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Genetic and Environmental Influences on Special Mental Abilities in a Sample of Twins Reared Apart

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Abstract. The Minnesota Study of Twins Reared Apart has conducted comprehensive medical and psychological assessments of monozygotic (N = 49) and dizygotic (N = 25) twin pairs, separated early in life (average age of separation = 0.3 and 1.1 years, respectively) and reared apart during the formative years (average age of reunion = 30.3 and 37.2 years, respectively). The twins are administered two special mental ability batteries. The Hawaii Battery (H-B), supplemented by several Educational Testing Service tests, is administered toward the beginning of the assessment week. The Comprehensive Ability Battery (CAB) is administered toward the end of the assessment week. All data are age- and sex-corrected. The average MZA and DZA intraclass correlations for the 15 H-B subtests were 0.45 and 0.34, respectively, and the average MZA and DZA intraclass correlations for the 13 subtests of the CAB were 0.48 and 0.35, respectively. Biometric model-fitting of these data indicate an average heritability of about 0.50. Data for groups of subtests in the Verbal, Spatial, Perceptual Speed and Accuracy and Memory domains were compared to a meta-analysis of the special mental ability findings in the ordinary twin literature. The Spatial domain appears to yield the highest and the Memory domain the lowest heritabilities.

Key words: Twins reared apart, Special mental abilities

INTRODUCTION

There have been numerous studies of special mental abilities using ordinary twins [3,18]. The earlier studies of twins reared apart by Newman et al [17], Shields [21], and Juel-Nielsen [9] focused primarily on IQ. The Minnesota Study of Twins Reared Apart, consequently, included an extensive battery of special mental abilities

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in order to expand knowledge in this area. The tests were chosen with several goals in mind. First, the tests had to cover the four major domains that are widely agreed upon as major special mental abilities: Verbal, Spatial, Perceptual Speed and Accuracy and Memory, with a minimum of four tests per domain. Second, it was desirable to use specific tests on which kinship data other than twins had been gathered. Thirdly, it was important to include tests representing Cattell's theory of fluid-crystallized intelligence.

Once the sample size is sufficiently large, the following questions can be addressed: a) Are the different cognitive abilities equally or differentially heritable? [4]; b) Are the genetic influences upon the individual cognitive abilities the result of a single and general genetic factor, or are there genes that specifically influence some cognitive tests, but not others? [13]; c) What is the degree of assortative mating for special mental abilities and how does it influence genetic and environmental variance estimates? In the meantime, the twin sample has been used as an ordinary adoption sample, in which the environmental correlates of special mental abilities, as well as their correlations with information-processing abilities have been explored [16]. In this paper, the results of estimating genetic and environmental influences on special mental abilities based on the twins reared apart sample using a model fitting approach are presented. In addition, a meta-analysis of ordinary twin studies of Verbal, Spatial, Perceptual Speed, and Accuracy and Memory abilities is presented, and the findings are compared with the results from the present study of twins reared apart.

METHOD

1. The Twin Sample

The sample consists of monozygotic (MZA) and dizygotic (DZA) twin and triplet sets who participated in the Minnesota Study of Twins Reared Apart [1,2]. Participants engage in approximately 50 hours of medical and psychological assessment at the University of Minnesota Psychology Department and Medical School. The majority of the twins reside in the United States and Great Britain, with several coming from other countries. Several twins did not complete the full test battery, due to age, disabilities, etc.; thus, the sample size varies slightly across tests. Table 1 presents characteristics for 146 individuals studied. The sample generally includes 49 MZAs (47 pairs and 2 triplets) and 25 DZAs (there were several MZA-DZA triplet sets, so that 4 of the sets shared a common member; a few twin pairs did not complete both test batteries). The sample is predominantly female (64%) and adult (mean age = 39.9 yr, sd = 11.8 yr). The sets of genetically related individuals were separated very early in life (0.5 yr on average) and were generally not reunited until middle adulthood (mean age of reunion = 32.6 yr). It would be difficult to account for much of the similarity between these individuals in terms of direct contact or shared environments.

Zygosity determination was based on the analysis of eight blood group systems, four serum proteins, six red blood cell enzymes, fingerprint ridge count, ponderal index, and cephalic index as explained by Lykken [11]. The probability that a DZA pair would be concordant on all markers, and thus missclassified, is less than 0.001.

Table 1 - Mean age at testing, separation and reunion of twins reared apart

Twin type	Number of sets	Mean age (yr) at Testing	Separation	Reunion
MZA				
Male[a]	20	35.8	0.2	28.8
Female	29	41.1	0.4	31.3
Total	49	38.9	0.3	30.3
DZA				
Male	5	40.8	1.2	35.4
Female	16	43.7	0.9	40.5
Opposite sex	4	29.5	1.3	27.5
Total	25	40.8	1.1	37.2

[a] Contains two sets of identical triplets.

