group test, by necessitating the identification of the parts of each model as a preliminary to the task of assembly, was thought to add to the value of the test and to reduce the possibility of a moderate degree of success being achieved by mere trial and error manipulation, especially with the simpler objects employed. Stenquist used a similar method in his earlier experiments, while later he devised a ' recognition ' test calling for the identification of mechanical parts by name. In this latter form, however, the test, as Stenquist himself points out, becomes rather a test of technical information than of grasp of mechanical relations.

On the other hand, we found that the group test method, as used, possessed certain disadvantages. It was impossible to eliminate copying without placing the subjects at such distances that detailed observations by a single examiner were no longer practicable.[2] Further, the difficulty of the models was found to vary for different individuals, some children, for example, being more successful with the chain, which occupied the last place in the series, than with the

[1] The problem of the timing of tests of mechanical ability and the inclusion of a speed bonus in the scoring is an important one which will receive attention at a later stage.

[2] Difficulties of this nature have been overcome in Germany by specially screened benches.

earlier problems. When, therefore, a child failed to complete the test there was always some doubt as to whether, if he had been allowed to select his own order of attack, he would have gained a better score. Moreover, if he were permitted to rectify his errors before the time allowance expired he might also do better. The procedure in the group test did not allow for spontaneous correction of mistakes subsequently discovered. On the other hand, the procedure of the Stenquist test, even when given to groups, can be modified to permit choice of order of attack on the problems, as well as the rectification of errors ; and we came to the conclusion that these conditions should be introduced. The system of scoring in our group test also appeared to need improvement, in order that, by assigning a larger number of marks to each model, partial credits could be more justly distributed.

(3) *The Revised Group Test*

Accordingly the group test was revised to give effect to these conclusions, but this compelled us to discontinue the endeavour to secure an accurate timing of each child's work on the separate problems in the test. We decided to leave such detailed observations to the more elaborate individual examination in which it was intended to use an adapted form of the Stenquist test. We still aimed, however, at a group test which would pick out those who possessed little or no ability in the apprehension of mechanical relations, reserving the individual test for use in obtaining a more accurate measurement of these abilities.

The revised group test consisted of the following five articles :

(1) Key-ring and Key (two components).
(2) Safety Razor (three components).
(3) Hinge (three components).
(4) Gas Tap (four components).
(5) Cupboard Catch (five components).

These articles were taken to pieces and placed before the child as a jumble of miscellaneous components in a small cardboard box. A time allowance of fifteen minutes was given for the complete test, and the child was allowed to proceed in any way he wished ; but obviously the most successful method was to sort out the parts of each object before commencing to assemble them.

The children were examined in groups of six, and by suitably spacing them copying was prevented.[1] Ten marks were awarded for each object, the maximum accordingly being 50. The test was given :

(*a*) to a group of 30 boys aged 14½ years, attending a junior technical school and commencing a course of training in engineering ;

[1] It is perhaps worth while to remark that copying is not necessarily deliberate, but the sight of a completed model is often sufficient to give a clue by which a fresh attack on the problem may be made.

(*b*) to a group of 163 children—86 boys and 77 girls—aged 13 years 10 months, attending elementary schools.

The results are shown in Table II and Figs. 5–7.

TABLE II

PERCENTAGE FREQUENCY OF EACH MARK FOR EACH OBJECT

Score	Key & Ring		Razor		Hinge		Tap		Catch	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
10	90	88	82	85	49	40	46	22	27	8
9	—	—	—	—	—	—	—	—	11	2
8	—	—	—	—	—	—	—	—	—	—
7	—	—	—	—	—	—	—	—	—	—
6	—	—	—	—	1	—	—	—	—	—
5	—	—	—	—	—	—	—	—	27	13
4	—	—	15	9	1	1	14	17	9	8
3	—	—	—	—	—	—	—	—	—	—
2	2	5	2	1	43	29	—	—	—	—
1	—	—	—	—	—	—	—	—	—	—
0	8	7	1	5	6	30	40	61	26	69

(4) *Results*

The junior technical school group was of course a selected one and, as was to be expected, the scores ranged considerably higher than in the case of the elementary school groups. Of the elementary school boys only 20 per cent. failed to obtain half marks (25), the median score being 36, and the test appears to be relatively easy for them. The distribution of scores for the group of girls seemed to show that the test was well adapted in difficulty for girls of this age.

However, the purpose of the group test would be served sufficiently well in the case of boys if it succeeded in discovering those whose abilities were not sufficient to enable them to deal successfully with a longer and more difficult test. To determine this an individual test was given to a large number of the same children. The test itself is described in the next section, but the results are more conveniently discussed at this stage.

The correlations obtained between the results of the two tests (group and individual) were :

(1) for the junior technical school group, 0·35 (p.e. 0·108).
(2) for the elementary school group, 0·34 (p.e. 0·080).

Although these correlations are significant, they are clearly not large enough to permit the use of one test in place of the other. It is apparent that some children found the individual test easier than the group test, and gained so much larger scores in the one than in the other that the correlations were very much

REVISED GROUP TEST

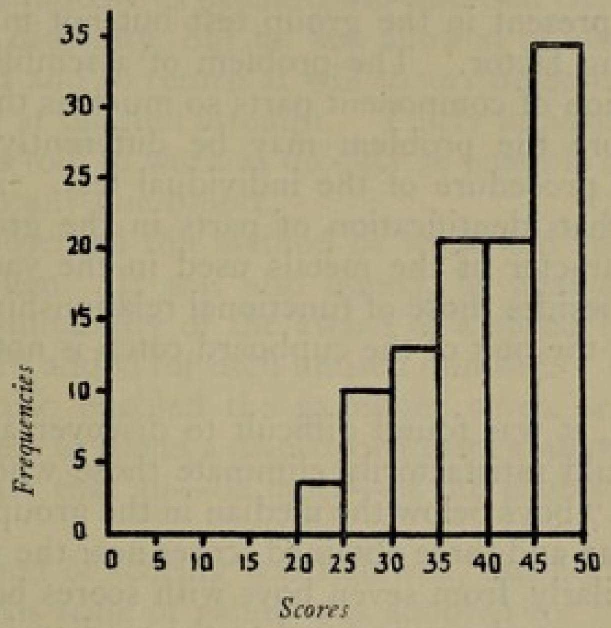

FIG. 5—JUNIOR TECHNICAL SCHOOL BOYS

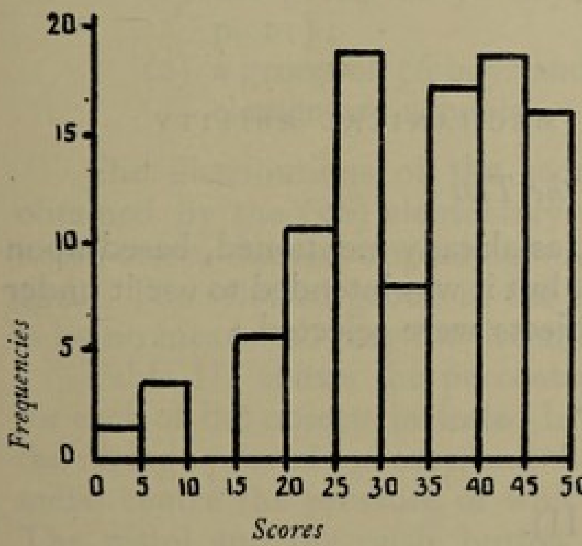

FIG. 6—BOYS

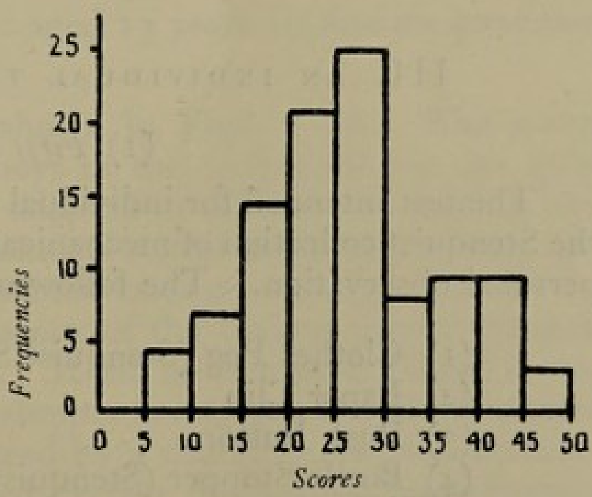

FIG. 7—GIRLS

ELEMENTARY SCHOOLS

affected by these changes in rank. So far as any differences in the psychological qualities called into play by the tests account for the result, it may be that the additional problem of recognizing which of the objects presented belong to each other (which is present in the group test but not in the individual test) introduces a disturbing factor. The problem of assembling does not in itself require the identification of component parts so much as the perception of their function, and therefore the problem may be differently approached in the more straightforward procedure of the individual test. At the same time, it must be mentioned that identification of parts in the group test is aided by differences in the character of the metals used in the various objects, so that there are other clues besides those of functional relationship (such, for example, as the realization that the bolt of the cupboard catch is not a component of the gas tap).

Be that as it may, it was found difficult to discover any pass mark in the group test which would satisfactorily eliminate those who failed badly in the individual test. Of 17 boys below the median in the group test, seven obtained scores above the median and three obtained scores near the upper quartile in the individual test. Similarly, from seven boys with scores below 30 in the group test, three obtained scores above or equal to the median in the individual test. Such variations, of course, occur in all tests, and in individual cases it is doubtless possible to find explanations of these differences. As we were not satisfied that the group test would give us a sufficiently satisfactory means of elimination, we depended in later work solely on the individual test, which by that time had been more fully developed and standardized.

