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The inheritance of scholastic abilities in a sample of twins

I. Ascertainment of the sample and diagnosis of zygosity

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There is now strong evidence that general intelligence as measured by ability tests is largely genetically determined, in western white societies at least (Eaves, 1975). The evidence for educational achievement is more conflicting and several studies have found lower heritabilities in school tests and examinations.

In this study we analyse the results of a sample of monozygotic (MZ) and dizygotic (DZ) twins who sat for the Intermediate examination of the Public Examinations Board of South Australia. This examination was taken by about two-thirds of the 15-year-old cohort in South Australia until 1968, after which it was abolished. A candidate was generally expected to have spent three years at secondary school preparing for examination in about seven subjects.

The twin method has been subjected to close scrutiny and considerable criticism which has not abated even in the centenary year of its inception by Galton in 1875 (Schwartz & Schwartz, 1974). Many of these criticisms have been dealt with at length (Vandenberg, 1966; Mittler, 1971; Eaves & Eysenck, 1975). Nevertheless, before accepting results of analyses of twin data it is important to try to estimate the effects of any biases in the ascertainment and composition of the twin sample.

One aim of biometrical genetics is to obtain estimates of parameters which will adequately describe observed phenotypic variation in a given character. In the absence of genotype–environment interactions, Jinks & Fulker (1970) show that initially the total variance may be partitioned into G_1 = within-family genetic component, G_2 = between-family genetic component, E_1 = within-family environmental component, E_2 = between-family environmental component.

In the case of twin studies, we can see that biased ascertainment will generally restrict the sampling range and cause underestimation of the between families components E_2 and G_2, while incorrect zygosity diagnosis could alter the values of E_1 and G_1, the within families components, and consequently affect the between families components as well. In this paper we attempt to estimate the importance of these two kinds of bias in this study.

ASCERTAINMENT OF THE TWIN SAMPLE

Until 1968 the Intermediate examination was taken by 14,000 tenth-grade students (about 15 years old) in South Australia. The Public Examinations Board gave us access to the magnetic tapes containing all the enrolments and results for the 1967 and 1968 examinations. Recorded were each candidate's full name, birthdate, and mark (out of 100) and grade attained in each

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Table 1. *Age, sex and zygosity distribution of the ascertained twin sample*

Year of birth	Males MZ	Males DZ	Males Unknown	Females MZ	Females DZ	Females Unknown	Opposite sex	Total
(a) Pairs who sat the Intermediate examination in 1967								
1949	—	2	—	1	—	—	—	3
1950	—	—	—	—	—	1	1	2
1951	3	2	—	4	4	1	5	19
1952	8	4	2	10	10	1	10	45
1953	1	—	—	—	—	—	2	3
Total	12	8	2	15	14	3	18	72
(b) Pairs who sat the Intermediate examination in 1968								
1951	—	1*	—	—	—	—	—	1
1952	5*	5	1	3	4	1	6	25
1953	6	8	—	13	5	1	15	48
1954	—	1	—	—	1	1	—	3
Total	11	15	1	16	10	3	21	77

* Includes one pair repeating the examination from 1967.

subject for which he was enrolled. A computer program was written to extract for each of the two years all pairs of candidates with the same surname and birthdate of whom 143 pairs were found for 1967 and 152 for 1968. We then searched manually through the enrolment files for the addresses of all candidates so extracted. We regarded as twins all pairs of candidates with the same surname, birthdate and address leaving us with 72 pairs for 1967 and 77 pairs for 1968, 149 pairs in all.

Disregarding the few pairs of twins who might have lived at separate addresses, we see that only half the pairs selected with the same surname and birthdate are twins.

Table 1 shows the age, sex and zygosity distributions of the twins for the two years. Diagnosis of zygosity is discussed in the next section. In both years about 60 % of twin pairs were 15 years old and about 30 % were 16 years old, so it seems likely that about 90 % of all twin pairs born in 1952 who subsequently took the Intermediate examination would have sat for it in 1967 or 1968. This number is 70 pairs. The average enrolment for the two years of the examination was 13,865. So if the age distribution of singletons taking the Intermediate examination is the same as that for twins then we should have expected 62·5 % (45/72) of those singletons born in 1952 to sit for the examination in 1967 and 32·5 % (25/77) in 1968; i.e. the number of singletons born in 1952 and sitting for the examination in 1967 or 1968 $= 13{,}865 \times 0{\cdot}95 = 13{,}167$.

Now census data show 192 pairs of twins born in South Australia in 1952 and 17,884 live births altogether, so we let $p = 13{,}167/17{,}884 = 0{\cdot}736$ be the probability that a child born in South Australia in 1952 is enrolled for the Intermediate examination in 1967 or 1968. If we assume no differential migration or death rate of twins and singletons then:

(*a*) if there be complete dependence between the co-twins with respect to Intermediate enrolment we expect $192p = 141{\cdot}4$ pairs to be ascertained,

(*b*) if there be complete independence between the co-twins we expect $192p^2 = 104{\cdot}0$ pairs to be ascertained, in either case a considerable excess over the 70 pairs found.

