ANALYSIS OF TWIN DATA AND ESTIMATION OF HERITABILITY EFFECTS

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In a statistical sense, the objective of twin research is to partition the variance on some criterion measure among genetic and environmental factors. Although certain elaborate models have been developed, these models do not supply a convenient test statistic to show which factors make a significant contribution. Consequently several procedures drawn from analysis of variance have been adapted for use with twin data.

In longitudinal research, when a particular variable such as physical growth or mental development has been measured at successive ages, it is desirable to have a model for determining whether twins follow a similar pattern of development over ages. We know that development during childhood may be subject to spurts and lags – a child may advance rapidly, and then seem to pass through a stage of slower development before picking up again. For example, in our analysis of mental development during infancy, we find that an infant may be precocious at one age but not at the next. This may be illustrated by looking at the mental development scores obtained by infants in the first two years of life. The scores for several pairs of MZ twins are displayed in the Figure.

The scores at each age are expressed in standard score form, with $\bar{X} = 100$ and SD = 16, so if an infant maintained the same relative status at each age, his score would remain the same. As the curves show, however, this is seldom the case. The more typical pattern is for an infant to show spurts and lags in the course of mental development, with corresponding changes in his scores from age to age. But the curves also show that MZ twins seem to follow much the same pattern of development, and this raises the question whether the spurts and lags might be subject to genetic control. How can the test scores of twins be analyzed to supply an answer?

We begin by selecting an analysis-of-variance design which is appropriate for repeated measures and which may be used with twin pairs. This would be a mixed design in which each twin pair is treated as a separate group, with two cases per group (Haggard 1958, Winer 1962). The sample of twins for whom we have data is regarded as a random selection of pairs from the larger population. The twins have been tested at 6, 9, 12, 18, and 24 months of age, and our principal interest is in how closely the twins match one another for the pattern of scores over age.

This is approached by looking at the interaction terms in the analysis of variance. There are two variance estimates from the interaction terms which relate directly to the following questions:

(1) Does each twin *pair* generate a distinctive profile of scores which is unique for them and differs from that of other pairs? To judge this, the score profiles of both twins are averaged together as the best estimate of the distinctive profile for that pair. Then the analysis performs a comparison among all the profiles to detect the variation between pairs in the shape or contour of the profile. The results are contained in the interaction of Pairs × Ages, and this term will become larger when there are many distinctively different profiles, or patterns of scores, represented among the twin pairs.

(2) The second question concerns the deviations from the profile that occur within each pair. The illustrations in the Figure are for twins that match each other very closely, but in the full sample

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there are pairs that are considerably less concordant. The analysis computes the deviations within each pair, and when summed across pairs this furnishes a generalized measure of the lack of similarity in score profile. It is represented in the Twins *w/i* Pairs × Ages interaction.

These two variance estimates may be used to test whether there is a significant degree of concordance among the twins for similarity in score profile. The test is given by: $F = \dfrac{MS_{Pairs \times Ages}}{MS_{Twins\ w/i\ Pairs \times Ages}}$, with DF $= (p - 1)(a - 1)$ and $p(a - 1)$. In this expression, p is the number of pairs, and a is the number of ages at which tests were given.

The larger the F-ratio, the better the evidence that each twin pair generates a distinctive profile of scores that is closely matched by both members of the pair. This can also be expressed as a within-pair correlation for profile similarity, which is given by:

$$R = \frac{MS_{Pairs \times Ages} - MS_{Twins\ w/i\ Pairs \times Ages}}{MS_{Pairs \times Ages} + MS_{Twins\ w/i\ Pairs \times Ages}}, \quad \text{or its equivalent,} \quad R = \frac{F - 1}{F + 1}.$$

The significance level for the correlation is exactly the same as for the F-ratio, and it indicates how confident an investigator may feel that the twins are matching each other for the spurts and lags in mental development.

This analysis has been performed for a sample of 33 MZ twin pairs, and the relevant results are displayed in the Table. They show that there was a highly significant degree of concordance for the score profiles of these MZ twins, leading to an intraclass correlation of 0.69. Clearly, the common genotype

Table. *Analysis of concordance for score profile among MZ twins*

Source of variance	DF	MS	F	R	p-value
*Within subjects**					
Pairs × Ages	128	224.9	5.53	0.69	< 0.001
Twins *w/i* Pairs × Ages	132	40.7			

* In the interests of clarity, the other sources of variance from this analysis are omitted.

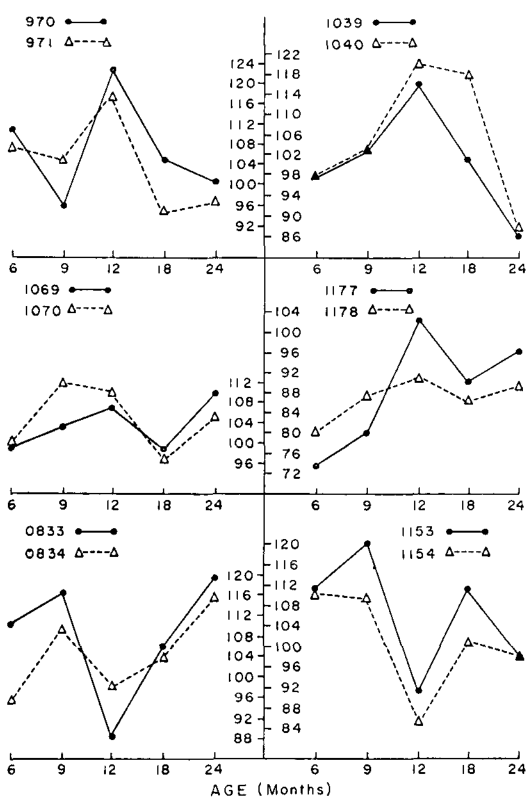

Figure. Infant mental development scores for six pairs of MZ twins. (From Wilson and Harpring 1972).

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plus the similarities in experience promoted a congruent pattern of changes for MZ pairs.

The same analysis may be performed for DZ twins, with the expectation that they would show an intermediate degree of concordance. The *F*-ratio and correlation coefficient would confirm whether DZ twins matched one another significantly better than chance for the pattern of changes over age. However, DZ twins should be less closely matched than MZ twins, due to genetic variation and possible differences in experience. This can be tested by transforming the correlation coefficients into *Z* scores, and then performing a critical ratio test to determine if the MZ correlation is significantly larger. A positive answer would support an interpretation that the course of mental development was significantly influenced by the genetic blueprint.

This is the basic model for evaluating longitudinal data on twins. It can be expanded in other dimensions — for example, an intelligence test which is used with older twins yields a series of 10 subtest scores, and the test has been administered at yearly intervals. The subtest scores reveal the profile of relative strengths and weaknesses among the abilities being tested, and the annual testing makes it possible to evaluate the stability of the subtest scores over age.

While the complexity of the model increases in these cases, the fundamental question remains the same: do the members of each pair match one another for the profile of scores, and is the match significantly better for MZ than DZ twins? If so, we would conclude that there was a significant genetic effect on these dimensions of mental development.

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