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Separated Fraternal Twins: Resemblance for Cognitive Abilities

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Thirty-four pairs of Swedish fraternal twins separated in the first 10 years of life were administered 12 tests of cognitive abilities. The average age of the twins was 59 years. Nineteen pairs were separated before the first year of life and 26 pairs (76%) were separated by the age of 5 years. Moderate positive twin correlations were found for all tests, reaching significance for Raven's Progressive Matrices and Word Beginnings and Endings. A twin correlation of 0.52 emerged for the first principal component (a measure of general ability). Moderate correlations were found for Spatial Ability and for Verbal Ability/Perceptual Speed factors; for the Memory factor the correlation was lower. The effect of early environment on cognitive ability was assessed by analyzing the association between a degree of separation index and twin resemblance. The importance of the separation measures taken individually was also examined. Some significant effects were found, but these were consistently in a counterintuitive direction: Twins separated earlier were more *similar than those separated later.*

KEY WORDS: separated twins; twin resemblance; ability.

INTRODUCTION

The most interesting and illuminating data in the area of human behavioral genetics come from adoption studies of twins separated early in life. The

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present report adds to these data in two ways. First, there has been no other study of a sample of separated *fraternal* twins. Previous studies have included only separated identical twins because such twins yield dramatic and intuitively appealing results: data on pairs of genetically identical individuals reared in uncorrelated environments directly estimate the contribution of heredity to behavioral variability. However, genetically identical individuals include all nonadditive, as well as additive, genetic effects. Thus, results for identical twins might not generalize to other familial relationships. First-degree relatives share only half of the additive genetic variance; parents and offspring share *no* nonadditive genetic variance, and siblings share only a small portion of the nonadditive genetic variance. Fraternal twins are, genetically speaking, like other siblings; thus, their results might be expected to generalize to other first-degree relationships.

Second, previous studies of separated twins (e.g., Farber, 1981; Taylor, 1980) have focused on general cognitive ability, usually IQ, rather than considering specific cognitive abilities. We shall report data for specific abilities as well as for general cognitive ability. In addition, the importance of the early environment will be considered in analyses of twin similarity as a function of the degree of separation.

METHODS

Sample and Measures

The separated fraternal twins were identified in the Swedish Twin Registry of the Department of Environmental Hygiene of The Karolinska Institute in Stockholm, which contains data from nearly 24,000 pairs of twins born in Sweden between 1886 and 1958 (Cederlöf, 1966; Medlund *et al.*, 1976). Twins were asked how long they had lived with their twin partner, and those who indicated that they had been separated from their twin in the first 10 years of life responded to a detailed early-environment questionnaire. Zygosity was assessed on the basis of the twins' report of physical similarity as children and as adults in the "peas-in-a-pod" item standard to the registry. The validity of this method has been examined by Cederlöf *et al.* (1961) on a subsample of twins in the older cohort of the Swedish twin registry and verified by Sarna (1977). Only pairs which were in agreement that they were no more alike than siblings in general, both during childhood and as adults, were considered for selection. The identification and characterization of twins reared apart have been described in detail elsewhere (Pedersen *et al.*, 1984). The present study was undertaken as a feasibility study preliminary to initiating plans for a large-scale investigation of the entire sample of separated twins.

Thirty-eight pairs of like-sexed fraternal twins were tested in Stockholm on a 6-h battery of tests and interviews. They ranged in age from 32 to 81 years (average age, 59; SD, 11.39), and 28 pairs were female. The pairs were selected to be representative of other separated twins in terms of age and geographical distribution. Because this was a feasibility study, twins who had experienced the greatest degree of separation were not included. Based on more detailed information obtained at the time of testing concerning the twins' separation, it was determined that two pairs of twins were not separated before the age of 10 years and were, therefore, unsuitable for our purposes. Two additional pairs were excluded from the analyses because of severe physical and/or learning handicaps.

Testing was conducted in small groups, usually consisting of two or three individuals. Seventy-six percent of the twin pairs were tested on the same day. The possible confounding effect of this procedure was reduced as much as possible by administering the tests at different times with different testers. Participants were reimbursed for travel, meals, and housing costs, and an honorarium of 100 crowns (approximately $20) was provided.

