AN EXPERIMENTAL STUDY OF THE INHERITANCE OF INTELLIGENCE*

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ALTHOUGH the development of factor analysis has led, at least operationally, to more precise description of the field of human cognition, controversy as to the nature of intelligence has not ended, although there has been a marked narrowing of the differences between extremes of view. On the one hand, the monarcheal, or single factor idea, has been superseded by Spearman's two factor theory which has in turn been extended to the consideration of group factors. On the other hand, the multifactorial approach has been narrowed and refined by Thurstonian Multiple Factor Analysis. The primary Mental Abilities described by this method were found to be intercorrelated giving rise to a second order factor which Thurstone has suggested, may be not unlike Spearman's "g". Despite this basic disagreement as to the nature of the variable under consideration, results obtained have led investigators to almost complete agreement that what they have measured as intelligence is largely genetically determined.

However, the problem of determining the effect of inheritance upon the several primary mental abilities has not been reported upon. These abilities would seem to offer the most clear-cut operational definition of intelligence available to date. This question of relative genetic determination of the various primary mental abilities can be encompassed in an experiment framed to yield information central to the problem of whether intelligence is a complex of genetically determined primary abilities which have in common only the correlated effects of environmental additions to their basic form: or whether, like Vernon's group factors v:ed and to a lesser extent k:m, they are the sum of an underlying "g" and a narrower "group" ability which is educable.

Thurstone found his ability measures to be intercorrelated, giving rise to a second order factor. If this second order factor is comparable to Spearman's "g", it would follow that intelligence could be regarded as a core of "g" upon which environmental influences impose a consistent though diverse pressure leading to the relative hyper-development of certain facets of ability.

Under these circumstances, second order factor score estimates should show a greater degree of genetic determination than any single ability score and we may investigate the following hypotheses.

Hypothesis I: The second order factor derived from primary mental abilities test scores is in large part determined by heredity, and such individual differences as appear with respect to it cannot be accounted for in terms of environmental influences.

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Hypothesis II: The second order factor score will be determined by heredity to a greater degree than any of the primary mental ability scores which contribute to it.

The method of twin study used in this investigation is one that has been used in a very large number of previous studies. In this method, differences found between identical twins being due to environment alone, are compared with differences between fraternal twins which are due to heredity and environment combined. Thus, where a marked discrepancy in difference scores is found between groups (identical twins showing less difference than fraternal twins), the influence of heredity is predominant. Where there is little discrepancy in difference scores, inheritance does not function in a causative role.

The twin method was pioneered in the 1883 study by Galton reported in Newman, Freeman and Holzinger (1937). Galton found that twins who were very much alike as children did not tend to become less alike, nor did twins who were unlike as children tend to grow more alike through living together. From this he concluded that environmental effects produce little change in physical and mental make-up which must, therefore, be mainly inherited.

Thorndike (1905) used an interesting method in carrying out the first twin study to employ psychological tests of the modern sort. These were tests which, on *a priori* grounds, opposed tasks which would be little modified by educational background and learning, to those in which learning played a major part. Finding no closer similarity in the latter than in the former, he concluded that the observed similarities were due to inheritance.

By 1924, Merriman (1924) was able to use standardized tests such as the Stanford Binet Scale and the Army Beta. He found much greater similarity between like-sexed twins than between unlike-sexed twins; results which were later confirmed by Wingfield (1928) and Hirsch (1930) in similar studies.

Further studies by Tallman (1928), Holzinger (1929), Herman and Hogben (1933), Byrns (1934) and Newman, Freeman and Holzinger (1937) have established that the level of correlation between intelligence test scores of identical twins is generally above ·90, whereas correlations for fraternal pairs tend to be lower, ranging upwards from ·50 (Hirsch, 1930; Merriman, 1924; Newman, Freeman and Holzinger, 1937; Wingfield, 1928; Eysenck and Prell, 1951).

Although in the reported studies many tests of general intelligence have been used and their scores have been shown to be affected by inheritance, no presently published study has gone a step further and sought information regarding the degree of inheritance of general intelligence as defined by factor scores. Another unanswered problem arises in connection with the relative genetic determination of scores on the Primary Mental Abilities Test. These scores are intended by Thurstone to represent factor scores and have been used as such in this investigation.