2. Measures

Participants in the Minnesota Study of Twins Reared Apart complete a six-day psychological and medical assessment. The present study is concerned only with the Special Mental Ability assessments.

The Special Mental Ability psychometric assessment consisted of two major test batteries, a supplemented version of the Hawaii Battery (H-B) and the Comprehensive Ability Battery (CAB). The H-B was chosen because it was previously used in the Hawaii study of cognition [4]. The University of Minnesota version was supplemented with three subtests selected from the Kit of Factor-Referenced Cognitive Tests (the Identical Pictures, Cubes and Paper Folding subtests [5]). In addition, two subtests were deleted because they closely resembled tests already included in the assessment. Data on the supplemented H-B has been previously reported [16]. The CAB [7] is composed of 20 subtests. The Aiming, Auditory Ability, Spontaneous Flexibility, Ideational Fluency, Originality and Representative Drawing subtests were not administred. Data from the Esthetic Judgment scale, which is not a mental ability test, is omitted from this report. A description of all the subtests used and their reliabilities is given in Table 2.

3. Procedure

The H-B was administered during the early part of the assessment week and the CAB was administered during the latter part. (See Bouchard [1] for a standard assessment schedule for a pair of reared apart twins.) Substantial age and sex effects

Table 2 - Description and reliabilities of the psychometrically assessed special mental abilities

Test	Description and source	Test time	Reliability
Verbal			
Vocabulary - H-B	Subject identifies which of four alternatives is a synonym of the probe word (PMA)	3 min	0.96
Vocabulary - CAB	Same as above	3.5 min	0.78
Proverbs - CAB	Subject identifies which of four alternatives is a synonym of the probe saying	3.25 min	0.78
Vocabulary - WAIS	Subject defines probe words	not timed	0.94
Similarities - WAIS	Subject indicates how two objects are similar	not timed	0.87
Comprehension - WAIS	Subject must furnish answers to questions	not timed	0.79
Space			
Card Rotation - H-B	Subject identifies all of 8 alternatives that are a two-dimensional rotation of the probe stimulus (ETS)	2 parts 3 min each	0.88
Cubes - H-B	Subject determines wether two cubes, with their three exposed sides labeled, are rotations of each other (ETS)	2 parts 3 min each	0.71
Mental Rotations - H-B	Subject identifies which two of four alternatives are rotations of a three-dimensional probe stimulus (Vandenberg)	10 min	0.88
Space - CAB	Subject identifies all of 8 alternatives that are a two-dimensional rotation of the probe stimulus	5 min	0.86
Paper Form Board - H-B	Subject shows how individual component figures can be used to constitute the desired arranged composites (ETS)	3 min	0.84
Paper Folding	Subject identifies which of five unfolded alternatives has a pattern of holes consistent with a single hole placed in the folded probe (ETS)	2 parts 3 min each	0.80
Hidden Patterns	Subject identifies which spatial patterns contain the probe figures (ETS)	2 parts 3 min each	0.92
Flexibility of Closure - CAB	Subject identifies the pattern found in a series of figures	5 min	0.79
Block Design - WAIS	A version of the Kohs blocks	varies	0.86
Perceptual Speed and Accuracy			
Lines and Dots - H-B	Subject forward traces a path through a grid in order to pass through as many heavy dots as possible	5 min	0.89
Identical Pictures - H-B	Subject identifies which of five alternative figures is identical to the probe figure (ETS)	2 parts	0.85
Perceptual speed - CAB	Subject identifies which pairs of numbers or letters are the same	4.5 min	0.64
Digit Symbol - WAIS	Subject must associate certain symbols with certain other symbols with speed and accuracy	1.5 min	0.92

(continued)

Table 2 - *Continued*

Test	Description and source	Test time	Reliability
Memory			
Immediate Visual Memory - H-B	Subject is given one minute to memorize pictures of 40 common objects and must then identify which of these objects is contained in a new list of 40 objects	1 min	0.58
Delayed Visual Memory - H-B	After 4 intervening tests (approximately 20 minutes) subject is again tested for recognition of originally memorized objects	1 min	0.62
Meaningful Memory - CAB	Subject must associate an item with a descriptor and identify the descriptor from alternatives when they are presented after an interfering task	1.5 min	0.84
Memory Span - CAB	A forward digit span task	8 min	0.96
Associate Memory CAB	Subject must associate a meaningless figure with a two-digit number and must identify the number from a list when shown the figure	5.5 min	0.79
Digit Span - CAB	A backward and forward digit span task	varies	0.71
Other Tests			
Pedigrees - H-B	Subject answers questions concerning familial relationships given access to a schematic family tree (PMA)	4 min	0.72
Word Fluency - CAB	Subject completes anagrams	3 parts 1.5 min each	0.78
Word Beginnings and Endings - H-B	Subject generates as many words as possible that begin and end with the specified letters (ETS)	2 parts 3 min each	0.71
Things - H-B	Subject is asked to generate as many instances as possible of things satisfying a specified criterion (ETS)	2 parts 3 min each	0.74
Subtraction and Multiplication - H-B	Subject subtracts two-digit numbers and multiplies a two-digit number by a one-digit number (ETS)	2 parts 2 min each	0.96
Speed of Closure - CAB	Subject must identify an incomplete word and choose it from a list of words with their letter order scrambled	5 min	**0.71**
Spelling - CAB	Subject must choose the incorrectly spelled word from a list of five	5 min	0.78
Mechanical Ability - CAB	Subject must identify tools and mechanical principles	not timed	0.72
Induction - CAB	Subject must identify one of five-letters series that does not follow the same rule as the others	6 min	0.74
Number - CAB	Subject must complete arithmetic problems	5.5 min	**0.79**

