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PRIMARY MENTAL ABILITIES OR GENERAL INTELLIGENCE? EVIDENCE FROM TWIN STUDIES

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I FEEL deeply honoured to have been invited to contribute to this Symposium. In my University lectures on individual differences, I always devote time to a discussion of Galton. I do not know whether Galton personally started the Eugenics Society; but at any rate he was a direct forerunner of those of us who are interested in the study of hereditary factors in human behaviour and their evolutionary history. This is true, even though our ideas about innate superiority and the importance of the environment have changed drastically in the last fifty years.

I want to acknowledge my debt to many friends and colleagues who repeatedly have allowed me to use their data, and to my assistants and co-workers. I am grateful to the US National Institutes of Health and the National Science Foundation for support of my research. All the serological tests of the twins' blood have been performed by Mrs. Jane Swanson of the Minneapolis War Memorial Blood Bank. Table I shows the tests we use, which provide 95 per cent

TABLE I

GENETIC MARKERS USED TO DETERMINE ZYGOSITY

ALWAYS USED	NOT ALWAYS USED	
A_1A_2BO	Mt^a	Martin
MNSs	Mi^a	Miltenberger
Rhesus tests CcDEe (Rh factor)	P_1	
Lutheran a and b	C^w	
Lewis a and b	Wr^a	Wright
Kell K	Vw	Verweyst
Cellano k	Yt	Cartwright
Kidd (Jk^a)	Do^a	Dombrock
Duffy (Fy^a)		

accuracy in diagnosing zygosity, which is sufficient, in view of the fact that many of the measures we study are considerably less accurate.

Before we delve into the topic, we may avoid unnecessary disagreement if we state clearly at the outset some issues that will *not* be discussed. We will talk about *hereditary* components of *human abilities*. In other words, there will be no reference in this paper to animal research and what it shows about behaviour genetics, nor to human personality, even though personality affects ability measures enormously, as, for instance, Professor Eysenck [5] has shown for introversion-extraversion and performance on learning tasks.

Most importantly I will not enter into the old controversy, as to whether it is more truthful or more useful to speak of intelligence in terms of a general factor plus some specific factors found in tests not measuring this general factor well, or whether the view is more apt that there are a number of separate abilities, some of which are perhaps somewhat correlated.

I suspect that most British psychologists hold the first view and many American ones the second, because of differences in the homogeneity of the samples of persons studied.

In the United States one encounters a wide variety of students and some of them may have reached the University in spite of marked shortcomings in certain of their high school studies. It is my impression that in the United Kingdom, as on the Continent, more than in the USA, most high school pupils bound for college or university are required to meet certain standards in all subjects before they are allowed to pass on. This alone could account for the controversy. The need for more cross-cultural validation studies happens to be one of my pet themes. A few studies in the United Kingdom and in the United States on similar subjects, using the same test battery, might lead to disappearance of the controversy. In any case, it will eventually be the power to predict success in some endeavour that will be the crucial test of the social usefulness of the competing views. Unfortunately, there have been few studies of Guilford's factors, which form the most extreme expression of the multi-factorial theory of intelligence.

Now that the issues that will *not* be considered are stated, what will I discuss? Regardless of the position one takes in the controversy between those who favour a general factor in intelligence and those who favour the multi-factor views, one can be uncommitted about the dimensions of the hereditary contribution to ability measures.

This is the question in which I have become interested. Are there specific hereditary disabilities or talents? It is generally accepted that the inheritance of intelligence must be controlled by a large number of loci, but how many we do not know. Several facts lead us to expect many. First of all there is the fact that the IQ seems to follow closely a normal distribution. This strongly suggests that many loci are involved, although Professor Thoday has shown that normal distributions may occur even when the number of genes segregating is quite limited.[10] Secondly, we know of a large number of genetic anomalies which all affect intelligence adversely. This alone is proof that many genes are involved in the normal development of intelligence. Could it be that the same or similar genes also control the *variations* in ability levels in the normal range? With perhaps the greater ability the fewer harmful genes? Or are there separate loci for superior ability? Inherent in this idea is the view of intelligence as a unitary trait and of the more or less equal value of the genes controlling intelligence.