This emphasis on the use of factor scores rather than individual test scores is considered essential in view of a criticism brought forth by Eysenck and Prell (1951). It seems requisite to discuss this criticism which bears upon twin studies of intelligence. They state: "Unless we can analyse the total variance of a test into its constituent parts, and measure these parts separately, no scientifically tenable conclusion can be drawn from the data."

They draw this conclusion by pointing out that the total variance of a test comprises general factor variance, group and specific factor variance and error variance. Assuming that more or less equal proportions of the variance are due on the one hand to the general factor variance, and on the other hand to group and specific factor variance (error variance being disregarded), it follows that

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equally high inter-twin coefficients could result either if the general factor alone is completely determined by inheritance; if the group and specific factors alone are completely so determined or if both are genetically determined to an intermediate degree.

By the use of factor scores and scores from the P.M.A. "factor" tests in this study, the above difficulty is avoided.

The sample was drawn from four Metropolitan Boroughs in South London. This was done with the co-operation of the London County Council, who wrote to Headmasters of all the L.C.C. Secondary Schools in the Boroughs of Camberwell, Southwark, Lambeth and Lewisham, requesting a report of any twins on their registers.

In this way 102 pairs of twins were located. The parents of 87 of these pairs were contacted by letter requesting permission to test the twins at the Maudsley Hospital. Permission was granted by the parents in the case of 59 pairs, from which group 56 pairs were subsequently tested. Data concerning the age, sex and ovularity of this group are summarized in Table I.

TABLE I

Age distribution, zygosity and sex of the experimental group

	Number of Cases			
	Female		Male	
Age in Months	Identical	Fraternal	Identical	Fraternal
140–149	1	1	1	0
150–159	3	2	3	1
160–169	4	4	3	8
170–179	4	3	4	4
180–189	1	3	2	0
Mean age	165·3	167·8	166·8	166·8
Standard deviation	11·8	11·1	12·1	6·7

The circumstances relating to the failure to test the 50 pairs not included in this study are presented in Table II.

TABLE II

Twins referred but not included in Experimental Group showing sex, zygosity and reason for non-inclusion

	Female			Male			
	Ident.	Frat.	?	Ident.	Frat.	?	Total
Refused	0	5	1	1	2	0	9
Did not answer letter of request	1	1	0	1	3	0	6
Left school before testing ..	3	2	0	3	3	2	13
Not approached as sample complete	3	0	0	0	5	0	8
Accepted but not tested as sample complete	3	0	0	0	0	0	3
Tested but not included ..	4	0	0	0	0	0	4
Too young	2	1	1	0	1	0	5
Non-English speaking ..	0	0	1	0	0	0	1
One twin mentally defective	0	0	0	0	1	0	1
Total	16	9	3	5	15	2	50

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There were 9 cases in which permission to test the twins was directly refused. There appears to be very little evidence in the present study for assuming that some common element determined these refusals and thus introduced a consistent bias.

Four pairs of identical girls were tested, whose results were not included as it was decided to include 13 pairs in each group. One of these four pairs was left out because testing was not completed, and the other three pairs were drawn out of the sample on a random basis.

One pair of girls were not approached because they could not speak English. Another pair, fraternal boys in this case, were not used because one of the twins was mentally defective. Leaving this pair out of the sample has undoubtedly reduced the intra-fraternal differences in intelligence which will be found. However, the tests were inadequate to deal with such a case and useful data could not have been obtained from a mental defect with the experimental battery.

The method of sampling through the schools has been criticized (Anastasi and Foley, 1949) as being subject to selective error. The selective factor here leads to an over-estimation of the closeness of relationship between results obtained by fraternal twins. This comes about since the twins most likely to be overlooked by the teachers are those fraternal twins who are quite dissimilar in appearance and behaviour.