III. AN INDIVIDUAL TEST OF MECHANICAL ABILITY

(1) *First Form of the Test*

The test intended for individual use was, as already mentioned, based upon the Stenquist collection of mechanical objects, but it was intended to use it under personal observation. The following ten objects were selected :

(1) Clothes Peg (Stenquist Series I).
(2) Paper Clip ,, ,,
(3) Push Button ,, ,,
(4) Bottle Stopper (Stenquist Series II).
(5) Hypodermic Syringe.
(6) Safety Chain (Stenquist Series I).
(7) Bicycle Bell ,, ,,
(8) Toy Pistol (Stenquist Series II).
(9) Lock (Stenquist Series I).
(10) Bicycle Hub.

These objects were arranged, in the above order, in the Stenquist box, the 'disassembled' parts of each object occupying a separate compartment and a screwdriver being included. The child was told that the objects were arranged roughly in order of difficulty, but he was allowed to attempt the problems in any order he pleased and to return at will to any object which he had failed to assemble completely at the first attempt. Thirty minutes were allowed for the test. The child was told to work as quickly as possible and to spend not more than five minutes on any one object.

The examiner observed the method of work and recorded the exact time spent on each problem. It was also hoped, by analysing the detailed time records, to test the suitability of the award of a speed bonus as employed by Stenquist (a half-mark added for each unused minute). The individual method of giving the test also enabled the examiner when necessary to check any tendency of the subject to spend a disproportionate amount of time on particular objects, and to ensure that all—or most—of the problems were attempted in every case.

Stenquist's method of scoring was followed, but no additional marks were given for speed. His scale of values was adopted for the eight models taken from his series of tests. In the case of the bicycle hub, in which the possibilities of error are numerous, the scoring of all but the commonest combinations of the parts was left to the discretion of the examiner.

The test was given to :

(1) the group of 30 boys aged 14½ in a junior technical school (*cf.* p. 11);
(2) a group of 56 boys and 26 girls aged 13 years 10 months attending elementary schools.

The distributions of the scores are shown in Figs. 8–10. The scores obtained by the (56) elementary school boys in the individual test are quite satisfactory, the test appearing to be well adapted in difficulty to boys of that age. The selected group in the junior technical school do better, but the test is by no means too easy for them, although a few boys gained high scores.

Table III shows the percentage frequency of the various marks obtained for each of the objects included in the test. It will be seen from Table III that the syringe proved too easy, and the bottle stopper (a rubber cork with a tapered metal centre the pressure of which is altered by a thumb screw) too difficult. The pistol and the push button displayed certain mechanical imperfections which eventually rendered them unsatisfactory. These four models were, therefore, removed from the individual test, four others being substituted. Although the lock proved to be a difficult test, it was retained for two reasons : first, such a test was needed to complete the necessary gradations in difficulty; and, second, the component parts made it possible to award credit for partially completed work.

INDIVIDUAL TESTS

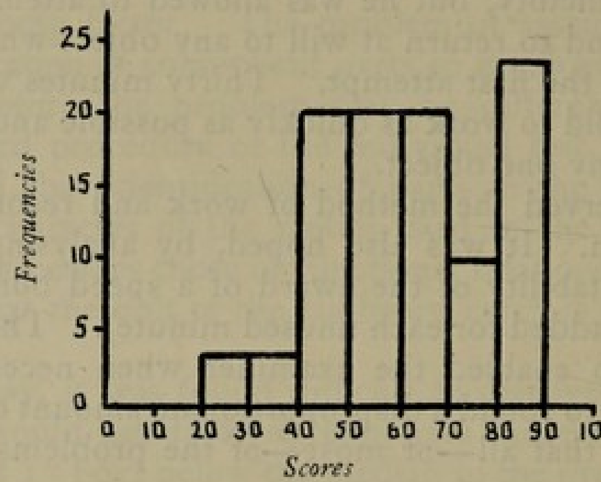

FIG. 8—JUNIOR TECHNICAL SCHOOL BOYS

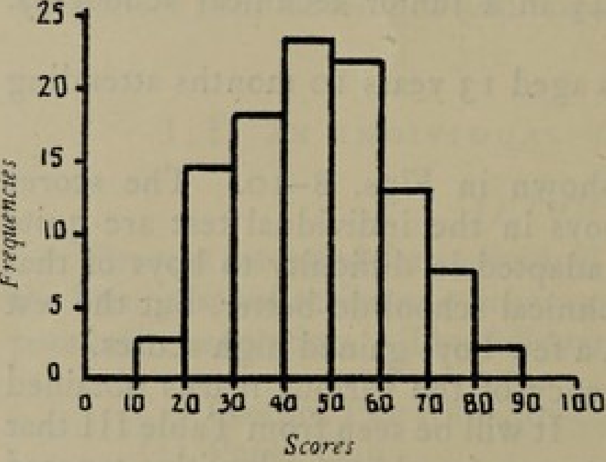

FIG. 9—BOYS

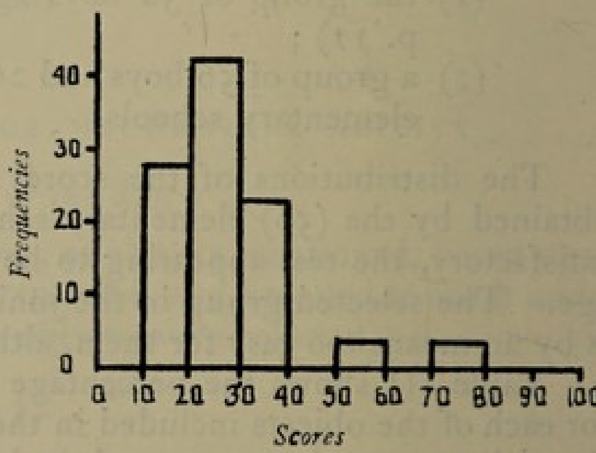

FIG. 10—GIRLS

ELEMENTARY SCHOOLS

TABLE III

PERCENTAGE FREQUENCY OF EACH MARK FOR EACH OBJECT

Score	Peg		Clip		Push-Button		Stopper		Syringe		Chain		Bell		Pistol		Lock		Hub	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
10	36	12	41	8	16	—	14	8	90	61	30	23	41	11	25	4	4	—	20	—
9	—	—	—	—	2	—	—	—	—	—	—	—	11	—	7	—	2	—	—	—
8	—	—	4	27	—	—	—	—	2	8	18	12	2	4	—	—	4	—	—	—
7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	—	—	25	—	13	—	23	42	3	19	—	—	7	8	—	—	10	4	—	—
5	—	—	—	—	—	—	—	—	—	—	—	—	12	19	—	—	14	8	12	15
4	—	—	—	—	5	3	—	—	—	8	2	4	4	19	—	—	4	—	—	—
3	—	—	—	—	30	39	—	—	—	—	—	—	5	4	18	8	—	—	2	4
2	28	15	21	19	—	—	—	—	—	—	9	12	7	8	14	15	4	11	14	—
1	—	—	—	—	25	39	—	—	—	—	—	—	2	—	2	4	30	31	2	—
0	34	69	9	35	9	19	63	50	3	4	30	26	9	23	30	61	21	31	11	39
Unattempted	2	4	—	11	—	—	—	—	2	—	11	23	—	4	4	8	7	15	39	42

(2) *The Revised Form of the Test*

The revised individual test in its final form consisted of the following ten models:

(1) Clothes Peg (Stenquist Series I).
(2) Paper Clip ,, ,,
(3) Spanner.
(4) Gas Tap.
(5) Cupboard Catch (Stenquist Series I).
(6) Safety Chain ,, ,,
(7) Bicycle Bell ,, ,,
(8) Electric Lamp-holder.
(9) Lock (Stenquist Series I).
(10) Bicycle Front Hub.

The method of giving the test was the same as before. For greater convenience in transport of the material, however, the models were placed in a more lightly constructed box, square in shape and provided with two rows of compartments instead of with one. The following were the revised directions for giving and scoring the tests—

TEST OF MECHANICAL ABILITY

Directions for Giving and Scoring

Place the box with the open lid (which is used as a working tray) next to the subject. Explain that—

1. Each compartment contains an object which has been taken to pieces, and that the examinee is required to re-assemble them all as quickly as possible.

2. The objects are arranged approximately in order of increasing difficulty from the left-hand end of the nearer row to the left-hand end of the farther row.

3. The examinee may attempt them in any order he pleases.

4. Not more than five minutes should be spent on any object which proves difficult.

5. The screwdriver may be used as much as is necessary, but in none of the tests will it be necessary to use brute force.

Record in the first 'time' column of the record-form the time or times on the stop-watch when the subject ceases work on each of the objects. The actual time spent on each object can then be determined by a simple process of subtraction, and should be entered in the second column. The time limit for the test is thirty minutes.