What if certain abilities were dependent in part on one or a few alleles at separate loci? One can readily think of some extreme examples of disabilities which do not really fall within the problem under discussion, but which help to focus our thinking. For instance, hereditary deafness would prevent development of musical skills, a crippling condition of athletic prowess, and blindness the appearance of certain mathematical or artistic skills. But what about less drastic limitations, and what of special gifts?

Could there be separate hereditary factors in ability, each due to one or more loci, for language skills such as reading, spelling and the learning of foreign languages, or for arithmetic, algebra and some other forms of mathematics, or for the ability to visualize two- and three-dimensional patterns? I believe that this possibility is subscribed to in a vague sort of way by many of us as the correct view.

We can approach this problem from two directions: one method is rather time-consuming, the other is a more economical short-cut. The first method consists of locating clear examples of persons deficient in only one of the basic skills such as reading,

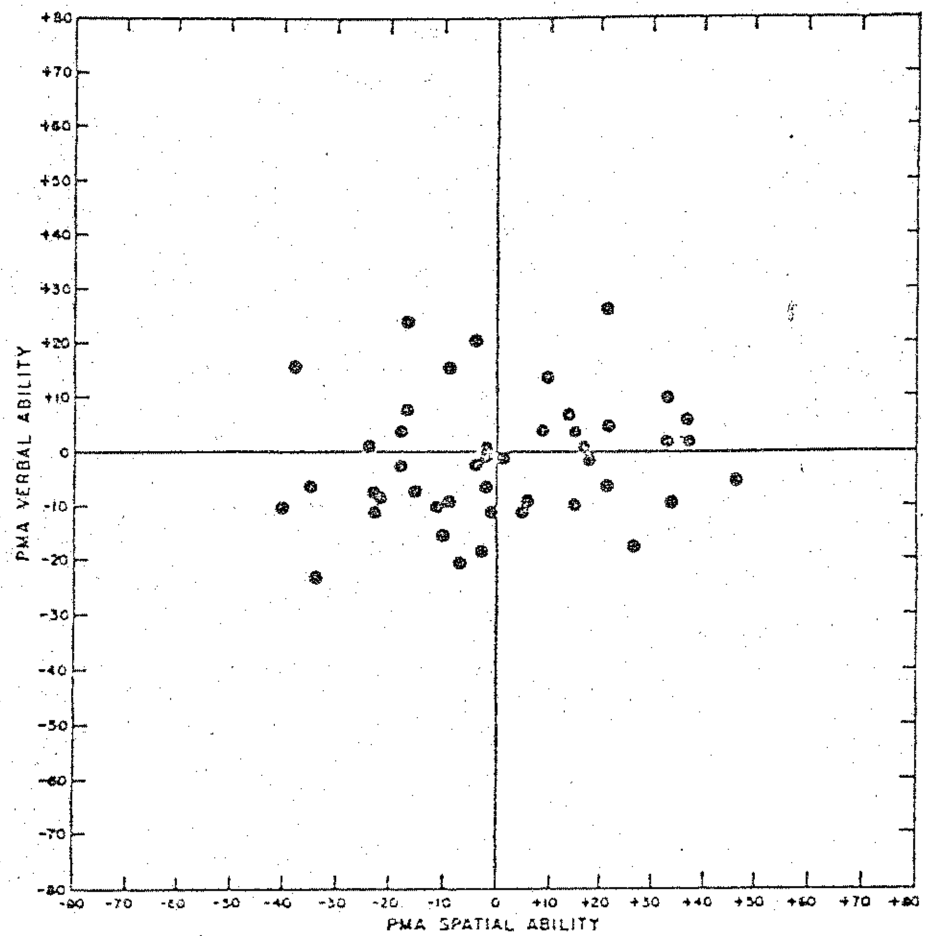


FIGURE 1

CORRELATION BETWEEN MZ TWIN DIFFERENCES IN SPATIAL AND IN VERBAL ABILITY. $N = 45$ $r = \cdot 137$

arithmetic or spatial visualization and collecting information about their relatives to see if this is a genetic deficiency and whether it is specific or whether it affects other abilities. One might even start with individuals with a specific syndrome such as Down's, Klinefelter's, Turner's, etc. If these individuals do indeed show specific psychological deficiencies, we would be able to locate the responsible gene on a specific chromosome.

This clinical approach is of course the preferred method in human genetics. It presupposes, however, that we know fairly well what to look for. It also requires that post-traumatic brain damage can be ruled out, something of which we cannot always be sure.