A rough check on the adequacy of the sampling can be made by comparing the number of binovular and uniovular twins reported. Census figures indicate that some 65 per cent. of all twins are of the same sex. Since all unlike sexed twins are binovular, it follows that 35 per cent. of twins are unlike sexed binovulars. Assuming equal distribution of sex among binovular twins, 35 per cent. of twins will be like sexed binovulars. In our sample we dealt only with like sexed twins, so that the expected ratio of referrals would be 35 fraternal twins to 30 identical twins. From this we can determine the probability of a statistically significant sampling error. Of the 102 cases referred, ovularity was not established in five cases. There remain 50 pairs of fraternal twins and 47 pairs of identical twins, that is 48 per cent. of those referred are identical and 52 per cent. are fraternal. The expected frequency would be 46 per cent. identical and 54 per cent. fraternal. The χ^2 in this case is ·16 and P greater than ·50. The difference is clearly not significant.

However, this is a crude check and although the difference is not statistically significant, selection could still have a psychological effect in that very few extreme cases need be missed to produce unrepresentative results. Let us therefore consider the possible consequences of missing such extreme cases. To the extent that such a sampling bias is operative in this study, its tendency is to bring about a reduction in the difference between intra-fraternal and intra-identical correlations. The nature of the hypotheses is such that this error, if present can in no way contribute to their support.

However, when a sampling error exists it is helpful to know how great an effect it could be exerting on the data. A hypothetical model which will enable us to estimate its maximum possible effect, can be set up as follows:

Let us assume that we have obtained maximum correlation between pairs of twins in our sample.

We then discover that only 80 per cent. of the sample has been tested. Assuming more or less equal variance in the tested and non-tested groups, the maximum error that could result from this omission would occur when no correlation whatsoever existed between pairs in the 20 per cent. of the group

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which was not tested, negative correlation being ruled out on the grounds that positive correlations are to be expected between twins in intelligence and personality scores.

Using the formula $r = \sqrt{\frac{\text{predictable variance}}{\text{total variance}}}$

we can calculate the variance which could be predicted had the entire sample been tested.

Thus, r (corrected) $= \sqrt{\frac{\text{percentage of sample tested. } r^2 \text{ (obtained)}}{\text{total variance}}}$

In the hypothesized case r (corrected) $= \sqrt{\frac{80 \times 1 \cdot 00^2}{100}}$

$\sqrt{\cdot 80}$

$\cdot 89$

Thus, allowing for the maximum error attributable to the error of missing 20 per cent. of the sample in the hypothesized situation, we would effect a decrease in the value of r from 1·00 to ·89.

To apply this formula to the experimental sample of fraternal twins, we must estimate the number of twins missed by the schools. In the L.C.C. schools the possibility that twins could attend the same school and not be known as twins is extremely remote. Rather the oversight occurs when the twins are in attendance at different schools. Of the 102 pairs located, there were 12 pairs in which the twins were separated and registered in different schools. Of these, there were 8 pairs in which both twins were registered at schools in the area covered.

From these 8 pairs we can get an estimate of the number of fraternal twins missed by sampling through the schools.

Of the 8 pairs, 4 were, as they should have been, reported by both of the schools concerned. The other 4 were reported by one school only. Thus, of the 16 individuals involved only 12 or 75 per cent. were reported.

Although if each school reports 75 per cent. of its cases, and only one school need give notification for the pair to be located, so that the mathematical probability of non-notification is only 1:16; from a psychological point of view, the circumstances which render one school unaware that a student has a twin, have a greater than chance probability of also being operative in the case of his or her twin. For this reason paired missing would tend to occur, both of the pair being missed because their twinship was less evident than that of the other pairs. For this reason we must adopt the maximum figure of 25 per cent. since those unreported may all constitute pairs of twins.

From this we can estimate that instead of the 12 divided pairs reported we should have received notification of 16 pairs. In other words, had we been notified in all cases, 54 pairs of fraternal twins would have been listed.

The maximum reduction of the intra-fraternal correlations which could have resulted from the inclusion of the omitted cases can now be determined by the previously outlined formula to be ·04.

One further source of error in twin studies is pointed out by Anastasi and Foley (1949). This is the mis-diagnosis of pairs of fraternal twins who are extremely alike, as identical. This results in a dilution of the identical sample and tends to decrease the differences between intra-identical and intra-fraternal correlations. Here also the error, if present, would tend to work against the considerations lending support to the hypotheses.