Scoring. Ten marks for each correctly assembled object. For partial successes marks are allotted as follows :

(1) *Clothes Peg*.	Spring correctly placed on one stick - - - -	2
	Spring in groove at wrong end of one or both sticks -	2
(2) *Paper Clip*.	Both levers fully inserted from concave side, but both reversed - - - - - - - - -	8
	Both levers fully inserted from concave side, but one reversed - - - - - - - - -	6
	Both levers correctly inserted, flaring blades partly entering spring, but one or both not pressed home -	6
	Both levers correctly inserted, flaring blade barely entering spring - - - - - - - -	2
	One lever only correctly inserted - - - - -	2
	Both levers inserted from *convex* side of spring with like sides outwards - - - - - - - -	2
(3) *Spanner*.	Washer in place at bottom but inverted, otherwise correct	8
	Any other combination of nut and washer, moving jaw correctly inserted - - - - - - -	6
	Washer omitted - - - - - - -	4
(4) *Gas Tap*.	Washer reversed (upside down), otherwise correct -	8
	Washer and screw not fitted tightly—tap does not function properly - - - - - - -	8
	Washer or screw omitted - - - - - -	2
(5) *Cupboard Catch*.	All correct but bolt reversed - - - -	5
	All correct but knob wrongly placed - - -	5
	All correct but spring wrongly placed or omitted -	5
	All correct but washer omitted or misplaced - -	9
	Bolt and spring only correct - - - -	4
	Bolt and knob only correct - - - - -	4
	Spring and knob only correct - - - -	4

(6) *Chain.*	For each pair of links correctly joined - - -	2
	For links half joined (but only when no links are correctly joined) - - - - - - each	1
	Max.	2
(7) *Bicycle Bell.*	Thumb lever correctly on pin - - - - -	2
	Thumb lever correctly on pin—reversed - - -	1
	Gear correctly on pin - - - - - - -	2
	Gear correctly on pin—reversed - - - -	1
	Knocker correctly on pin - - - - - -	2
	Knocker correctly on pin—reversed - - -	1
	Spring properly fixed - - - - - - -	4
(8) *Lamp-holder.*	Smaller ring *or* cable grip omitted - - - -	8
	Smaller ring and cable grip both omitted - - -	6
	Larger ring omitted - - - - - - -	2
	Porcelain omitted - - - - - - -	2
(9) *Lock.*	Lug correctly placed - - - - - - -	4
	Bolt correctly placed - - - - - - -	1
	Spring correctly placed - - - - - -	4
	Cover fitted with screw - - - - - -	1
(10) *Bicycle Hub.*	Cones inverted, otherwise correct - - - -	5
	Balls omitted, otherwise correct - - - -	2
	Other combinations at discretion of examiner.	

The test in this, its present form, has been given to the following groups of boys, none of whom received the group test previously described :

School	Age	Number
Elementary	13–14—average $13\frac{9}{12}$	125
Day Continuation	14–15—average $14\frac{6}{12}$	78
Junior Technical (2)	15–$16\frac{9}{12}$—average 16	(1) 85, (2) 350
Secondary	14–18—average $16\frac{6}{12}$	100

The test was not given to girls, because the results obtained with the earlier form of the test seemed to indicate a general defect in this sort of ability among girls and because in the practical work of vocational guidance we could not afford the time to give tests which would be helpful only in exceptional cases. There are, of course, *some* girls of good mechanical ability whose scores in this test would equal those of many boys, but further study of this particular question is needed before a satisfactory explanation of the marked difference between the *average* abilities of boys and girls in mechanical things can be found.

The distributions of the total scores for these different groups and the percentage frequency of the various marks obtained in the separate problems by the elementary and secondary school boys are given in Figs. 11–15 and

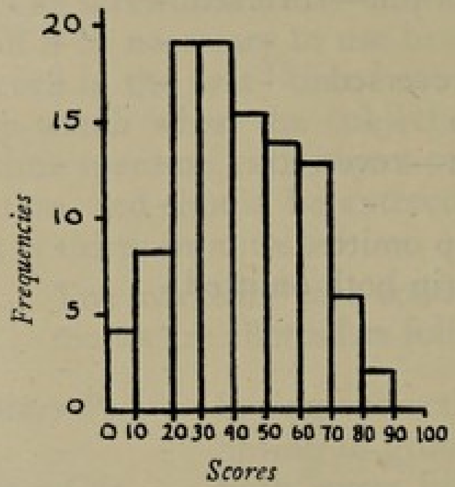

FIG. 11—ELEMENTARY SCHOOL BOYS

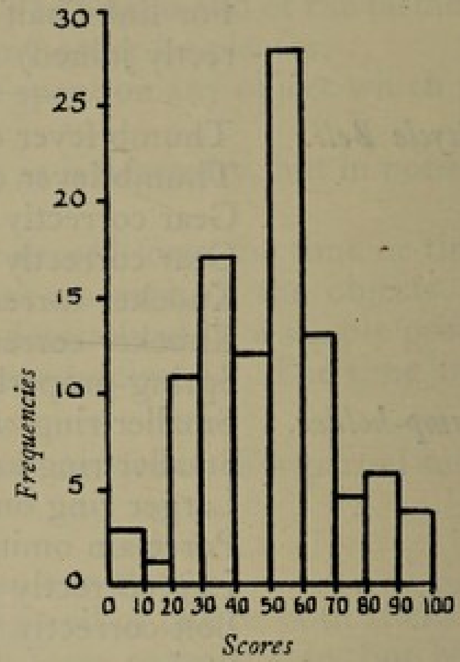

FIG. 12—DAY CONTINUATION SCHOOL BOYS

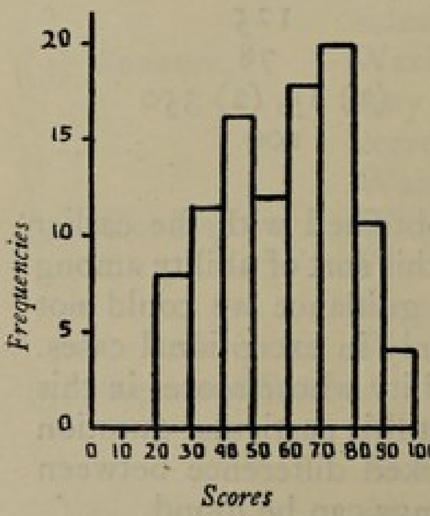

FIG. 13—JUNIOR TECHNICAL SCHOOL BOYS

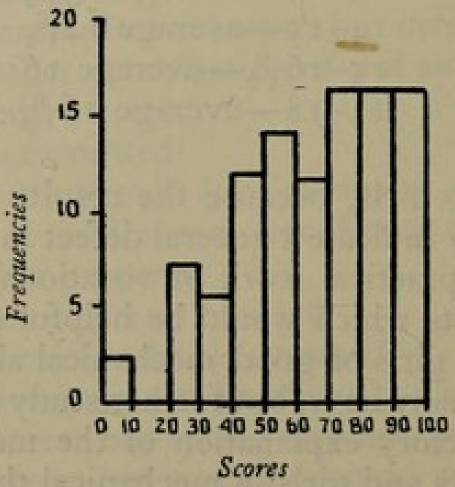

FIG. 14—SECONDARY SCHOOL BOYS AGE 14–16

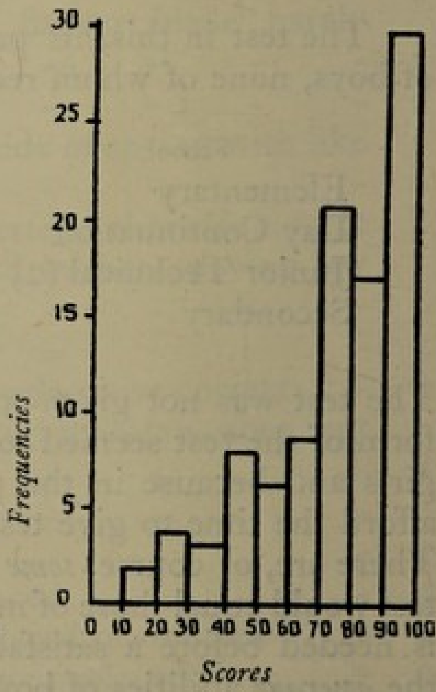

FIG. 15—SECONDARY SCHOOL BOYS AGE 16–18

Tables IV–VI. A table of tentative percentile[1] norms is given in Table VII. The number of secondary school boys in the individual year groups was too small to justify separate statistical treatment. These boys have, therefore, been arranged in two larger groups, one containing 33 boys aged 14 to $15\frac{11}{12}$, and the other 67 boys aged 16 and upwards.