The second method, which *I* have mainly used, is a modification and expansion of the traditional twin method to the multivariate case.

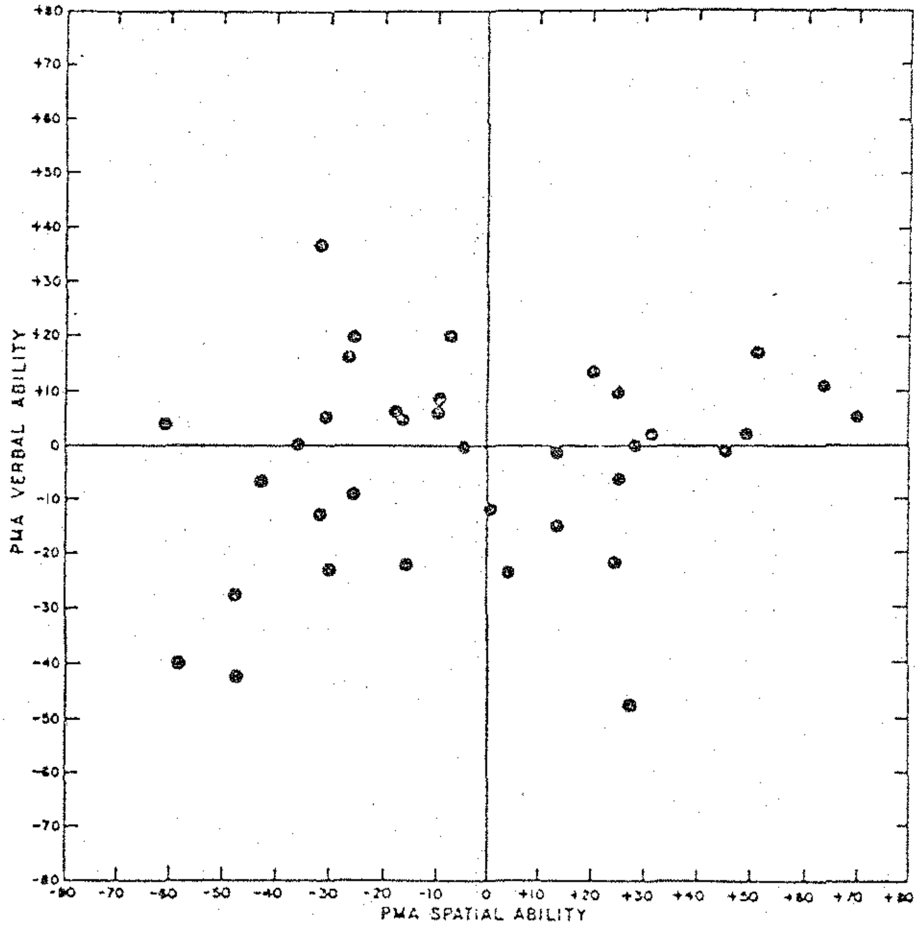


FIGURE 2

CORRELATION BETWEEN DZ TWIN DIFFERENCES IN SPATIAL AND IN VERBAL ABILITY. $N = 37$ $r = \cdot 215$

In essence we are going to ask whether the twin John does better than his brother James on *all* ability tests, as he would if there is one set of genes that affects all abilities, assuming of course that specific environmental influences on different abilities are not too important. Figures 1 and 2 show that the same twin does not always score higher on various tests. If he did, there would only be entries around the leading diagonal, i.e. in the lower and left upper right quadrants. Actually, we have to be more precise. We know now that there are two kinds of twins. Identical pairs are the result of the splitting of one fertilized egg and therefore have the same genes, while fraternal pairs result from the fertilization of two separate eggs by separate spermatozoa, so that half of their genes, on the average, will be different.

Differences between identical twins reared together will not tell us much, except about intrafamily influences. Fraternal twins *will* give us some information. In fact, if we can assume that the influences within the family are on the average equally important in producing identical and fraternal twin differences, we can take a step further. This step consists of comparing the identical and fraternal twin differences, or rather the variances of these two sets of differences, as well as the covariances of differences on different abilities. In other words, we can make a generalization to the multivariate case of the traditional evaluation for evidence of heredity of a variable by the twin method. This means that all the statistical techniques used in twin studies of a single trait can be considered for application in the multivariate situation.