The twins were tested on a 2-h battery of cognitive tests chosen to assess major factors of cognition similar to those assessed in the Hawaii Family Study of Cognition (DeFries *et al.*, 1979) and the Colorado Adoption Project (DeFries *et al.*, 1981). Major factors identified in those studies were Visual Memory, Spatial Ability, Verbal Ability, and Perceptual Speed. The tests were translated and adapted for use in Sweden. Parallel forms were constructed for all tests except Raven's Progressive Matrices and the Swedish version of Word Beginnings and Endings (WBE). The tests, their origins, and the parallel-form reliabilities are included in Table I. The two forms of the tests (A and B) were administered at different times, with a 45-min pause intervening.

The early-environment questionnaire requested details concerning the reasons for separation, the timing of separation, the biological relatedness of the rearing parents and information concerning contact after separation (for example, whether the twins attended the same school, whether they had lived together again after their separation, and the frequency of contact after separation). The twins were separated primarily because of the illness or death of one or both of the parents and/or economic hardships. Nineteen of the 34 pairs were separated in the first year of life; the 15 other pairs were nearly evenly distributed in their age at separation from 1 to 10 years. Forty-seven percent of the pairs were reared by parents who were biologically unrelated to each other; when the twins were reared by biologically related individuals, in most cases the mother (or mother and father) reared one twin and her sister or her

Table I. Parallel-Form Reliabilities and Factor Loadings for the Cognitive Battery

Test	Source[a]	Parallel-form reliability[b]	Factor loadings[c]			
			1st unrotated, general ability	Rotated factor		
				Memory	Spatial ability	Verbal ability/perceptual speed
Figure Memory/Immediate	HFSC	0.70	0.79	0.83	0.18	0.30
Figure Memory/Delayed	HFSC	0.72	0.67	0.79	0.09	0.24
Picture Memory/Immediate	HFSC	0.74	0.68	0.80	0.14	0.18
Picture Memory/Delayed	HFSC	0.74	0.80	0.78	0.30	0.28
Mental Rotations	HFSC	0.61	0.50	0.11	0.90	0.03
Card Rotations	ETS	0.89	0.71	0.17	0.75	0.40
Raven's Progressive Matrices	HFSC	—	0.72	0.28	0.67	0.37
Word Beginnings and Endings	ETS	—	0.69	0.25	0.11	0.77
Pedigrees	PMA	0.90	0.76	0.23	0.35	0.72
Identical Pictures	ETS	0.83	0.63	0.16	0.15	0.72
Vocabulary	DBA	0.83	0.74	0.45	0.09	0.67
Number Comparisons	ETS	0.74	0.78	0.30	0.42	0.63

[a] HFSC, Hawaii Family Study of Cognition; ETS, Educational Testing Service; PMA, Primary Mental Abilities; DBA, Delta Battery (standard Swedish test).
[b] Reliability calculated by the Spearman formula $2r/(1 + r)$, where r is the correlation of form A and form B. Parallel forms were not available for Word Beginnings and Endings or for Raven's Progressive Matrices (HFSC abbreviated version).
[c] Based on age-standardized scores, forms A and B combined.

Table II. Distribution of the Degree of Separation Index for 34 Pairs of Fraternal Twins Reared Apart

Degree of separation	N	Percentage
0 (most separated)	3	8.8
1	12	35.3
2	18	52.9
3	1	2.9
4 (least separated)	0	0

parents reared the other. Eighty-five percent of the pairs were not reunited before the age of 17 years, and 56% of the twins had attended different schools. The distribution of the contact frequency is bimodal, with 48% of the pairs meeting a few times a year or less. Schooling and contact frequency were positively correlated ($r = 0.76$) and relatedness of the rearing parents was negatively correlated with age at separation ($r = -0.35$). Because of the varying forms of postseparation contact, an index of the degree of separation was constructed by adding 0 or 1 scores each from age at separation (after first birthday = 1), relatedness of the rearing parents (related = 1), school attendance (same school = 1), and whether the twins lived together again between the age at separation and 17 years of age (yes = 1). This measure, the distribution of which is presented in Table II, was calculated for the purpose of assessing the effect of the degree of separation on twin similarity.

Information on the education and occupation of the rearing parents was obtained in order to provide a rough assessment of selective placement. Education proved not to be a useful index of selective placement because of its constrained variability—the education of 91% of the parents ended with elementary school. We converted the rearing fathers' occupations to a ranking based on the empirically derived rating of job status developed by Duncan (see Reiss, 1961) for the National Opinion Research Center (NORC). Because of the agrarian nature of Swedish society in the early 1900s, there were numerous farm-related specialties that had to be grouped into the more general categories of the NORC. The average status was 55, which is the level of small farmers, and the standard deviation was 9.25. The correlation between the occupational status rankings of the rearing fathers of the twin partners was 0.35, which suggests the presence of some selective placement. This is modest when one considers that placement for fraternal twins reared together is 1.0 and not particularly surprising in that these twins were selected for the feasibility study because they did not pass the most stringent tests of separation. The possible effects of selective placement are addressed in the Discussion.