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The criteria used in this study to differentiate between identical and fraternal pairs of twins were the following:

1. Facial features.
2. General habitus.
3. Hair colour and distribution.
4. Iris pigmentation.
5. Shape of ears.
6. Teeth.
7. Standing height.
8. Weight.
9. Ability to taste Phenyl-thio-carbamide.
10. Blood groupings.
11. Fingerprints.

For criteria 1 to 6, a three-point rating scale of closeness of similarity such as that used by Eysenck and Prell (1951) was utilized. Criteria 7 and 8 were straightforward measures in inches and pounds. For the tasting test with phenyl-thio-carbamide the subject was handed two test tubes, one filled with water and the other with a 1 in 20,000 solution of P.T.C. He was asked to describe any difference in the taste of the two liquids. Blood grouping was done at the Lister Institute by Race and Sanger who have demonstrated (1950) how to estimate, on the basis of parental blood groupings, the probability that same sexed twins with the same blood groups are dizygotic. Fingerprint analysis was carried out by the Genetics Department of the Maudsley Hospital, using the complex Discriminant Function Score developed by Slater. Reports giving the probability of binovularity in each pair were returned.

Twin identification was carried on for criteria 1 to 6 by three judges who made independent assessments.

In the sample generally, there was little difficulty in distinguishing between fraternal and identical twins. The fraternal pairs, with one exception, were quite obviously unlike in appearance, and even in the much more difficult task of determining identicality, pronounced doubt was present in only one case. Thus on the basis of appearance alone only two cases offered serious difficulty in diagnosis. These two difficult pairs were readily classified on the basis of taste reactions to phenyl-thio-carbamide, blood groupings and fingerprints.

It is interesting to contrast this with the more objective measures provided by blood groupings and fingerprint analysis.

While all pairs identical in appearance had the same blood types, it was found that three pairs, classified by appearance, taste reaction to P.T.C. and fingerprints as fraternal also had homogeneous blood groupings. It transpired that this was a result of the marked similarity between the blood groups of the parents.

On the basis of fingerprint analysis Nixon reports a mis-classification of 13 per cent. of the identical pairs and 42 per cent. of the fraternal pairs and overlapping in 60·7 per cent. of the cases. He points out that the very low probability of obtaining so high a mis-classification of fraternal pairs using Slater's discriminant function, indicates that this particular sample of fraternal twins is atypically similar as regards fingerprints.

In summary, it seems that the best method of differentiating between identical and fraternal twins is to make use of several indices, for in cases in which one index fails there is most frequently unanimous agreement among the other measures.

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The intelligence tests used were the Thurstone's Chicago tests for the Primary Mental Abilities for ages 11–17, and the Nufferno Tests of Intellectual Level and Intellectual Speed. The twins were tested in pairs at the Maudsley Hospital and tests of intelligence were administered in the above order. In all cases the tests were administered in early afternoon.

The P.M.A. Tests are in such general usage that it would serve no purpose to describe them here. The directions given in the Revised Manual (1949) were followed in administration and Thurstone's scoring methods were used.

The Nufferno Tests are as yet unpublished and a brief discussion of their rationale and general form might be useful at this point. The tests are devised to take into account the generally neglected fact that in attempting any problem a person may derive a correct answer, a wrong answer, or no answer at all. Since most intelligence tests are scored in terms of correct answers returned in given period, they yield composite scores involving these three types of behaviour in amounts which vary between individuals. To assess intellectual speed properly, time spent in arriving at unscorable solutions (i.e., incorrectly answered or abandoned items) must not be taken into account. Accordingly, the Speed Test was so devised as to give scores involving only time spent in producing correct answers.

The test is made up of letter series items such as those used in the Reasoning test of the P.M.A. battery, found to be of equal difficulty, that is items passed by the same percentage of standardizing groups. They are relatively easy having been passed by 80 per cent. of that group. Stress is laid on speed not only in the instruction when the subject is told to work as quickly as he can, but also when, at a signal given every twenty seconds, he circles the last item he has completed.

In scoring, intervals during which wrong answers have been returned are disregarded. The score is the average of the logarithm of the time in seconds taken to solve each item, this score being used because solution time was found to increase disproportionately to item difficulty, whereas the relationship between log time and item difficulty was found to be linear. The score so derived appears to be a unidimensional measure of intellectual speed, being independent of level (for at least the top 80 per cent. of the population) since the test items are of equal difficulty and being purified of the effects of time spent in obtaining unscorable answers.