TABLE IV

PERCENTAGE FREQUENCY OF EACH MARK FOR EACH OBJECT

125 Elementary School Boys. Median Age 13 yrs. 10 mths.; Quartiles 13 yrs. 9 mths., 13 yrs. 11 mths.

Score	Clothes Peg	Paper Clip	Spanner	Gas Tap	Catch	Chain	Bell	Lamp-holder	Lock	Hub
10	30·4	27·2	5·6	41·6	40·0	15·2	26·4	22·4	0·8	22·4
9	—	—	—	—	7·2	—	5·6	—	—	1·6
8	—	5·6	21·6	25·6	—	11·2	1·6	4·0	—	2·4
7	—	—	—	—	—	—	0·0	—	—	0·8
6	—	21·6	38·4	—	—	2·4	20·8	4·8	12·8	0·0
5	—	—	—	—	21·6	—	8·8	—	16·8	8·8
4	—	—	24·8	—	9·6	2·4	4·8	—	—	0·8
3	—	—	—	—	—	—	7·2	—	—	0·0
2	21·6	14·4	—	5·6	—	11·2	6·4	2·4	0·0	6·4
1	—	—	—	—	—	1·6	0·0	—	20·0	0·8
0	45·6	28·8	9·6	24·0	21·6	45·6	14·4	49·6	36·0	27·2
Unattempted	2·4	2·4	0·0	3·2	0·0	10·4	4·0	16·8	13·6	28·8

TABLE V

PERCENTAGE FREQUENCY OF EACH MARK FOR EACH OBJECT

33 Secondary School Boys. Age 14 to 16 yrs.

Score	Clothes Peg	Paper Clip	Spanner	Gas Tap	Catch	Chain	Bell	Lamp-holder	Lock	Hub
10	70	72	14	60	53	32	74	70	14	43
9	—	—	—	—	4	—	2	—	—	0
8	—	4	7	23	—	14	2	5	—	0
7	—	—	—	—	—	—	0	—	—	0
6	—	4	75	—	—	0	18	0	15	0
5	—	—	—	—	29	—	0	—	7	24
4	—	—	2	—	0	0	0	—	—	0
3	—	—	—	—	—	—	0	—	—	0
2	19	0	—	5	—	5	2	4	0	2
1	—	—	—	—	—	0	0	—	30	0
0	11	20	2	12	14	49	2	21	34	31
Unattempted	0	0	0	0	0	0	0	0	0	0

---

[1] The percentile rank method is a very convenient way of expressing a person's score in a test relative to the scores of other persons in the group. Thus, supposing the scores obtained for any group of 100 children are arranged in order of merit for the test concerned, the worst child will occupy the percentile rank approximating to zero, the best child the percentile rank approximating to 100, the middle child the 50th percentile rank, and so on. A child whose percentile rank is 55 has gained a higher mark than 55 per cent. of his competitors. It is comparatively simple to find the percentile rank corresponding to any given score for any given group (*cf.* any text-book dealing with the statistical treatment of psychological data).

TABLE VI

PERCENTAGE FREQUENCY OF EACH MARK FOR EACH OBJECT

67 Secondary School Boys. Age over 16 yrs.

Score	Clothes Peg	Paper Clip	Spanner	Gas Tap	Catch	Chain	Bell	Lamp-holder	Lock	Hub
10	72	68	31	63	67	49	82	76	42	57
9	—	—	—	—	3	—	0	—	—	0
8	—	9	18	27	—	13	0	0	—	1
7	—	—	—	—	—	—	0	—	—	0
6	—	11	45	—	—	1	7	0	13	0
5	—	—	—	—	16	—	5	—	5	23
4	—	—	4	—	2	0	0	—	—	1
3	—	—	—	—	—	—	1	—	—	1
2	12	6	—	1	—	2	1	9	1	0
1	—	—	—	—	—	0	0	—	16	0
0	16	6	2	9	12	35	4	15	23	17
Unattempted	0	0	0	0	0	0	0	0	0	0

TABLE VII

PERCENTILE RANKS AND CORRESPONDING SCORES FOR DIFFERENT GROUPS

Percentile.	Elementary.	Day Continuation.	Technical.	Secondary.	
	Ages $13\frac{10}{12}$	$14\frac{6}{12}$	16	14–15	16–18
90th	70	77	85	94	99
75th	58	64	72	84	92
50th	43	51	61	67	77
25th	29	39	46	49	61
10th	19	28	34	34	40

IV. ANALYSIS OF RESULTS OBTAINED FROM THE INDIVIDUAL TEST

As explained in Section I, the purpose of a test of this kind is to enable an observer to obtain an adequate measure of the ability of an individual in tasks which require speed and accuracy in the handling of mechanisms. In establishing the value of any particular test or combination of tests, it is necessary to show that it is capable of performing this task reasonably well. In other words, we have to consider what ability or group of abilities the test actually measures. In addition, we have to consider whether the procedure and the scoring of the test are entirely satisfactory. Several questions arise in connection with both these problems which are best dealt with separately. We shall consider the procedure and scoring problems first.

(I) *Problems Connected with the Procedure and Scoring of the Test*

(*a*) *Procedure.* Comparison between the procedure adopted in the various forms of the group test and that adopted in the individual test points definitely to the superiority of the latter. Most of the reasons for the adoption of this procedure have already been stated. In its final form the individual test may be used without the separate timing of each of the ten objects, only the total score being taken into account in assessing the ability of the subject. The adoption of this procedure enables the test to be given simultaneously to a group in the way Stenquist used it ; but we are of opinion that whenever it is possible to give the test individually this should be done. During the observations which are possible in individual examinations considerable information may be gained concerning the methods of attack adopted by the boy ; and, should he appear to have any special difficulty in dealing with some particular problem, judicious questioning at the end of the test may throw light upon the nature of his difficulties. In the practical work of vocational guidance such incidental observations are of great value.

(*b*) *The order of difficulty of problems and the time usually required for a successful solution.* The order of difficulty of the problems was determined by analysing the time spent on each object in relation to the number of marks obtained. There were, of course, considerable variations, some boys obtaining full marks after a very short time, others finding it necessary to spend a comparatively long time at the problem before discovering the solution. There were also cases in which a certain amount of time would be spent upon an object to no purpose, and where, therefore, there was some doubt whether greater persistence would or would not have been rewarded. But the average times taken for each test (see Table IX, p. 24) show that in dealing with at least half of the objects the boys who were quickest gained the highest marks, and consequently it is only reasonable to suppose that the speedy apprehension of the solution of the problem is significant of mechanical ability, whether this be due to innate ability, to acquired knowledge, or to both.

In Table VIII the objects have been arranged as nearly as possible in the order of difficulty given by adding the percentages obtaining half marks and over.

TABLE VIII

PERCENTAGE OF CASES ACCORDING TO GRADED MARKS

125 Elementary School Boys.

	Percentages obtaining—			
	10 marks	5–9 marks	4–0 marks	Not attempting the test
1. Cupboard Catch - -	42	28	30	0
2. Gas Tap - - -	41	25	30	4
3. Spanner - - - -	6	59	35	0
4. Bicycle Bell - - -	24	36	36	4
5. Paper Clip - - -	29	25	43	3
6. Clothes Peg - - -	26	0 [1]	71	3
7. Lamp-holder - - -	18	12	50	20
8. Chain - - - -	17	15	57	11
9. Bicycle Hub - - -	15	11	38	36
10. Lock - - - -	1	29	57	13

[1] In the scoring of the clothes peg there are no marks greater than 4 for a partial success.

In Table IX the objects have been arranged in the same order as in Table VIII, so that the mean time taken to obtain a given score may be seen in relation to the percentage number obtaining that score. Comparison shows, for example, that the bell is relatively easy for this group of boys but requires a comparatively long time to put together. Similarly, the bicycle hub is easier than the lock but requires a longer time for its assembling. The paper clip takes very little time to put together, but it is easy to make mistakes in it.

TABLE IX

MEAN TIME TAKEN FOR EACH TEST

125 Elementary School Boys.

	Mean Time in Seconds for those obtaining—		
	10 marks	5–9 marks	4–0 marks
1. Cupboard Catch (5 components)	151	170	233
2. Gas Tap (4 components)	130	169	195
3. Spanner (4 components)	216	190	130
4. Bicycle Bell (5 components)	250	342	304
5. Paper Clip (3 components)	85	72	71
6. Clothes Peg (3 components)	140	—	133
7. Lamp-holder (6 components)	219	324	252
8. Chain (6 components)	133	129	166
9. Bicycle Hub (6 components)	399	324	285
10. Lock (6 components)	275	342	235
Total	33 minutes	34 minutes	33 minutes

TABLE X (*for comparison with Table VIII*)

33 Secondary School Boys. Age 14–16.

	Percentages of cases obtaining—			
	10 marks	5–9 marks	4–0 marks	Not attempting the test
Spanner	14	82	4	0
Bicycle Bell	74	22	4	0
Cupboard Catch	53	33	14	0
Gas Tap	60	23	17	0
Paper Clip	72	8	20	0
Lamp-holder	70	5	25	0
Clothes Peg	70	0	30	0
Bicycle Hub	43	24	33	0
Chain	32	14	54	0
Lock	14	22	64	0
67 Secondary School Boys. Age 16–18.				
Spanner	31	63	6	0
Bicycle Bell	82	12	6	0
Gas Tap	63	27	10	0
Paper Clip	68	20	12	0
Cupboard Catch	67	19	14	0
Bicycle Hub	57	24	19	0
Lamp-holder	76	0	24	0
Clothes Peg	72	0	28	0
Chain	49	14	37	0
Lock	42	18	40	0

On the whole, the figures in Tables VIII, IX and X suggest that where the test is intrinsically easy (cupboard catch, gas tap, bell, and paper clip) the quickest workers are the most successful, those spending the longer time at the object gaining only partial credits. On the other hand, where the test is intrinsically hard (clothes peg, bicycle hub, and lock) there is a definite tendency for the best results to be obtained by those who spend longer on the test. But it must be borne in mind that those who are quickest in solving the easier problems have more time to spend on the harder ones, and that, generally, the best total scores are obtained by those who have this time to spare. Those who have spent a good deal of time on the simpler problems (successfully or otherwise) have not much time left for the harder ones ; the figures in columns 2 and 3 of Table IX are undoubtedly influenced by this fact.

It would appear, then, that the effects of ability (or inability) in this test are cumulative, just as they are in a pencil and paper intelligence test of many items. Accordingly, it seems unnecessary to award any bonus for rapid work ; the additional time secured for the solving of the harder problems is in itself sufficient bonus.