In order to speak to the issue of the representativeness of the sample, we compared educational and occupational information for the separated twins to data from 60 pairs of Swedish fraternal twins reared together, ranging in age from 43 to 68 years (Crumpacker *et al.*, 1979). Means and standard deviations for NORC ratings were lower for the separated sample ($\bar{X}$ = 64.14, SD = 10.94) than for the sample reared together ($\bar{X}$ = 70.57, SD = 9.44). A greater percentage of the twins reared together continued their education beyond obligatory schooling. As Price and Vandenberg (1980) point out, the sample of Crumpacker *et al.* is somewhat better educated than is the case for the registry as a whole. The proportion of separated twins in the present sample who continued their education is, however, similar to the general twin registry values for the same age group.

Data on a shortened version of Raven's Progressive Matrices, a culture-fair test of reasoning that was used in both studies, were also compared. Means and standard deviations on the Raven test for the separated twins ($\bar{X}$ = 13.8, SD = 6.42) and for the twins reared together ($\bar{X}$ = 14.4, SD = 5.63) were not significantly different (t = 1.18). These values suggest that the separated twins are representative of Swedish fraternal twins for cognitive ability.

Analyses

Scores on the parallel forms were combined, age corrected using residuals from a regression of each test on age (McGue and Bouchard, 1984), and submitted to principal-component factor analysis. The first unrotated principal component accounted for 50.6% of the variance; its high loadings on all tests indicate that it is a measure of general cognitive ability (see Table I). Three factors with eigenvalues greater than 1.0 were submitted to Varimax rotation, and the resultant factor loadings are also presented in Table I. These factors can be interpreted as Memory, Spatial Ability, and Verbal Ability/Perceptual Speed. This factor structure largely replicates the results of our previous studies using these measures; however, in this sample, a single factor emerged for verbal and perceptual speed tests, even when four factors were extracted for rotation. Factor scores were computed for the unrotated first principal component, which we shall refer to as general cognitive ability, and for the three rotated factors. Because combined scores for the parallel forms were used, data for five pairs in which one or both twins did not complete the second form were lost.

The twin results are presented as intraclass correlations using a double-entry procedure on age-standardized scores (Snedecor and Cochran, 1967, p. 295), partialing out degree of separation. Because members of a twin pair are of the same age and were separated in the same way, any average effects of age or degree of separation will artificially inflate twin correlations. In order to assess the effect of degree of separation on twin resemblance, the following hierarchical multiple regression (HMR) model (Cohen and Cohen, 1975) was employed:

$$Y = \underbrace{B_1X_1}_{\text{step 1}} + \underbrace{B_2X_2 + B_3X_1X_2}_{\text{step 2}} + C.$$

Y is one twin's expected score, X_1 is the other twin's score, X_2 is the degree of separation, X_1X_2 is the interaction product of twin score and degree of separation, and C is the regression constant. The interaction indicates the extent to which twin resemblance differs as a function of the degree of separation, a direct test of the significance of the early rearing environment as it affects twin similarity in adulthood. The significance of the partial regression coefficient B_3 is tested after the "main effects" of B_1 (twin resemblance) and B_2 (mean effects of degree of separation) are removed.

This HMR approach is considerably more powerful than the frequently used arbitrary dichotomization of a single continuous variable (such as dichotomizing the twin sample into two groups: twins separated before 1 year of age and twins separated after 1 year) and then testing for the significance of the difference between the two correlations. For example, a sample of over 300 pairs in each group is needed to detect a significant difference 80% of the time between true population correlations of 0.40 for one group and 0.20 for the other group at the $p = 0.05$ level (Cohen, 1977). In contrast, the HMR model with the present small sample size will detect a significant R^2 of 0.30 or greater with 80% power. A significant B_3 interaction in this model will be detected with 80% power when it accounts for 22% of the variance at its point of entry into the equation.