The Power or Level test is made up of letter series problems in cyclical order of difficulty. The usual time limit is thirty minutes, the subject being told that he has ample time for the test and that the examination is to determine not how quickly he can work but rather, how difficult a problem he can solve. He is accordingly instructed to try as hard as possible to complete each item as he comes to it and to leave no problem undone until he is certain that he cannot answer it. In the present study the length of the battery limited the time available for the test to 20 minutes.

Speed does not effect the score to the degree that it does scores in most intelligence tests since a subject can obtain as high a score by completing only the first section of ten items as by attempting all of the fifty items in the five sections of the test. Beyond the first set of items the cycles attempted only increase the reliability of the estimate of intellectual level, as the score is the average number of items correctly completed in the sections attempted.

This score is regarded by Furneaux (1953) and by Eysenck (1953) as a composite one including, as well as a measure of intellectual level, an element of persistence, enhanced by the fact that time necessary to complete problems correctly increases markedly as item difficulty is increased. However, the test is

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no more at fault in this regard than other intelligence tests, and would appear to be a much better measure of level than any speeded test.

Results

Age was found to correlate with the verbal fluency and total scores of the P.M.A., while bi-serial correlations were found between sex and the Furneaux level tests, the P.M.A. Number, Fluency, Space, and Reasoning Scales. Age and sex were therefore partialled out of the matrix using Garrett (1947), Formula 87.

$$r12 \cdot 3 = \frac{r12 - r13\ r23}{\sqrt{1 - r^2 13}\quad\sqrt{1 - r^2 23}}$$

The correlations given in Table III are thus independent of age and sex.

Table III

Intercorrelations of the Intelligence Scores

	1	2	3	4	5	6	7
1. P.M.A. Verbal							
2. P.M.A. Number	·411						
3. P.M.A. Space ..	·396	·225					
4. P.M.A. Reason ..	·496	·425	·515				
5. P.M.A. Fluency	·583	·401	·225	·490			
6. P.M.A. Total ..	·741	·689	·617	·813	·734		
7. Furneaux Level ..	·348	·297	·490	·691	·286	·597	
8. Furneaux Speed	·369	·204	·232	·411	·352	·440	·269

These P.M.A. sub-tests (factor) and total scores were included, with the Nufferno Tests of Intellectual Level and Intellectual Speed in an inter-correlation matrix of 20 variables. Twelve of the variables in this matrix were measures of personality and are irrelevant to this discussion.

The total score included for the P.M.A. test was calculated according to the formula V+S+2N+2R+W in keeping with the practice outlined by Thurstone in the Test Manual (1949). The intercorrelations between the sub-test scores and this total score are spuriously high. The coefficients are Verbal ·734; Number ·689; Space ·617; Reasoning ·813; and Fluency ·734.

The total score was included to give a point of rotation for the intelligence factor. By such a procedure intelligence has been defined for this study as the Primary Mental Abilities total score as calculated in the above formula.

The Thurstone method of analysis as demonstrated in Thurstone (1947) was used and four factors were extracted.

The first centroid was clearly of a cognitive nature. It accounted for 20 per cent. of the variance. The loadings of the intelligence tests on this centroid were Verbal ·752; Number ·544; Space ·514; Reasoning ·704; Fluency ·675; Total ·902; Furneaux Level ·583; and Furneaux Speed ·486.

The second centroid which took up 6 per cent. of the variance appeared to be an autonomic factor loading on physiological measures.

The third factor accounting for 5 per cent. of the variance appeared to be a factor of general emotionality (neuroticism). No attempt was made to identify the fourth factor extracted, which accounted for some 3 per cent. of the variance and left insignificant residuals.

The first factor was rotated through the P.M.A. total score criterion. The positions of the remaining three factors were determined by rotating for simple structure. Six rotations were needed. The centroid and rotated factor loadings of the intelligence tests are given in Table IV.