I mentioned earlier the assumption of similar within-family conditions for identical and fraternal twins. I have elsewhere reviewed the objections to this assumption [13] and the sparse evidence and have concluded that the assumption may be more valid than has been supposed by romantic theories of special twin interactions. These, I believe, are derived from biased psychiatric material which is really quite rare and unrepresentative.

In choosing a statistical method, I have preferred the one which has a test of statistical significance. This method is less easily misinterpreted, and also can be generalized to the multivariate case in a more rigorous way. I am speaking of the F test between the fraternal and identical within-pair variance. In addition this method allows further partitioning of the variance, for instance, between sexes, between trials, between alternate versions of the questionnaire, or ability measure, and so on. It will be convenient to use the conventional abbreviations: MZ for monozygotic or one-egg (identical) twins and DZ for dizygotic or two-egg (fraternal) twins. Using these symbols, the formula for the F test is:

$$F = \sigma_W^2 \, DZ/\sigma_W^2 \, MZ, \tag{1}$$

where the within-pair variance of the twins

$$\sigma_W^2 = 1/N \sum_{i=1}^{N} (X_{iA} - X_{iB})^2 \tag{2}$$

and where A and B are twins.

If we rewrite equation (1)

$$\sigma_W^2 \, DZ - F\sigma_W^2 \, MZ = 0, \tag{3}$$

we can generalize this to

$$[\, C_{DZ} - \Lambda \, C_{MZ} \,] = 0, \tag{4}$$

where C is the within-pair variance-covariance matrix, or, more simply, the matrix of the cross products of the twin differences on the different variables divided by N.

A typical element of C would be

$$c_{XY} = 1/N \sum (X_{iA} - X_{iB}) \; (Y_{iA} - Y_{iB}) \tag{5}$$

Equation (4) is a canonical equation for which, fortunately, computer routines are available. There are several ways of interpreting this equation. Let me only say here that we find first *that* linear combination of the variables which leads to the best discrimination of MZ and DZ twins. This will be one hereditary component. After removing this composite we ask whether another linear combination still allows us to separate the two kinds of twins. This would be another independent hereditary component; and so we continue, as long as the significance test indicates that another root of the equation may be interpreted.

Originally[12] I used a significance test for the homogeneity of the remaining *r-k* roots after extraction of the first *k* roots.[1] This is a test for symmetric matrices only, but I knew of no better procedure. Since that time Professor Bock has called to my attention another significance test designed by Bartlett [2] which is the proper one to use in this situation.[3]

The first time this multivariate analysis was applied was with data on high school students from the Michigan twin study on 45 pairs of identical and 37 pairs of fraternal twins. The variables were the six scores of Thurstone's Primary Mental Abilities test: Verbal, Number, Spatial Visualization, Word fluency, Reasoning and Memory. The first four of these six abilities had a significant hereditary component.[11] Was this hereditary component the same for these tests and the the lack of correlation between the tests due only to environmental influences? The solution of the canonical equation is shown in Table II. Of the six roots, three were significant, even for this rather small sample. If a rotation of the axes

TABLE II

SOLUTION OF $| C_{DZ} - \Lambda C_{MZ} | = 0$ FOR THE 6 PMA SCORES OF 37 FRATERNAL (DZ) AND 45 IDENTICAL (MZ) TWIN PAIRS OF HIGH SCHOOL AGE [12]

	I	II	III	IV	V	VI
root λ,	4·000	2·232	1·587	1·001	0·646	0·382
N	0·035	–·030	0·345	–·181	–·112	–·173
V	–·183	0·701	0·186	–·239	–·288	0·207
S	–·219	–·011	0·316	0·029	0·318	0·058
W	0·004	–·401	0·237	0·289	–·547	0·048
R	0·504	0·385	–·099	0·584	0·505	–·248
M	0·815	–·436	0·809	–·696	0·500	0·927

were performed, one might be able to find a rational interpretation of the roots. I have not done so because a rotation is not meaningful with so few variables.

In a Finnish study of adult male twins over forty years of age, eight variables were used.[9] While the actual tests were different, they were quite similar to the ones in the previous study. There was a measure of verbal ability, one of word fluency, two of spatial visualization, two of number ability, and two of memory. The solution of the canonical equation is shown in Table III, where the variables are identified by their initial letter. Four of the roots are significant for this sample. It is tempting to conclude, as I have done sometimes, that the same hereditary components were found in both studies.