RESULTS

Table III presents the intraclass twin correlations for age-standardized scores on the 12 cognitive tests, the first principal component (general cognitive ability), and the three rotated factors with degree of separation partialed out. The median correlation for the 12 tests is 0.28. The sample

Table III. Intraclass Correlations for Separated Fraternal Twins for Age-Standardized Cognitive Test and Factor Scores with Degree of Separation Partialed Out

Factor or test	*N* pairs	Correlation[a]
General cognitive ability	29	0.52
Memory	29	0.11
Figure Memory/Immediate	29	0.31
Figure Memory/Delayed	29	0.29
Picture Memory/Immediate	29	0.28
Picture Memory/Delayed	29	0.15
Spatial Ability	29	0.30
Mental Rotations	29	0.29
Card Rotations	29	0.21
Raven's Progressive Matrices	33	0.44
Verbal Ability/Perceptual Speed	29	0.18
Word Beginnings and Endings	33	0.38
Pedigrees	29	0.14
Identical Pictures	29	0.27
Vocabulary	29	0.28
Number Comparisons	29	0.24

[a] The critical value for significance ($p = 0.05$) with $N = 29$ is 0.35.

size for Ravens and WBE is larger (33 vs. 29 for the other subtests) because these tests were presented in part A only. Data were not lost due to lack of participation in part B. Correlations for the tests loading most highly on each of the three factors do not provide any strong evidence for differential twin similarity. The only significant twin correlation among the factors is for general cognitive ability. Although some familiality is suggested for the Spatial Ability and Verbal Ability/Perceptual Speed factors, little twin resemblance was found for the Memory factor.

The data were not corrected by sex. When analyzed for the 24 pairs of sisters alone, the intraclass correlation for the first principal component was 0.53.

No significant interaction terms were found for the index of degree of separation in the HMR analyses. However, when age of separation was taken singly, significant interactions were found for Picture Memory Delayed, Identical Pictures, and Number Comparisons and for the Verbal Ability/Perceptual Speed factor. Proportions of variance explained (R^2) in total and for the interaction terms are presented in Table IV.

Examination of intrapair differences by age of separation gives an indication of the nature of the interactions. For those tests and factors for which the interaction reached significance, a counterintuitive result was found: twins separated earlier were more similar than those separated later.

Table IV. Proportion of Variation (R^2) for Two-Way Interactions of Cotwin's Score for Cognitive Measures with Degree of Separation Index and with Age at Separation

Factor or test	Proportion of variance explained (R^2)			
	Separation index		Age at separation	
	Interaction	Total	Interaction	Total
General cognitive ability	0.005	0.326*	0.007	0.314*
Memory	0.012	0.025	0.017	0.043
Figure Memory/Immediate	0.021	0.122	0.006	0.104
Figure Memory/Delayed	0.087	0.183	0.005	0.100
Picture Memory/Immediate	0.007	0.113	0.005	0.115
Picture Memory/Delayed	0.023	0.073	0.156*	0.187
Spatial Ability	0.087	0.186	0.054	0.148
Mental Rotations	0.000	0.089	0.010	0.108
Card Rotations	0.005	0.156	0.005	0.098
Raven's Progressive Matrices	0.007	0.212	0.011	0.234*
Verbal Ability/Perceptual Speed	0.082	0.192	0.216*	0.287*
Word Beginnings and Endings	0.037	0.260*	0.008	0.203
Pedigrees	0.021	0.097	0.104	0.146
Identical Pictures	0.019	0.110	0.177*	0.262
Vocabulary	0.037	0.131	0.002	0.090
Number Comparisons	0.029	0.165	0.146*	0.241

* $P < 0.05$. Degrees of freedom for tests of significance calculated counting each pair once.

DISCUSSION

These data add yet another piece of converging evidence to the conclusion that individual differences in cognitive functioning are influenced in part by genetic differences among individuals (Plomin and DeFries, 1980; Bouchard and McGue, 1981). This first report of cognitive resemblance for separated fraternal twins is consistent with data obtained in studies with other designs. Substantial separated-twin correlations are obtained for general cognitive ability. Although Spatial Ability and Verbal Ability/Perceptual Speed factors did not reach traditional levels of statistical significance, it should be noted that the present sample size has only 70% power to detect correlations of 0.40 or larger. If the true correlation for separated fraternal twins is 0.20–0.30, the sample size would have only 30% power to detect correlations of that magnitude. The low twin correlation for the Memory factor agrees with the results of other studies in suggesting that memory shows less heritability than do other specific cognitive abilities (DeFries *et al.*, 1976).