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TABLE IV

Centroid and Rotated Factor Loadings

	Centroid Loadings				Rotated Factor Loadings			
	F_1	F_2	F_3	F_4	F'_1	F'_2	F'_3	F'_4
1. P.M.A. Verbal	·752	·12	·08	−·18	·681	−·10	·24	−·22
2. P.M.A. Number	·544	·13	−·19	−·28	·608	−·02	−·09	−·14
3. P.M.A. Space	·514	·29	−·14	−·09	·573	·13	·07	−·01
4. P.M.A. Reason	·704	·34	−·40	·19	·781	·11	·08	·35
5. P.M.A. Fluency	·675	−·07	−·14	−·14	·630	−·25	·04	−·07
6. P.M.A. Total	·902	·27	−·33	−·17	·971	·00	·01	·01
7. Nufferno Level	·583	·24	−·28	·19	·614	·04	·11	·29
8. Nufferno Speed	·486	·18	·10	·21	·393	·01	·37	·10

Factor scores were computed in accordance with Lubin and Summerfield's (1951) square root method.

To compute intelligence factor scores, all of the intelligence test scores were used except the total score which had been used as a criterion of rotation for the intelligence factor. The Beta weightings derived for the tests used were: Reasoning ·313; Number ·241; Verbal ·208; Fluency ·186; Space ·177; Power ·114; and Speed ·001.

CONCLUSIONS

The first of the hypotheses is supported by the data to the extent that when the test scores are weighted in accordance with the second order loadings reported by the Thurstone's (1941), the intra-identical correlation for the weighted total score is ·754, whereas that for the fraternal sample is ·394 giving rise to an h^2 of ·594. When the scores are weighted on the basis of the regression equation derived from the factor loadings of the present analysis, the total score so obtained, has an intra-identical correlation of ·732 and an intra-fraternal correlation of ·406 and an h^2 value of ·549.

These h^2 values are lower than one would anticipate in the case of cognitive tests. However, as Eysenck and Prell (1951) point out, more reliance can be placed on the correlation coefficients than upon the h^2 statistic. According to Newman, Freeman and Holzinger (1937), the distribution of h^2 is very probably not normal. For this reason, it is not possible to assess the significance of differences between values of h^2. This fact makes it difficult to assess the evidence regarding the second hypothesis.

The class intercorrelations and the h^2 values for the P.M.A. tests and for the total and factor scores are given in Table V.

The fact that the h^2 values for all the total scores are considerably lower than those for the Verbal, Reasoning and Fluency test scores may be interpreted as support for the view that these abilities are determined to a greater extent by heredity than is the general factor to which they give rise. These results would indicate that in the tests having higher h^2 values than the total scores, group or specific factor variance as well as that contributing to the general factor is determined by inheritance.

A case can, however, be presented for the contention that the total and factor scores are more determined by inheritance than are the sub-scores.

As has been stated, the significance of the difference between values of h^2 cannot be determined, so that the differences found cannot be considered conclusive invalidation of the hypothesis.

Further, it will be noted that there is a very close correspondence in the rank order between the size of the h^2 for each of the tests and the size of the

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TABLE V

Factor Saturations, h^2 Values and Beta Weights for Intelligence Tests

	Rotated Factor Saturations	Thurstone's 2nd Order Factor Saturations	Intra-Identical Correlation	Intra-Fraternal Correlation	h^2 Value	Beta Weights
Intelligence Factor Scores	—	—	·764	·443	·576	—
Verbal	·681	·715	·726	·145	·680	·208
Space	·573	·502	·630	·248	·508	·177
Number ..	·608	·399	·489	·449	·073	·241
Reason ..	·781	·630	·708	·188	·640	·313
Fluency ..	·630	·615	·734	·257	·642	·186
Total A* ..	·971	—	·583	·369	·339	—
Total B† ..	—	—	·754	·394	·594	—
Total C‡ ..	—	—	·732	·406	·549	—
Furneaux Speed	·393	—	·134	·372	—	·001
Furneaux Level	·614	—	·640	·309	·479	·114

* P.M.A. Total Score from formula V+S+2N+2R+W.

† P.M.A. Total Score calculated on the basis of the square of Thurstone's second order factor loadings.

‡ P.M.A. Total Score calculated on the basis of weights derived from the Experimental Group.

loading which Thurstone (1947) found the tests to have on the second order factor of intelligence.