TABLE III

SOLUTION OF $| C_{DZ} - \lambda C_{MZ} | = 0$ FOR 8 ABILITY TEST SCORES OF 157 FRATERNAL (DZ) AND 189 IDENTICAL (MZ) ADULT, MALE, FINNISH TWIN PAIRS [2]

V	330*	421	−470	−029	−210	408	−718	−002
W	518	100	080	−877	461	−054	224	−220
S_1	432	414	152	405	284	272	262	−030
S_2	196	281	347	−032	−233	−633	−029	256
N_1	256	−432	−332	008	−476	259	493	601
N_2	−148	−012	−652	184	322	−521	020	−217
M_1	493	−189	120	129	−380	−056	137	−666
M_2	261	−582	282	122	367	−117	−322	182
Size of root	3·556	2·256	1·785	1·682	1·246	1·166	1·132	0·974
H	0·72	0·56	0·44	0·41	0·20	0·14	0·12	0·03

* Decimals omitted.

The next study was by Bock and Vandenberg.[3] This time the variables were the sub-tests of the Differential Aptitudes Test (DAT for short). These scores are not quite so independent of one another as are the PMA sub-tests, but they have higher reliabilities and are extremely well validated against school criteria. The eight scores are Spatial visualization, Numerical reasoning, Abstract reasoning, Verbal reasoning, Mechanical reasoning, Clerical speed and accuracy, Spelling and finally Grammar. The solution of the canonical equation for these variables is shown in Table IV for the boys and in

TABLE IV

DAT ANALYSIS: CHARACTERISTIC ROOTS AND VECTORS OF $| C_{DZ} - \lambda C_{MZ} | = 0$ FOR BOYS [3]

TEST	VECTORS 1	2	3	4	5
1. Spatial	0·245	0·470	0·080	−·473	0·447
2. Numerical	0·304	−·402	0·100	0·214	0·766
3. Abstract	0·401	0·139	−·650	0·054	0·035
4. Verbal	0·500	−·177	0·177	−·022	−·167
5. Mechanical	−·131	0·590	−·195	0·015	0·166
6. Clerical	0·196	0·399	0·191	0·822	−·041
7. Spelling	0·484	−·097	−·339	−·077	−·325
8. Sentences	0·383	0·223	0·583	−·214	−·223
Root	3·529	2·570	0·900	0·623	0·376

Table V for the girls. For the boys there were three significant roots, but for the girls only two. This may be partly due to the relative lack in the girls of spatial visualization and of mechanical reasoning.

TABLE V

DAT ANALYSIS : CHARACTERISTIC ROOTS AND VECTORS OF $| C_{DZ} - \Lambda C_{MZ} | \% O$ FOR GIRLS [3]

	VECTORS				
TEST	1	2	3	4	5
1. Spatial	0·300	0·468	0·204	–·542	0·430
2. Numerical	0·434	–·092	0·054	0·293	0·095
3. Abstract	0·364	0·339	0·091	0·571	0·069
4. Verbal	0·414	–·194	–·207	0·048	–·509
5. Mechanical	0·296	0·562	–·115	–·129	–·427
6. Clerical	0·234	–·316	0·859	–·113	–·188
7. Spelling	0·389	–·296	–·218	0·122	0·561
8. Sentences	0·353	–·341	–·324	–·497	–·092
Root	5·005	1·619	0·747	0·444	0·185

Dr. Bock took the analysis a step farther and constructed the estimated correlation matrix for the heritable part of the DZ twin differences. This allowed an interpretation of the nature of the dimensions. A strong general hereditary component appeared in both male and female samples, plus a second hereditary component defined by the contrast between mechanical reasoning + spatial relations versus numerical + grammar. The third component for the boys was defined by the clerical speed and grammar tests.

Rather than discuss the details of each of these three studies, I should like to propose a general conclusion. Twin studies are not different from other studies: depending on the degree to which the variables in each study are measuring basically different abilities or rather more related abilities, one will find a general hereditary ability factor of low, moderate or high importance plus one or more factors that tend to be limited to one or more abilities. As this canonical method is applied to further test batteries, I expect that we shall find several classes of tests, or rather of abilities. In some tests the hereditary component will be quite high.[7] By checking twin concordance item by item one could increase the hereditary component perhaps, as Loehlin[8] suggested. These tests may in part prove to have some overlapping hereditary variance; in part, the hereditary variance will be independent. Other tests may turn out to have insignificant hereditary components, except in extremely large samples.