If discordance in enrolment were a significant factor in the deficiency of ascertainment, then we should expect a greater proportion of DZ than of MZ twins to be missed for this reason. This should be reflected in a relative deficiency of opposite-sex pairs ascertained at Intermediate. Inspection of census data giving the sex composition of twin pairs born in 1952 shows a slight but non-significant deficiency of opposite sex pairs ascertained (22 expected, 16 observed), so it seems that discordance in enrolment is unlikely to be an important contributor to the considerable deficiency of twin pairs ascertained, and will only account for about 12 missed pairs ($2 \times (22-16)$).

One may postulate that some twin pairs were not ascertained because the co-twins lived at different addresses, were born either side of midnight and registered with different birthdays, sat for the examinations in different years or were missed because of clerical errors, but no more than a few pairs are likely have been missed for these reasons. More likely causes of the deficiency are the differential death rates and differences in intelligence of twins and singletons.

Bulmer (1970, p. 54) gives the infant mortality rates for twins and singletons in England and Wales for 1950, data which should be applicable to our results. The infant mortality during the first year of life per thousand live births was 27 for singletons and 111 for twins. The rate in the second year of life was 2·4 for singletons and 2·5 for twins, so the differential had disappeared. If the probability of death of a twin in the first year is $p = 0{\cdot}11$ and $p+q = 1$, then if deaths occurred at random in twin pairs we should expect only $192q^2 = 152$ complete pairs at the end of the first year. If only complete twin pairs died we should expect $192q = 171$ pairs alive at the end of the first year. It is clear that the higher infant mortality of twins could account for a substantial part of the observed deficiency.

Mittler (1971, pp. 29–35) reviews the extensive evidence showing that twins have a mean IQ about five points lower than singletons. If we assume that a student's enrolment in the Intermediate examination is a function of IQ alone, then we can estimate what effect this lower mean IQ of twins will have on ascertainment.

First we estimate the losses of twin pairs from the 192 pairs born in 1952 as 30 from death of one or both co-twins (i.e. the average of 40 for complete independence and 21 for complete dependence), leaving 162 pairs to be sampled.

We next estimate the proportion of the population cohort who sat for the Intermediate. At the 1966 Census the number of persons of each of the three ages 13, 14 and 15 in South Australia was about 21,000. Given an approximate Intermediate enrolment of about 14,000 the proportion of the cohort sitting Intermediate was about $14{,}000/21{,}000 = 2/3$. So assuming the cohort has mean IQ of 100 and standard deviation of 15 points and that there is a threshold requirement in IQ for Intermediate enrolment, then the total enrolment must represent the upper 67 % of the normal distribution, i.e. have IQ $> 93{\cdot}6$.

This is about the same as the mean IQ for twins, so if there is complete concordance for taking the examination we should only expect about 50 % of twin pairs to sit for the Intermediate, i.e. about 81 pairs. The extra 11 pairs can easily be accounted for by some discordance and the other sources of error mentioned above such as different addresses and clerical errors.

Although there are several approximations and assumptions in this argument, the analysis shows that our sample probably represents very nearly full ascertainment. Since it was probably only the upper 67 % of the cohort that sat the examination, the low mean IQ of the twin population will be automatically corrected so that the ascertained twin sample is, phenotypically at least, fairly representative of the general population.

We describe below how a subsample of the ascertained same-sex pairs was given an IQ test. If there has been truncation selection for Intermediate enrolment on the basis of IQ then one can calculate the expected mean and variance of the fraction of the population selected. The mean of the selected fraction is $i = z/p$ while the variance is $1-i\ (i-x)$ (Howe & James, 1973), where the proportion selected, $p = 0{\cdot}67$, the point of truncation in standard units, $x = -0{\cdot}43$, and z is the height of the ordinate at the point of truncation. For a normal distribution with mean 100 and variance 225, the truncated fraction of the curve will have mean 108 and variance 106. The observed mean IQ of the selected subsample is 110 and the variance 120, showing good agreement with the predictions and, given that the subsample is representative of the whole sample, further suggesting that the twin sample is representative of the population of Intermediate candidates.

Even so, it is difficult to know how to regard estimates of genetical and environmental parameters for the traits in question. We have shown that they are threshold traits, albeit with a low threshold, and we can only really regard any parameters as applying to the population at risk and not to the fraction below the threshold.