It would seem to follow from this that since the tests showing the highest degree of genetic determination are contributing most heavily to the factor scores, the factor scores themselves should show a more pronounced degree of genetic determination than the contributing sub-test scores. In other words, it would seem that a total score weighted on the basis of these second order factor loadings would have a very high probability of producing an h^2 value in excess of the h^2 for any of the contributing tests. That such was not the case in this study may be due to the unreliability of the h^2 statistic. Another possibility is that error producing unreliability is not equally distributed as between the fraternal and identical samples. In this connection, the greater reliability attendant upon the increased number of items comprising total scores as opposed to sub-scores does not appear to affect the identical and fraternal correlation coefficients equally. Whereas the intra-identical correlations are not much enhanced, intra-fraternal coefficients are markedly increased.

In any case, aside from these considerations, it may be pointed out that the inter-identical correlations are higher for the weighted total scores than for any of the Primary Mental Abilities test scores. That this is not simply a reflection of increased reliability due to an increase in the number of test items is strongly suggested by the fact that intra-identical correlations for the total score calculated on the V+S+2R+2N+W formula is lower than are the coefficients for four of the Primary Mental Abilities Tests.

However, although evidence can be cited in favour of the hypothesis, it cannot, in view of the obtained values of h^2, be considered to have been established and the conclusion must be drawn that hypothesis two has not been supported.

Certain of the findings merit further consideration. The fact that Verbal Comprehension and Word Fluency Tests are found to be determined by inheritance to a larger extent than the other tests, would seem to call into question Vernon's (1950) suggestion that the principal group factor in intelli-

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gence, v:ed, is a verbal factor which is developed by education. It is also contradictory to Thurstone's (1947) view: "The growth of Verbal Comprehension is difficult to appraise because the estimation of this factor is more influenced by schooling and experience than some of the other primary factors."

The findings of the present study indicate that the Number, and to a lesser extent, the Spatial Factor, would be more readily educable than verbal or reasoning ability. One might speculate on this basis that good General Arts students, relying as they do on facility with verbal material, are born; whereas the mathematicians, statisticians, engineers and so forth must toil to earn their skills. Herein, too, may lie the stimulus of the avoidance reaction which statistical courses frequently evoke in the devotees of Psyche.

The relationship of the Furneaux Speed Test to the other tests in the battery is interesting. The speed and level tests yielded intra-identical correlations of ·134 and ·640 respectively, and intra-fraternal correlations of ·372 and ·309. The h^2 value for the Level Test is ·479 while that for the Speed Test would come out as a meaningless, negative value. This is apparently due to error. There is some restriction of variance in the scores of the identical sample on the speed test, but the F ratio between the variance for the identical and fraternal samples is not significant even at the ·10 level.

It appears that the speed test insofar as it is a measure of level for the age group tested does correlate with the tests of intelligence. However, when factor scores are calculated, it is found to contribute nothing toward the prediction of the weighted scores so that the factor scores are independent of speed.

The results indicate that very little, if any of the individual differences in speed, as measured by the test are due to inheritance.

Summary

The Primary Mental Abilities Tests and the Furneaux Test of Intellectual Level and Intellectual Speed were administered to a group of 52 pairs of like-sexed twins between the ages of 12 and 15 years. The sample was evenly divided in terms of sex and zygosity. Test results were intercorrelated and the factor analysis was carried out using the Thurstone method. The first factor, accounting for 20 per cent. of the variance, was identified as an intelligence factor.

Factor scores were determined on the basis of the regression equation. h^2 values were calculated for these factor scores.

The first of the hypotheses put forward in regard to intelligence was supported by the data. The total score for the Thurstone Primary Mental Abilities Tests weighted in accordance with the factor loadings of the tests on Thurstone's second order factor and the total score weighted on the basis of the present analysis give h^2 values of ·594 and ·549 respectively. In each case the intra-identical correlation exceeds the intra-fraternal correlation, the difference being significant beyond the ·01 level of confidence.

The second hypothesis stated that the total score would be determined in larger part by inheritance than would any of the individual Primary Mental Abilities scores. The data did not support this hypothesis since the h^2 values of three of the Primary Mental Abilities tests—Verbal Comprehension, Space and Reasoning—exceeded those of the total scores.

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