It should be remembered that the hereditary component in a test will vary as a function of the age, sex and other aspects of the sample studied. In addition, we have to remember that the tests have to be reliable enough to permit fairly high MZ concordance. Some of the most interesting twin studies in the past used tests which do not meet this criterion.

In proposing that there are several hereditary factors, I am going beyond the idea of Professors Cattell[4] and Horn,[6] who suggested that there are two general ability factors—one largely acquired, the other largely hereditary. Because the acquired ability factor shows up mostly in tests requiring long-term familiarity with cultural conventions, it was labelled by Cattell and Horn *crystallized*, and the hereditary factor *fluid*. At first sight this choice of labels might be thought to be confusing, especially if one were making the mistake of thinking of innate abilities as levels of individual performance fixed at the moment of conception. Of course this is a mistake *we* will not make, but some will. What *is* fixed is the reaction norm or range within which a given person's performance can lie, the environment determining the level actually realized. Because the term *fluid* for the hereditary ability factor makes it impossible to think of the hereditary factor as leading to a fixed level, the term may have pedagogic utility. Nevertheless, the term *crystallized* seems an unhappy choice for an ability factor that is primarily acquired. Cattell and Horn used a conventional factor analysis of data from a number of unrelated children to support their theory. Of course one cannot obtain information about heredity from such a study.

I have already mentioned further multivariate analyses of twin differences that are planned. Until these are done we cannot say to what extent the various abilities found to have a significant hereditary component are based on the same or different sets of genes. As part of a review of our present knowledge I have been collecting the results from a number of twin studies. Using a very crude method—namely simply averaging the F ratios from ten studies and forcing all the tests used in these studies into one of seven categories I came up with the results shown in Table VI.

TABLE VI

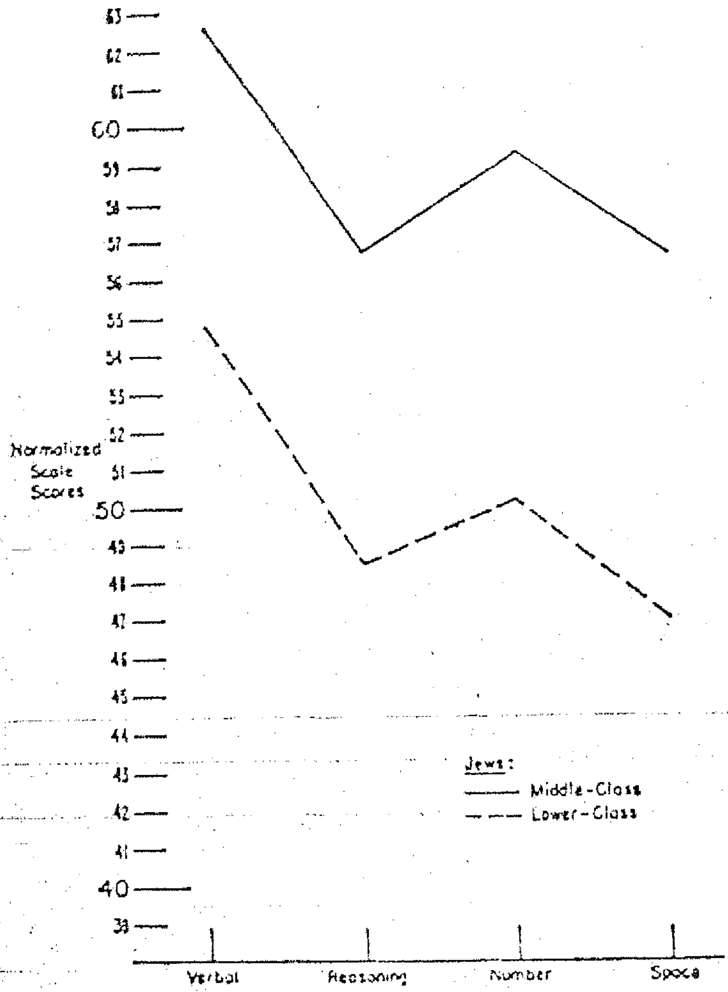
COMBINED RESULTS OF 10 TWIN STUDIES SHOWING THE RELATIVE IMPORTANCE OF HEREDITY FOR 7 ABILITIES