One other point, however, deserves attention in this connection. What would be the effect of allowing unlimited time for the test ? Would those who gain low scores within the time limit of half an hour gain full marks if they were allowed, say, a couple of hours for the task ? We have no data on this point ; but we may reasonably suppose that the general situation is, as regards time allowances, analogous to that in intelligence tests. If, to perform a given task, one person requires double the time taken by another person, they cannot be regarded, other things being equal, as equally capable. Moreover, in dealing with the measurement of abilities of the kind under consideration here we must have some regard to the practical applications of the test. In those occupations in which mechanical ability is required, efficiency depends upon a speedy grasp of the problem, and those who are slow in understanding the problem and in finding a solution for it are not likely to be very successful. Of course, the tests are only finally valid if they select with reasonable reliability those who do actually succeed in practical mechanical work. Stenquist's researches show that a test of this description, with a comparatively short time limit, can prove a satisfactory instrument of measurement.

(*c*) *Influence of age on success in the Mechanical Ability Test.* The effects of increase in age are seen in Figs. 11 to 15 and Tables IV to VII. From Table VII it appears that the ability measured by the test increases steadily from 14 to 16 both for elementary and for secondary school boys, but that the average ability of the secondary school boy of 15 years is greater than that of the ex-elementary school boy of 16. Tables IV to VI and VIII to X show the following results. The clothes peg, paper clip, bell, lamp-holder, and hub are considerably easier for the secondary school boy than for the elementary school boy (although, as previously remarked, success in the two latter may be due to time gained on the easier objects). The spanner, gas tap, and cupboard catch are also easier but not to the same extent, while the chain and the lock are not often more successfully attempted by the secondary than by the elementary school boys. Possibly the fact that the secondary school boy more frequently possesses a bicycle than the elementary school boy may have something to do with these differences.

(II) *Problems Connected with the Abilities Measured by the Test*

The principal problems may be stated as being :

(i) what abilities does the test measure ?
(ii) how are these abilities related to those measured by other tests and to efficiency in practical engineering work ?

These problems, however, are so closely related that they must be considered together.

One of the most useful methods of comparison between the results of a number of different tests is that provided by a study of the table of correlations between them. In the present research we were able to compare the results of the individual Mechanical Ability Test with those obtained from the following tests :

(1) A Group Test of Intelligence.
(2) A Group Test of Form Relations.
(3) Four tests taken from a series of Performance Tests of Intelligence, viz.:
  (i) A Cube Construction Test.
  (ii) A Formboard Test (Dearborn).
  (iii) A Picture Completion Test (Healy II).
  (iv) A Cube Imitation Test (Knox).

A brief description of the first two of these tests is here given. The four tests of the Performance Test series are fully described in a previous report of the National Institute of Industrial Psychology published by the Industrial Fatigue Research Board.[1]

(1) *Group Test of Intelligence.* This is a Group Test (No. 34) devised by the Institute for use with elementary school children at or near school leaving age. It consists of the usual component tests, such as opposites, analogies, and completion of sentences. It also includes two tests presented pictorially.

(2) *A Group Test of Form Relations.* This is a paper and pencil test. It consists of a number of geometrical figures so drawn that in each one a portion is presented as missing. The subject is asked to choose from among a number

[1] "The Use of Performance Tests of Intelligence in Vocational Guidance," *Industr. Fat. Res. Bd.* Report, No. 53.

of alternatives the 'part' which belongs to each incomplete 'whole.' The figures are arranged in sets of five, the sets being graded in difficulty, the most difficult requiring the selection of two 'parts' to complete the whole. Each set of forms is presented separately. Marks are awarded for correct identification of forms, time limits being imposed for each part of the test.

Study of Inter-correlations of Tests

Table XI shows the correlations between the revised individual Mechanical Ability Test of this Report and the six tests above mentioned.

TABLE XI

INTER-CORRELATIONS OF SEVEN TESTS

125 Elementary School Boys.

	1	2	3	4	5	6	7
1. Form Relations Test	—	0·48	0·38	0·47	0·31	0·41	0·31
2. Cube Construction Test	0·48	—	0·45	0·25	0·29	0·24	0·4
3. Formboard Test (Dearborn)	0·38	0·45	—	0·41	0·40	0·19	0·30
4. Picture Completion Test (Healy)	0·47	0·25	0·41	—	0·33	0·39	0·28
5. Cube Imitation Test (Knox)	0·31	0·29	0·40	0·33	—	0·33	0·18
6. Intelligence Group Test	0·41	0·24	0·19	0·39	0·33	—	0·09
7. Mechanical Ability Test	0·31	0·43	0·30	0·28	0·18	0·09	—

The lowest coefficient which exceeds thrice the probable error is 0·18.

The three tests which appear first in Table XI are tests in which the ability to deal with relations of shape and form is an important factor.[1] The next two tests are tests of general intelligence of a non-verbal type, while the sixth is a test of intelligence of a verbal type. Taking the average correlations of the Mechanical Ability Test with tests of these different types, we get Table XII.

TABLE XII

AVERAGE CORRELATION OF MECHANICAL ABILITY TESTS WITH TESTS GROUPED ACCORDING TO ABILITIES INVOLVED

	Average Correlation of Mechanical Ability Test with—			
	Tests 1, 2, 3, dealing with relations of form.	Tests 1, 2, 3, 4.	Performance Tests of Intelligence. Tests 4 and 5.	Group Test of Intelligence. Test 6.
In the elementary school group	0·35	0·33	0·23	0·09
In the technical school group	0·38	—	0·09 *	0·04

* The average correlation of the Mechanical Ability Test with a Maze Test and a Substitution Test for the same group is ·15.

From Table XII it will be seen that the relation between the Mechanical Ability Test and tests in which the perception of form relations enters is

[1] See "The Use of Performance Tests of Intelligence in Vocational Guidance," *Industr. Fat. Res. Bd.* Report, No. 53.

appreciably greater than that between the Mechanical Ability Test and the tests of intelligence included in the table. This leads one to suppose that one of the factors in mechanical ability is concerned in some way with the perception of relations of shape and form. This factor does not appear to be allied to intelligence—as measured by the group test of intelligence at any rate—for the latter plays little part in success in the Mechanical Ability Test, although it clearly influences the situation in the Form Relations and Performance Tests, as the following figures show :

	Average Correlation of Group Intelligence Test with—	
	Tests 1, 2, 3, dealing with relations of form.	Performance Tests of Intelligence. Tests 4 and 5.
In the elementary school group -	0·28	0·36

A rough pictorial image of the situation may be obtained by imagining two areas (representing respectively mechanical ability and intelligence) which overlap one another very slightly and are both much overlapped by a third area (representing the abilities measured by form relations or performance test). We may suppose that the latter tests are influenced by a certain ' form relations ' factor which also enters into the Mechanical Ability Test, but which has little or no influence on the group intelligence test.

These suggestions are confirmed by the results obtained from a group of secondary school boys. It will be recalled that the group of elementary school boys was homogeneous as regards age and fairly homogeneous as regards training and experience. The secondary school boys constituting the group now under consideration were not all of the same age and differed widely in experience. (It might be assumed, of course, that as regards formal instruction they would be equal, age for age, but there were undoubtedly large differences in their outdoor interests and pursuits.) It is possible to allow for differences in age, but we have no information which would make it possible to adjust for differences in experience.

The raw correlations for six of the tests with each other and with age are shown in Table XIII. (The Form Relations Test was not given to this group of boys.)

TABLE XIII

INTER-CORRELATIONS OF SIX TESTS AND AGE

Secondary School Boys.

	1	2	3	4	5	6	7
1. Cube Construction Test - -	—	0·31	0·30	0·45	0·63	0·51	0·23
2. Formboard Test - - -	0·31	—	0·20	0·10	0·15	0·32	0·13
3. Picture Completion Test -	0·30	0·20	—	0·12	0·36	0·37	0·17
4. Cube Imitation Test - -	0·45	0·10	0·12	—	0·45	0·30	−0·04
5. Intelligence Group Test -	0·63	0·15	0·36	0·45	—	0·19	0·36
6. Mechanical Ability Test -	0·51	0·32	0·37	0·30	0·19	—	0·27
7. Age - - - - -	0·23	0·13	0·17	−0·04	0·36	0·27	—

The lowest coefficient which exceeds thrice the probable error is 0·20.

Since age may be a disturbing factor in some tests, the inter-correlations which would occur if the influence of age were excluded were calculated.[1] They are shown in Table XIV.

TABLE XIV

INTER-CORRELATIONS OF SIX TESTS, AGE BEING HELD CONSTANT

100 Secondary School Boys.

	1	2	3	4	5	6
1. Cube Construction Test	—	0·29	0·28	0·47	0·60	0·48
2. Formboard Test	0·29	—	0·18	0·11	0·11	0·29
3. Picture Completion Test	0·28	0·18	—	0·13	0·33	0·35
4. Cube Imitation Test	0·47	0·11	0·13	—	0·51	0·32
5. Intelligence Group Test	0·60	0·11	0·33	0·51	—	0·11
6. Mechanical Ability Test	0·48	0·29	0·35	0·32	0·11	—

The lowest coefficient which exceeds thrice the probable error is 0·28.

Grouping as before, we get—

AVERAGE CORRELATION OF MECHANICAL ABILITY TEST WITH—

	Tests of Form Relations.	Non-verbal Intelligence Tests.	Verbal Intelligence Tests.
In the secondary school group	0·39	0·33	0·11
In the elementary school group	0·35	0·23	0·09
In the secondary school group[2] when age is not allowed for	0·42	0·34	0·30

It will be observed that the figures for the elementary school and secondary school groups do not differ very much when the influence of age is allowed for. Moreover, the effect of age is greatest in the verbal tests of intelligence, and least in the non-verbal tests.