Although funds were not available to test fraternal twins reared together as part of this study, it is useful to compare the results for the separated twins to other reports of fraternal twins reared together. The

Table V. Comparison of Correlations for Factor Scores for Separated Fraternal Twins in the Present Study and Fraternal Twins Reared Together in Two Other Studies

Factor	Separated fraternal twins	Fraternal twins reared together	
	Adults, Sweden (present study) (N = 29 pairs)	Adult males, Finland (Partanen *et al.*, 1966) (N = 189 pairs)	High school, United States (Schoenfeldt, 1968) (N = 156 pairs)
Spatial Ability	0.30	0.36	0.41
Verbal Ability		0.53	0.48
	0.18		
Perceptual Speed		0.50	0.51
Memory	0.11	0.32	0.19

correlation of IQs of fraternal twins are about 0.62 on the average (Plomin and DeFries, 1980). The correlation of 0.52 in the present study suggests that similarity for twins reared together may largely be due to their genetic similarity. Conclusions concerning the precise amount of genetic influence should be limited considering the fact that the 95% confidence interval for the correlation of 0.52 is from 0.19 to 0.75.

There have been few investigations of specific cognitive abilities in twins. Two studies of fraternal twins reared together (Partanen *et al.*, 1966; Schoenfeldt, 1968) found twin correlations for cognitive factors similar to those of the present study. Table V compares the correlations obtained in these three studies. Although the two studies of fraternal twins reared together used quite different samples, their results are similar. The correlations for separated fraternal twins are lower than those for fraternal twins reared together; however, the differences do not reach significance. It is noteworthy that the lowest correlation in all three samples is for memory.

The sample of Swedish twins reared together mentioned earlier allows a comparison of twins of the same nationality. The reared-apart twin correlation of 0.44 for Raven's Progressive Matrices is not significantly lower than the reared-together twin correlation of 0.48.

Two factors could influence the similarity of fraternal twins reared apart in the present study: degree of separation and selective placement. As mentioned earlier, the sample was intentionally selected not to meet the most stringent criteria for separation. The influence of degree of separation was, however, examined and found not to interact significantly with twin similarity. Selective placement [in this case 0.35 for socioeconomic status (SES)] may also affect measures of twin similarity. That SES is an important environmental variable influencing cognitive ability is suggested by the correlation of 0.42 between the twins' first principal-component scores and the rearing fathers' SES. However, this is not an indication that twin similarity is elevated as a result of selective placement for SES. The difference in the SES of the cotwins' fathers correlates only 0.005 with differences in the cotwins' first principal-component scores. Another way of examining this is to partial out the difference in the fathers' SES from the cotwins' correlations for cognitive ability. When this is done, the twin correlations for general cognitive ability are diminished only slightly (from 0.52 to 0.50). Thus, selective placement for SES has a negligible effect on twin resemblance in this study.

The power of the present study is limited to detecting major effects of the degree of separation on twin resemblance. No significant effects were found for the index; however, significant effects, including an influence on Verbal Ability/Perceptual Speed, were found for *age* at separation. The results are in a counterintuitive direction: twins separated earlier are more similar than twins separated later. Although an effect was not found for the measure of general cognitive ability, the direction of significant effects found was similar to that found in a study of IQ of separated identical twins (Vandenberg and Johnson, 1968). For 37 pairs of identical twins, the mean IQ difference for twins separated before 12 months of age was 7.6; for twins separated after 12 months of age, the difference was 9.6. Even the lack of a significant interaction between twin similarity and degree of separation suggests that shared early environment does not contribute to twin similarity later in life. These results are particularly convincing in that several aspects contributing to early contact were included in the separation index. Vandenberg and Johnson (1968, p. 218) conclude,

> It should be noted that the chief finding is that a longer common environment does not result in greater similarity between members of twin pairs, even though the negative obtained relation also appears to merit consideration and, if possible, explanation.

Taylor (1980, p. 86) takes issue with the conclusions of Vandenberg and Johnson, arguing that

> if there is any effect at all, it is in the direction of an environmental hypothesis: the IQ correlations for the late separation are generally higher.

However, Taylor's analyses are based on the arbitrary and impotent approach of dividing the small samples of separated twins into those separated before 6 months or after 6 months and then computing correlations for the two samples. Taylor does not find significant correlations with age at separation, nor does Bouchard (1983), replicating Taylor's approach but using data from an alternate IQ test administered to most of the separated twins.

The present sample is too small and lacks appropriate data to test hypotheses explaining the counterintuitive findings. Additional studies of samples including identical twins reared apart and matched samples of twins reared together implementing model testing techniques are necessary to assess more definitively the relative importance of additive genetic and shared and nonshared environmental factors for general and specific cognitive abilities. The major import of the present results, in agreement with Vandenberg and Johnson, is that a shared early environment does not appear to make twins more similar in cognitive ability later in life.

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