DIAGNOSIS OF ZYGOSITY

The 77 pairs of 1968 candidates with the same surname, birthdate and address were sent in May 1969 a questionnaire to confirm that they were twins, and to ask whether they were MZ or DZ. Seventy-five pairs returned the questionnaire signed by their parents. Some of the pairs gave equivocal answers as to whether they were 'identical' or 'non-identical', so we wrote to the school principals of all the same-sex pairs to obtain their opinions on the zygosity of the twins. In September 1969 we wrote to the 72 pairs of 1967 candidates and received 66 replies.

In the questionnaires sent to both years of twins and to the school principals of the 1968 pairs, the main criterion given for diagnosis of zygosity was: 'Non-identical twins are no more alike than ordinary brothers/sisters [depending on the sex being written to]. Identical twins, on the other hand, have such a very strong resemblance to each other in stature, colouring, features of the face and other details of natural appearance that people often mistake one for the other.' Questions such as this in postal surveys have achieved better than 90% correct diagnosis in other studies (Cederlöf *et al.* 1961; Nichols & Bilbro, 1966). We decided to determine the reliability of the postal diagnosis by blood-grouping a subsample of the same-sex pairs.

In April 1972 we wrote to the same-sex pairs asking whether twins were willing to be tested in the Department of Genetics at the University of Adelaide. Seventy replies were received and we finally tested 47 same-sex pairs – just under half the sample. The composition of this sample with respect to year, sex and zygosity did not differ significantly from the total same-sex sample, although there was a slight (non-significant) excess of MZ females and deficiency of DZ males. This is common experience in nearly all twin studies, and is probably due to the greater mobility of males and the greater willingness of females to co-operate in surveys.

Each pair was blood-grouped for eight systems using some or all of the following antisera, Anti-A, B, A1 (*Dolichos biflorus*), M, N, S, s, C^w, C, c, D, E, e, K, Fy^a, Jk^a, Jk^b, Le^a, Le^b and P_1. The twins were also typed for two other systems: haptoglobin type was determined by polyacrylamide gel electrophoresis and phenylthiocarbamide (PTC) tasting ability was measured using the serial dilutions of Harris & Kalmus (1949). The results of the PTC tasting have already been reported (Martin, 1975).

In assessing zygosity we also asked the twins whether they were ever mistaken for each other,

Table 2. *English grades for individuals from* 1967 *and* 1968 *same-sex twin pairs*

	1	2	3	4	5	6	Totals
Tested individuals	17	14	24	23	8	6	92
Untested individuals	7	12	33	28	15	3	98
	24	26	57	51	23	9	190

$\chi^2_5 = 9{\cdot}18,\ 0{\cdot}05 < P < 0{\cdot}10.$

and we recorded their hair colour and form, eye colour and whether their ear lobes were free or attached. We photographed each twin and tested for red–green colourblindness using Ishihara plates (13th ed., 1958). We also measured the stature and gave each twin the Australian Council for Educational Research Higher Test, a 45 min. I.Q. test.

Eighteen of the tested pairs differed in at least one of the ten markers and were classified as DZ and so was another pair who were concordant but had large differences in height and colouring. The other 28 pairs were concordant for all ten markers and the probability that they were DZ was calculated using the tables and the method of Smith & Penrose (1955). Similar tables for PTC tasting ability, haptoglobin type, Lewis blood group (determined with both anti-Le^a and anti-Le^b) and Kidd blood group (determined with both anti-Jk^a and anti-Jk^b) were constructed and also used in the calculation. The probability that each concordant pair is DZ is between 0·002 and 0·035 with a mean probability of dizygosity for all 28 concordant pairs of 0·016 and these pairs were classified as MZ.

There was perfect agreement for all 47 pairs between the diagnosis from testing and the assessment of zygosity given by the twins and their parents in response to the 1969 questionnaire.

It could be argued that the 47 pairs we have tested are more intelligent, more careful or more observant and therefore more likely to be correct in assessing their own zygosity than the half of the sample we have not tested. One way that we can compare the tested and untested fractions of the sample is to look at the distribution of grades for English (which nearly all candidates took) in the Intermediate examination. Table 2 shows the numbers of candidates gaining each grade for the tested and untested twins. The highest grade is 1.

On the basis of the English grades there is some evidence, although not significant, that we have tested a slightly brighter than average subsample. However, it appears unlikely that incorrect zygosity diagnosis is a serious source of error in this study.

SUMMARY

A sample of 149 twin pairs was ascertained by extracting all pairs of candidates with the same surname, birth date and address from the files of a public examination taken by about two-thirds of the 15-year-old cohort in South Australia. Of these there were 39 opposite sex pairs and 100 same-sex pairs whose zygosity was determined by postal questionnaire. This diagnosis was checked and found to be accurate by typing 47 pairs for ten independent genetic markers. Several analyses suggest that the ascertained twin sample is fairly representative of the fraction of the cohort who took the examination so there is no evidence to suggest that between families components of variance will be underestimated for this reason.

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