We may conclude, therefore, that the abilities called for by the Mechanical Ability Test are more closely allied to the abilities needed in the tests of form relations than to those required in the group test of intelligence. The exact part played by intelligence so measured is seen in Tables XV and XVI, which show the inter-correlations of Tables XI and XIV when the factor measured by the intelligence test is held constant. It will be seen that the average correlation of the Mechanical Ability Test with the two groups of tests (Form Relations and Non-verbal Intelligence Tests) is hardly affected at all.

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[1] Using Yule's formula:

$$r_{12\cdot3} = \frac{r_{12} - r_{13} \times r_{23}}{\sqrt{1 - r^2_{13}}\,\sqrt{1 - r^2_{23}}}$$

[2] For another secondary school group of 66 cases more recently examined, the correlation between the Mechanical Ability Test and the Form Relations Tests was 0·44, and between the Mechanical Ability Test and the Verbal Intelligence Test ·30.

TABLE XV

INTER-CORRELATIONS OF SIX TESTS, INTELLIGENCE (GROUP TEST) BEING HELD CONSTANT

125 Elementary School Boys.

	1	2	3	4	5	6
1. Form Relations Test	—	0·43	0·34	0·37	0·19	0·30
2. Cube Construction Test	0·43	—	0·42	0·18	0·23	0·42
3. Dearborn Formboard Test	0·34	0·42	—	0·38	0·37	0·29
4. Picture Completion Test	0·37	0·18	0·38	—	0·23	0·26
5. Cube Imitation Test	0·19	0·23	0·23	0·37	—	0·16
6. Mechanical Ability Test	0·30	0·42	0·26	0·29	0·16	—

The lowest coefficient which exceeds thrice the probable error is 0·18.

whence the average correlation of the Mechanical Ability Test with

	Tests of Form Relations (Nos. 1, 2, 3)	Non-verbal Tests of Intelligence (Nos. 4, 5)
is in the elementary school group	0·34	0·21

TABLE XVI

INTER-CORRELATIONS OF FIVE TESTS, INTELLIGENCE (GROUP TEST) BEING HELD CONSTANT

100 Secondary School Boys.

	1	2	3	4	5
1. Cube Construction Test	—	0·28	0·11	0·23	0·52
2. Dearborn Formboard Test	0·28	—	0·15	0·06	0·28
3. Picture Completion Test	0·11	0·15	—	−0·05	0·33
4. Cube Imitation Test	0·23	0·06	−0·05	—	0·30
5. Mechanical Ability Test	0·52	0·28	0·33	0·30	—

The lowest coefficient which exceeds thrice the probable error is 0·23.

whence[1] the average correlation of the Mechanical Ability Test[2] with—

	Tests of Form Relations (Nos. 1, 2)	Non-verbal Tests (Nos. 3, 4)
in the secondary school group is	0·40	0·32
The corresponding figures for the elementary school group are	0·34	0·21

The meaning of the results so far examined will now be apparent. The Mechanical Ability Test measures some ability or combination of abilities that have little, if anything, in common with those measured by a verbal test of intelligence. The latter test deals with the abstract symbols which are derived from, and which are used to represent, concrete experiences. On the other

[1] Similar results would have been obtained by applying the partial correlation formula to the average correlations at the foot of Table XIV, but Tables XV and XVI show the variations from test to test.

[2] For a group of secondary school boys recently examined, the average correlation between the Mechanical Ability Test and the Form Relations Tests was 0·39.

hand, the Mechanical Ability Test, it would appear, may be successfully attempted without bringing into play any ability (innate or acquired) for dealing with abstract ideas. Each problem is a concrete one and is solvable by practical manipulations from which relationships of part to part may be directly seen. There is no need for reasoning of that higher order which requires the selection and retention in memory of relevant data, the analysis in terms of symbols of the problem to be solved and cognate processes. When reasoning enters into these problems it is essentially of a concrete and practical order. Consider the case of the building of a motor garage. The builder may, by carefully drawn plans and calculations (abstract symbols), determine exactly what materials will be needed, what they will cost, and what the completed structure will look like. He can estimate the total cost and the time needed to erect it. Alternatively, he may content himself with a somewhat general mental picture of what is required and, after arranging for a supply of suitable materials, he may deal with the problem in piecemeal fashion, solving each difficulty as it arises by practical rather than theoretical methods. Of course, in situations such as these it is better for various reasons to 'plan ahead'; but whether this be done fragmentarily, so to speak, or as a whole, depends upon the abilities and experience of the individual. The 'practical' man may find himself hampered by too elaborate plans, in that he can more effectively solve the problem when he has the materials to his hand.

But the applications of the practical methods are limited. Although the ability to work in abstract symbols and to plan ahead in elaborate fashion is not always essential, yet, other things being equal, those who are capable of doing so are, in spite of the lack of some specific ability for a particular problem, in general more successful than those who are not so capable. It is probably for this reason that secondary school boys do better in the Mechanical Ability Test than the elementary school boys; age for age they may be expected to be more intelligent, and although no elaborate mental processes are required in these particular problems, general ability plays its part. The fact that there is no close relation between the Mechanical Ability Test and the Verbal Intelligence Test when age is held constant does not mean that intelligence may not sometimes influence the result. It only means that a number of boys of medium or average intelligence as measured by a verbal test are capable of gaining more marks in the Mechanical Ability Test than boys of the same age who are cleverer in other ways. This suggests an ability which the cleverer boys lack—an ability which finds its best outlet in dealing with practical problems, and which, as we have seen, seems to have some connection with the perception of relations of shape and form. Hence *some* elementary school boys may do better in the Mechanical Ability Test than many secondary school boys of superior general ability, owing to a special ability for these particular problems.

Confirmation of this suggested connection of the Mechanical Ability Test with form relations seems to be provided by the study of sex differences.

These have already been described for the Mechanical Ability Test ; the differences in the case of the Form Relations Group Test are :

Boys (69), mean score	20·61	Difference of means, 3·42 ± 0·20
Girls (63), „ „	17·19	

Thus, as in the case of the Cube Construction Test and the Dearborn Formboard Test,[1] there is a significant difference between the sexes. Since no such differences are found in the case of the Intelligence Group Test, it would appear that the ability to deal with relations of form is more developed in boys than it is in girls, and this may be a partial explanation of the differences between the sexes disclosed by the Mechanical Ability Test.

But the apprehension of relations of form appears to be closely linked with the apprehension of the functional relations of the parts. Cox[2] in his study of mechanical aptitude found a high correlation between the ability to understand the working of ' models ' (where the problem is presented *concretely*—though no handling of the mechanism is permitted) and the ability to understand ' mechanical diagrams ' (where problems similar to those of the models are presented *pictorially*). This high relation he further found to be due not merely to the influence of a general intelligence factor but also to the effect of a group factor (m). As to the nature of this group factor, Cox suggested that it consists in " eductive thinking,"[3] as well as in the cognition of " spatial fundaments or space relations." In practice it seems impossible to separate these. Tests such as the Form Relations Group Test demand " eductive thinking " of this kind, while it is even more obviously necessary in the Cube Construction and Formboard Tests. Similar mental processes (with spatial elements of a more specific and less formalized nature) contribute to success in the Picture Completion Test—a test which also exhibits sex differences of the same order,[4] and which has a significant, although slightly lower, correlation with the Mechanical Ability Test.

Possibly the value of all these tests lies in the way they combine two important mental processes by making use of materials which exhibit relations of space and form, and by compelling thinking of a particular kind about them. From the vocational point of view the application of such tests will be found in situa-

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[1] See " The Use of Performance Tests of Intelligence in Vocational Guidance," *Industr. Fat. Res. Bd.* Report, No. 53. Similar differences have been found by Cox, the scores of boys being greatly in excess of those of girls.

[2] *Op. cit.*

[3] *Cf.* Spearman, *The Abilities of Man* (London : Macmillan and Co. 1926) and *The Nature of Intelligence and Principles of Cognition* (London : Macmillan and Co. 1923). Among the " laws of cognition " propounded by Spearman are the " apprehension of relations " and the " eduction of correlates."

[4] See " The Use of Performance Tests of Intelligence in Vocational Guidance," *Industr. Fat. Res. Bd.* Report, No. 53.

tions which require similar thinking—although not necessarily about similar material; for the same sort of space relations may be found in a great variety of materials.

From an analytic point of view it would be advantageous to separate and measure these two component mental processes; but as we cannot do this effectively we must be content with the determination of their combined effect. This is the case in the data now under consideration, and the measure of the group factor (m) obtained by Cox[1] may be similarly regarded. It is very significant to find that the tests, between which this group factor was found to occur, were all concerned with problems and materials in which both the perception of form relations and "eductive thinking" about them are the principal features.

Is there a Group Factor of Spatial Perception?

Although the comparisons described above strongly suggest some factor common to the tests included in Tables XII–XVI, they do not determine its nature. The common element in these tests may be thought to be the 'g' factor of the Spearman hypothesis and nothing else. It is, therefore, desirable to apply the tetrad difference criterion to the data in order to determine whether or not group factors are present.

The tetrad differences calculated from Table XI are distributed as follows:

Mid-value F	= 0·01	0·03	0·05	0·07	0·09	0·11	0·13	0·15
Frequency	= 22	25	16	18	13	6	4	1
p.e. of F	= 0·035							

whence

3 × p.e. of F = 0·105; 4 × p.e. of F = 0·140; 5 × p.e. of F = 0·175]

There are only four tetrad differences in excess of three times, and none in excess of four times the probable error. Although the median tetrad diffference (0·044) is not equal to the probable error (0·035), we ought perhaps to say, in view of the distribution of tetrads, that the criterion *is* satisfied and that the seven variables not only possess the common factor 'g' but also possess no 'group' factors.