ABILITY	F
Verbal	2·53
Word fluency	2·47
Perceptual speed	2·26
Spatial	2·25
Memory	2·18
Number ability	1·91
Reasoning	1·65

The results for the reasoning tests seem a little puzzling. They seem to indicate that heredity plays only a minor role in reasoning, even though this might be regarded as close to the heart of intelligence, if we are to believe Spearman. I would suggest that the reason for the rather low degree of hereditary control is due to an artefact. Many reasoning tests allow one to reach the correct conclusion through several different approaches. Identical twins frequently select different routes, one of which may be speedier. Such more or less accidental differences in the method used would lower the MZ concordance on that test and, hence, the F ratio or whatever statistic is used to evaluate the hereditary component.

Besides the refinements of statistical and pyschological techniques employed in twin studies, future research in human behaviour genetics in the next few years may be expected to test specific hypotheses, perhaps including modelling of various traits under the control of x number of genes with one or more loci contributing more to a trait than the other loci. Perhaps a family study of height may be worth while to-day.

We may also expect more detailed psychological studies of persons with genetic anomalies and of their close relatives.


Normalized Scale Scores
60
50
40
Jews:
Middle-Class
Lower-Class
Verbal
Reasoning
Number
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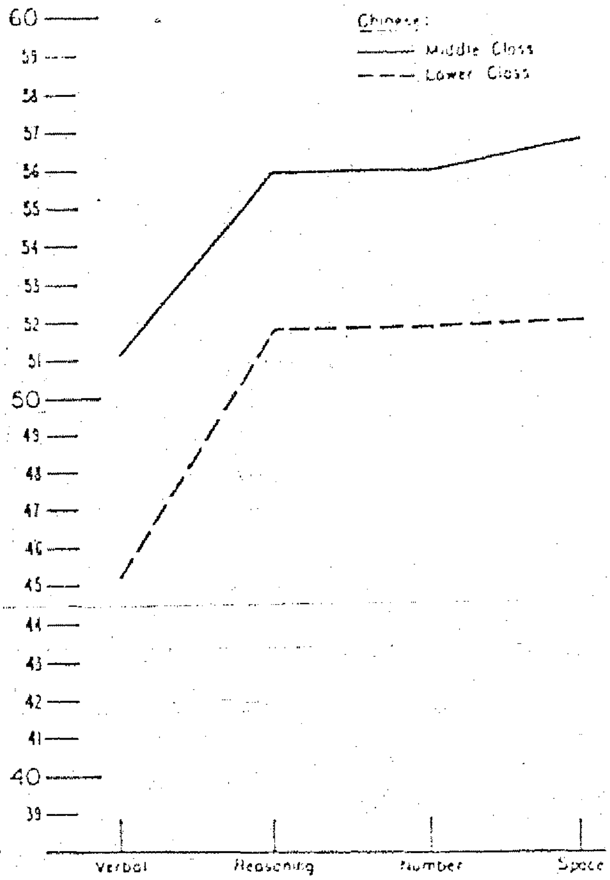
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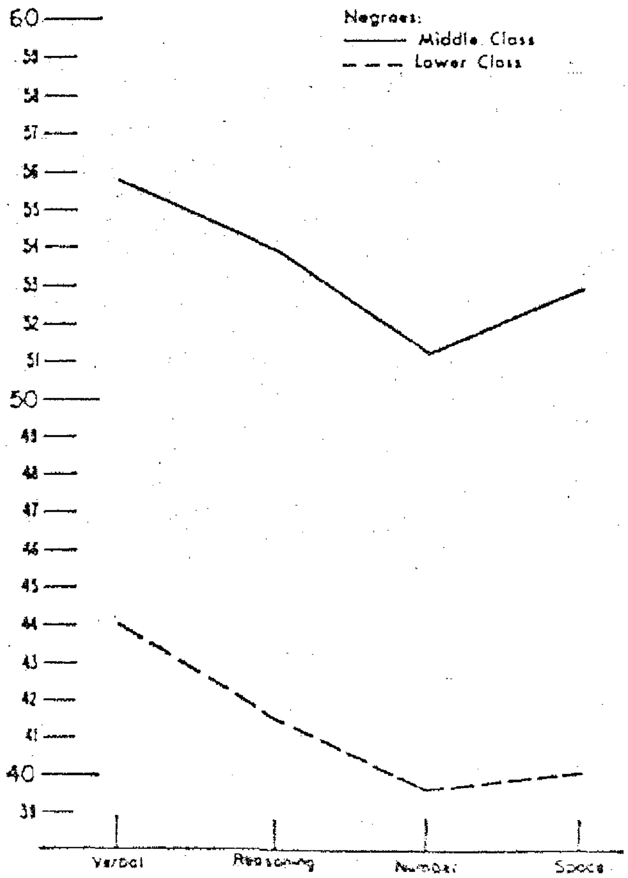
Chinese:
Middle Class
Lower Class
Verbal
Reasoning
Number
Space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Negroes:
Middle Class
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Verbal
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Number
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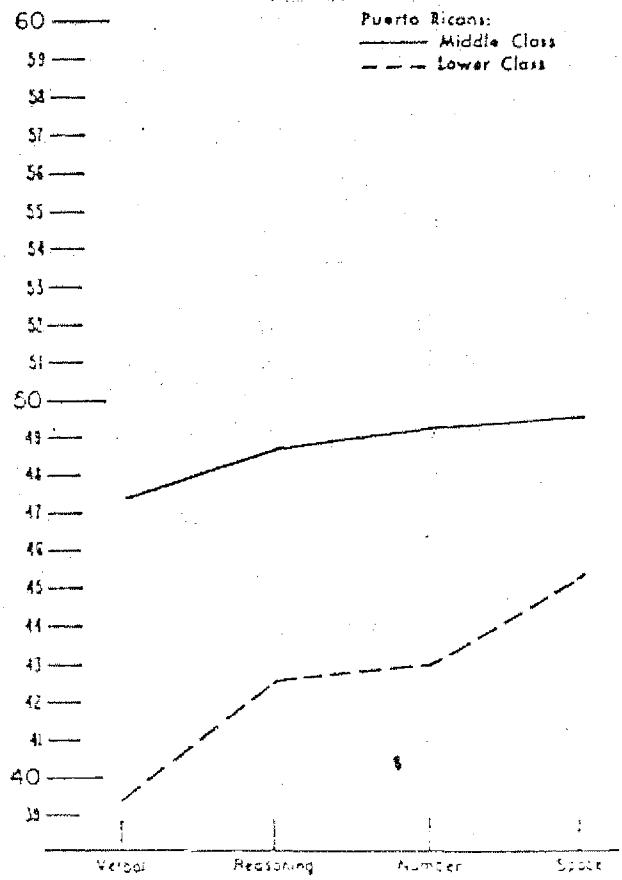
60
50
40
Puerto Ricans:
Middle Class
Lower Class
Verbal
Reasoning
Number
Space