But if the inter-correlations for 'g' constant are calculated, there remains a specific correlation of 0·241 ± 0·071 between the Mechanical Ability Test and the Cube Construction Test. This, of course, may be due to chance, but it seems rather peculiar that specific correlations between tests in which the perception of spatial relations enters should frequently be found even when the tetrad difference criterion is apparently satisfied.[2]

Bearing this in mind, it seemed worth while to construct a table of ten variables by adding three tests of manual dexterity, two being tests in which

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[1] *Op. ci.*.

[2] *Cf.* "The Use of Performance Tests of Intelligence in Vocational Guidance," *Industr. Fat. Res. Bd.* Report, No. 53.

speed and accuracy of movement are combined and one being a test in which speed of movement alone enters.

The new table is shown below.

TABLE XVII

	1	2	3	4	5	6	7	8	9	10
1. Form Relations Test		0·47	0·48	0·38	0·31	0·31	0·41	0·29	0·36	0·02
2. Picture Completion Test			0·25	0·41	0·28	0·33	0·39	0·25	0·24	0·07
3. Cube Construction Test				0·45	0·43	0·29	0·24	0·05	0·06	0·20
4. Dearborn Formboard Test					0·30	0·40	0·19	0·12	0·01	0·05
5. Mechanical Ability Test						0·18	0·09	0·28	0·18	0·21
6. Cube Imitation Test							0·33	0·20	0·17	0·05
7. Intelligence Group Test								-0·07	0·28	0·13
8. Speed of Movement Test									0·25	0·30
9. Dexterity Test I										0·16
10. Dexterity Test II										

The lowest coefficient which exceeds thrice the probable error is 0·18.

The result of applying the tetrad difference criterion to this table of correlations is as follows :

DISTRIBUTION OF TETRADS

Mid-value of F	= 0·01	0·03	0·05	0·07	0·09	0·11	0·13	0·15
Frequency	= 187	137	110	93	52	32	14	5
p.e. of F	= 0·031							

whence

3 p.e. = 0·093 ; 4 p.e. = 0·124 ; 5 p.e. = 0·155

Of these tetrad differences 51 exceed three times, 12 exceed four times, while none exceeds five times the probable error.

On calculating the correlations for ' g ' constant, the following specific correlations are obtained :

The Mechanical Ability Test and the Cube Construction Test
= 0·234 ± 0·071 (*cf.* 0·241 for 7 variables).

The Cube Construction Test and the Formboard Test
= 0·262 ± 0·070.

The Cube Construction Test and the Form Relations Test
= 0·180 ± 0·073.

The Formboard Test and the Cube Imitation Test
= 0·188 ± 0·073.

The Speed of Movement Test and the Speed and Accuracy of Movement Test
= 0·239 ± 0·071.

The Mechanical Ability Test and the Speed and Accuracy of Movement Test
= 0·130 ± 0·074.

The Mechanical Ability Test and Intelligence Group Test
= −0·223 ± 0·072.

Once more it is curious that the tetrad difference criterion should be satisfied (although there are now proportionately twice as many tetrads in excess of three times the probable error as before), while at the same time there are 'residual' coefficients indicating 'specific correlation.'

However, using Spearman's formula for the correlation of sums, the following results are derived :

	Mechanical Ability Test.	Form Relations Test.	Intelligence Tests. Non-verbal.	Intelligence Tests. Verbal.
Correlation between 3 manual tests combined and—	0·32	0·23	0·29	0·23

whence (by the partial correlation formulae) the correlation between dexterity tests and the Mechanical Ability Test for verbal intelligence constant = $0·31 \pm 0·068$, and the correlation between dexterity tests and form relations tests for intelligence constant = $0·16 \pm 0·073$. Similarly for the other combinations.

It is difficult, therefore, to see how the various relations shown by the coefficients in Tables XII to XVII can be explained *solely* by the 'g' hypothesis. Hence we suggest that there is a group factor of spatial perception influencing success in the Mechanical Ability Test. Further, there appears to be some connection between the dexterity tests and the mechanical ability tests which is independent of the form relations factor as well as of the 'g' factor. This point is dealt with more fully in the next section.

The Influence of Manual Dexterity on Success in these Tests

It is now opportune to consider the extent to which manual dexterity influences success in a mechanical ability test of this particular kind. The mechanical aptitude tests devised by Cox are quite independent of manipulative or digital skill (or, as we prefer to call it, manual dexterity). But the tests described in this Report are not. In fact, any tests which require the assembling of objects, whether they aim at the measurement of an elusive 'constructive ability'[1] or of a 'practical ability,'[2] must be influenced to some extent by dexterities of hand and arm, even though success cannot be gained without the ability to carry through the mental processes appropriate to the occasion.

In the present case the question arises whether those who are skilful in putting together the easier objects such as the cupboard catch and the bicycle bell may by such dexterity gain so much time as to be helped appreciably towards a solution of the more difficult problems. The detailed observation of individuals during their work at the test suggested that, although the influence of this factor could not be very large, it might be sufficiently large to require to be taken into account. Studies have, therefore, been made of the relation between success in the Mechanical Ability Test and success in a number of

[1] T. L. Kelley, "A Constructive Ability Test," *J. of Educ. Psychol.*, vol. vii, pp. 1–16.

[2] M. McFarlane, "A Study of Practical Ability," *Brit. J. of Psychol. Monograph Supplement* No. 8, 1924.

tests of manual dexterity. These tests included tests which appear to depend primarily on speed of movement and tests which depend upon dexterous control of movement with and without tactual cues.[1] For convenience the results are reported under the following heads :

(*a*) tests in which speed and dexterity of movement are combined ;
(*b*) tests in which speed of movement is the only factor ;
(*c*) a test in which tactual discrimination is the only factor.

The correlations are given in Table XVIII.

TABLE XVIII

CORRELATIONS BETWEEN MANUAL DEXTERITY TESTS AND THE REVISED MECHANICAL ABILITY TEST

66 Boys. Age $14\frac{5}{12}$.

Manual Dexterity		Mechanical Ability
Group (*a*) tests	1	0·10 (Elementary school group 0·18)
	2	0·22 (Elementary school group 0·28)
	3	0·12
	4	0·16
	5	0·24
		average $\bar{r}$ = 0·17
Group (*b*) tests	6	0·11 (Elementary school group 0·21)
	7	0·20
	8	0·19
		average r = 0·17
Group (*c*) test	9	0·08

It will be observed that although there is a small positive correlation in every case, it is only large enough to be significant in two of the dexterity of movement tests and in one of the speed of movement tests. In both these dexterity tests speed of movement is a contributory factor (these two tests, in fact, of all the five in group (*a*) giving the highest average correlation with the tests of group (*b*)). We may, therefore, reasonably conclude that the dexterity factor which influences success in the Mechanical Ability Test is that which represents the individual's ability to perform a more or less dexterous movement at a comparatively rapid rate. This is indeed what observation suggests, and the degree to which it affects success is represented by an average correlation coefficient of the order of 0·20 which just exceeds three times its probable error.

But the proof that manual dexterity is a factor in this particular test need not affect its validity for the purposes it is intended to serve. Validity rests on other grounds, and this question is considered below. What the results so far described encourage us to say is that mechanical ability as measured by this particular test is not a single entity, but a complex of several factors. One of these is connected with space relations, while another is manual dexterity. Cox, in the work already referred to, considered the inclusion of the latter factor to be a defect (though until now there had been no proof that manual dexterity does

[1] For fuller details see subsequent report on manual tests.

materially influence success in this test), and he arranged his own tests in such a manner as to eliminate it. Consequently his series of tests of mechanical aptitude are more nearly tests of a 'single' ability—if such can be said to exist —than the tests described here. More will be said on this point when some further points in connection with the results have been examined.

Relation between the Mechanical Ability Test and Proficiency in a Skilled Occupation

Stenquist obtained correlations varying from 0·50 to 0·90 between his Mechanical Ability Test and proficiency in the workshop itself. Our opportunities for study in this direction have been limited, and, up to the present, we are only able to report the results obtained from apprentices in the trades of fitter, carpenter, blacksmith and electrician.[1] In an investigation carried out for the Industrial Fatigue Research Board, in the course of which the revised individual test was given to apprentices undergoing training in the above-mentioned trades, rankings for proficiency in the trade were obtained from the shop instructors and these were correlated with the test results. The correlations are shown in Table XIX.

TABLE XIX

Trade	Number in group	Correlation of test with instructor's estimate of proficiency half-way through the course	Correlation of test with proficiency as measured by trade tests at conclusion of training course
Fitter - - -	20	0·49 ± 0·11	0·66 ± 0·08
Carpenter - -	18	0·82 ± 0·05	*
Smith - - -	16	0·37 ± 0·15	0·16 ± 0·16
Electrician - -	21	0·07 ± 0·15	0·23 ± 0·14

* Result not yet known.

It will be observed that significant correlations were obtained between the Mechanical Ability Test and the instructors' rankings for trade proficiency in the case of fitters and carpenters, but not in the case of smiths and electricians. It is also interesting to observe that the result obtained for the fitters is confirmed by the larger coefficient between the test and the result of the 'passing out' examination. This suggests that there is a definite connection between the abilities measured by the test and those needed in the trade of fitters. This is in agreement with the results obtained by Tagg, who included an 'assembling' test in his selection tests for engineer apprentices.

Further confirmation of this result for fitters was obtained from two other groups of apprentices, the correlations between the test and the instructor's ranking being 0·47 ± 0·09 and 0·37 ± 0·12 respectively. Bearing in mind

[1] We hope to be in a position to report further results at a later stage.

the fact that these rankings are influenced by many factors which the tests do not claim to measure, this correlation, even though it is not a high one, is worthy of note. On the other hand, the absence of a similar relation in the case of smiths and electricians is equally significant. The correlations from two other groups of lads were respectively 0·30 ± 0·16 and 0·20 ± 0·17 for the smiths; 0·35 ± 0·14 and 0·39 ± 0·12 for the electricians. Only one (*i.e.* the last) of these four coefficients is statistically significant. In the case of carpenters, the results showed a large and, at present, unaccountable variation, the correlation of 0·82 ± 0·05 from one group being offset by correlations of 0·14 ± 0·11 and 0·18 ± 0·11 from two others.

In considering these results it is advisable to bear in mind the fact, demonstrated above, that the test does not measure one single factor, but rather a combination of factors. Similarly, the instructors' estimates of trade proficiency are usually made up of a number of components, such as (in fitting) reliability, patience and method. Of these, on our present information, only the factors of dexterity, perception of form, and intelligence enter into the accuracy of the work. Consequently, it is not to be expected that the correlations of such a test with trade proficiency will be consistently so high as those obtained between intelligence tests and school teachers' estimates (and even these vary greatly in magnitude).

The part played by factors such as manual dexterity and the perception of form relations in proficiency in the four trades above mentioned is further illustrated by the average correlation coefficients (shown in Table XX) obtained from the application of these tests to three different groups of apprentices, each group having received about half the prescribed course of training.

TABLE XX

CORRELATIONS BETWEEN PROFICIENCY IN TRADE (AS ESTIMATED BY INSTRUCTOR) AND VARIOUS TESTS

	Mechanical Ability	Intelligence	Form Relations	Manual Dexterity	
Fitter	av. r = 0·42	av. r = 0·03	av. r = 0·33	Assembling nuts and bolts	av. r = 0·31
				Dynamometer	av. r = 0·29
				Wrist twisting	av. r = 0·21
Smith	av. r = 0·25	av. r = −0·09	av. r = 0·21	Assembling nuts and bolts	av. r = −0·43
				Finger dexterity	av. r = −0·38
Carpenter	av. r = 0·16	av. r = 0·17	av. r = 0·28	Finger dexterity	av. r = 0·34
				Assembling nuts and bolts	av. r = 0·29
				Dynamometer	av. r = 0·20
Electrician	av. r = 0·37	av. r = 0·25	av. r = 0·30	Assembling nuts and bolts	av. r = 0·37
				Finger dexterity	av. r = 0·27

None of the tests shows any high correlation with the instructor's estimates, but it is significant that both the Form Relations Test and some of the dexterity tests bear a closer relation to proficiency in these trades than does the intelligence test. It should, therefore, be possible to construct a battery of tests (to include form relations tests and manual dexterity tests) which will give a sufficiently high prediction of practical efficiency for most ordinary purposes. The really important point, however, is that the correlations between the form relations tests and trade proficiency—as also between the dexterity tests and trade proficiency—are of such an order that, combined with the intelligence test, their multiple correlation with trade proficiency would, in general, be roughly equivalent to that actually found between the Mechanical Ability Test and proficiency in the trades. But the weights attaching to the component factors vary considerably from trade to trade, the contribution of the intelligence factor being in some cases negligible.

Hence, so far as these inquiries are concerned, we may conclude that the Mechanical Ability Test possesses a predictive value for certain kinds of work, in which the factors of form relations and manual dexterity are important. But since there are also specific elements in the test which may be different from those involved in the work, its predictive value is not as high as one would like it to be.

It should, however, be pointed out that in judging the predictive value of the test from the data here given, a difficulty arises from employing a test graded to suit the experience of boys of a certain age (14) in order to judge the ability of older boys (16) with more experience of manual and mechanical work. What is needed is either a test or series of tests for boys of different ages, or else a much longer and more elaborate test covering all grades of difficulty and suitable for all ages from 13 upwards.

As to the desirability of eliminating all manual dexterity factors from the tests, the answer seems to depend upon the purpose for which the tests are to be used. If we wish to measure the all-round ' mechanical ability ' of the fitter, manual dexterities cannot be excluded. It is clear that, when a task requires both the mental ability to grasp the problem and the manual skill to carry it out (as all manual trades do), we cannot be content to test solely for the mental factors. But whether we should use a battery of separate tests each dealing with one single factor, or whether we should use complex tests (such as the modified Stenquist test described here), seems to require further examination. If comparatively simple tests can be found which involve the majority of the component factors required in the work under consideration, common sense suggests that they should be employed. But it does not seem easy to obtain such tests, and it looks as though the more satisfactory way, in the long run, will be to get the component factors of an ability clearly identified and to combine tests which give partial measures of these factors (it seems impossible to get complete measures) according to established statistical principles.

From this point of view we should regard the Stenquist type of test as suitable mainly for young and inexperienced boys, and we should endeavour to supplement its results by the use of other tests which give information about the factors entering into it. For older boys, and especially for boys entering particular trades, we should seek tests which more clearly identify the elementary factors. This is what Cox's tests of mechanical aptitude do. They have been very carefully restricted to a particular type of space relation—one which has a definite bearing upon the group of mechanical principles. The group factor ' m ' (which Cox calls ' mechanical aptitude ') is indubitably a ' form relations ' factor similar to that which appears in the results above described. Whether or not it is the *same* factor it is at present impossible to say. But the line of further research is now clearly indicated ; and we may hope that, in due course, the exploration of mechanical aptitude at all stages of development will become an accomplished fact.

Meanwhile, imperfect though the assembling test may be as a single test for predicting success in a manual trade, it has its value in a vocational guidance test programme, especially when its limitations are understood and the factors which influence success in it are known. In using it for such a purpose a boy's performance in it should be compared with his response to other tests (such as the Form Relations Test) in which similar factors enter. If we desire to estimate the boy's ' practical ' abilities from the evidence of such tests, we shall have to proceed in much the same way as we do in dealing with the abstract or ' verbal ' abilities, where scholastic records are compared with the results of intelligence tests of various types and the relative effects of intelligence and of special abilities are estimated. With the information provided by studies of the kind described in this Report, it should be possible to assess the ability of the boy (or girl) for any practical task in which the factors of form relations, manual dexterity, intelligence and the like are known to operate.

V. SUMMARY

Norms

In this Report the results obtained from the use of an assembling test of mechanical ability have been examined. Quartiles, medians and other figures for groups of different age and experience are given for the guidance of those who wish to use this test in practical work (pp. 14–22).

Preliminary Work on a Group Test

A brief account of preliminary work on a test intended for group use has also been included (pp. 7–12). From this account, however, it will be apparent that no test with a small number of items (in each of which the range of marks must of necessity be small) can give a sufficiently precise discrimination even for the rough and approximate purpose of excluding from a more refined examination those who possess little or no abilities of the kind it is desired to measure (pp. 12–14).

Abilities Needed for Success in the Test

It has been shown that success in this test is apparently influenced by at least three factors, viz. the general factor 'g,' a factor of spatial perception (pp. 33–35), and a factor of manual dexterity (pp. 35–37).

Obviously these factors may operate in varying degrees so that the conclusions to be drawn from an individual's success in the test can only be applied in situations which demand (and probably secure from the individual) similar *combined* responses ; they cannot be successfully applied in situations in which one or other of the component factors is disproportionately present. In other words, this Mechanical Ability Test will not have high predictive value in a situation in which the 'g' factor is dominant while the spatial perception and dexterity factors are correspondingly of small importance ; conversely, it will have its highest predictive value when the factors in occupational life are balanced to approximately the same extent as they are in the test.

Relations between Success in the Test and Proficiency in Manual Trades

The connections disclosed between success in this test and proficiency in certain manual trades are given (pp. 37–40). The work of the fitter, which on analysis by observation appears to depend upon all three factors to an approximately equal degree, shows the highest correlation with the test (p. 37). The work of the electrician, on the other hand, when analysed, appears to require less of the dexterity factor but relatively more of the 'g' and the form relations factors. The work of the smith, again, shows a lesser dependence upon the factors in question, while the possession of fine manual dexterities is inversely correlated with success in this trade (p. 38).

Suitability of Test for Use with Apprentices

These results also have a bearing upon the value of the test for use with boys who have had a practical training which has given them facility either in the perception of spatial relations or in the manipulation of objects or both. Although it is possible to establish norms for groups of different experience (as, for example, secondary school boys on the one hand and technical school boys on the other), it would seem desirable to develop special tests for such groups.

General Value of the Tests

The test described in this Report is most suitable for use with boys up to 15 or 16 years of age whose training has not been in any way specialized (pp. 39–40). It may be taken to be of broad diagnostic value in that it gives evidence of ability to deal with a practical situation in which the same factors are similarly combined. This is, in fact, the principal purpose we have required it to serve. But in using it for vocational guidance between the ages of 14 and 16, it should always be considered in its bearing upon practical situations such as arise in different occupations in which the factors of spatial perception and manual dexterity enter. For more refined purposes, indeed, it may be desirable to develop tests which measure these factors separately and to combine the results by weightings appropriate to the actual situation for which prognosis is desired.

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