Perhaps someone will start collecting data on children whose personality is markedly different from that of both parents and of their other children, to see whether the same personality can be found among other relatives. I am thinking of the occasional shy child in a sociable, outgoing family or the boisterous, happy child in a subdued, withdrawn family.

If independent hereditary abilities are found and identified it may perhaps be possible to return to a study of national or racial differences in ability with more hope of success, because patterns of ability might be found independent of the level of general intelligence. This possibility is strongly suggested by a study of children from middle and lower class families of four different ethnic groups.[7] Figure 3 shows that in each group the same patterning of abilities occurred for the two socio-economic classes, even though there were marked differences between the groups. If, as I have suggested, there may prove to be a number of independent hereditary abilities as well as a general hereditary ability factor, one might ask why the situation is so similar for the hereditary components and the phenotypic variables. The answer is, of course, that man's heredity helped to shape his environment and man's environment helped to select his genes, so that it is to be expected that they will fit together rather nicely.

One may ask where these peculiarly human abilities came from. Were they newly invented during man's evolution? I believe not. Many human abilities are present in rudimentary forms in various animals. We find an ability to orient oneself in space in many animals; a primitive number sense exists in some animals; an ability to manipulate objects has been observed in some animals, and so on. In man, these abilities have been perfected and magnified by verbal representation and mental rehearsal, while speech also allowed systematic instruction of the young by parents and by individuals with special skills.

FIGURE 3

COMPARISON OF TEST PERFORMANCE OF CHILDREN FROM MIDDLE AND LOWER CLASS FOR FOUR DIFFERENT CULTURAL GROUPS[7]

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