Note: All tests are discussed elsewhere [4,5,7,14].
CAB = Comprehensive Ability Battery, ETS = Educational Testing Service Kit of Confirmed Factors, PMA = Primary Mental Abilities, WAIS = Wechsler Adult Intelligence Scale.
Reliabilities are internal consistency measures unless they are in bold. Bold figures are retest measures. All figures are taken from the sources cited above.

could lead to overestimation of both the degree of twin similarity and the magnitude of the correlation between test scores [15], so all variables were adjusted for these effects prior to estimation of correlations. All available data were used to estimate the coefficients in the regression of test score on age and age^2, fit separately for the two sexes. These coefficients were then used to define the age-sex adjusted scores.

4. Genetic Analysis

Details of our model have been described elsewhere [16]; we consequently provide only a brief summary. We assume: 1) all resemblance between reared apart relatives owes to genetic factors, 2) there is no assortative mating, 3) all genetic effects are additive (ie, there is no dominance or epistasis), 4) genetic and environmental effects are independent (ie, there is no genotype-environment covariance) and combine additively in the determination of the phenotype (ie, there is no genotype by environment interaction).

The evidence indicates that selective placement on factors likely to influence special mental abilities does not pose a problem for this data set [16]. The effect of assortative mating is to increase the genetic resemblance among first-degree relatives as compared to what their resemblance would be under random mating. Assortative mating (which certainly exists for cognitive abilities) will lead to an increase in DZA relative to MZA resemblance and thus an underestimation of the magnitude effects. Finally, there is little empirical support that either genotype-environment covariation [19] or genotype-environment interaction [20] are important sources of variation for cognitive abilities.

Based upon this assumed model, the expected mean squares between and within MZA and DZA sets can be derived as functions of two parameters, the variance of genetic factors, V_g, and the variance of environmental factors, V_e.

We fitted two models: 1) a "general" model that involved estimation of both V_g and V_e, and 2) a restricted model that involved estimation of V_e only. The statistical test associated with the general model tests the adequacy of fit of the general model to the twin data and is primarily sensitive to two of the constraints imposed by that model: the total variance for the two types of individuals is equal, and the DZA correlation is half the MZA correlation. Comparison of the restricted model with the general model is used to test the significance of genetic factors.

RESULTS

The twin mean squares and intraclass correlations, as well as the results of the genetic analyses, are given in Tables 3 and 4 for the H-B and the CAB, respectively. The results of the genetic analysis include 1) the variance component estimates, 2) the proportion of variance associated with genetic factors (ie, the heritability, h^2), 3) the p-value for the test of the fit of the general model and 4) the p-value for the

Table 3 - Mean squares, intraclass correlations and results of genetical model analysis for Hawaii Battery

Variable	MZA			DZA			Parameter estimates			p-value for test of	
	MSB	MSW	r	MSB	MSW	r	G	E	h	General model	No genetic effect
Vocabulary	1.65	0.61	0.46	1.16	0.64	0.29	0.45	0.55	0.45	0.64	<0.001
Word Beg. & End.	2.14	0.45	0.65	0.84	0.14	0.71				0.006	
Pedigrees	1.30	0.50	0.44	1.74	0.61	0.48	0.56	0.49	0.53	0.28	<0.001
Things	1.32	0.67	0.32	1.43	0.59	0.41	0.38	0.64	0.37	0.48	0.01
Subt. & Mult.	1.50	0.72	0.34	1.48	0.40	0.57	0.38	0.62	0.38	0.13	0.01
Card Rotations	1.62	0.31	0.67	1.56	0.78	0.34	0.74	0.32	0.69	0.76	<0.001
Cubes	1.33	0.56	0.41	1.25	1.12	0.06	0.42	0.65	0.39	0.40	0.03
Mental Rotations	1.42	0.46	0.51	1.42	0.88	0.23	0.55	0.48	0.53	0.69	0.001
Paper Form Board	1.81	0.57	0.52	0.83	0.62	0.15	0.53	0.54	0.50	0.25	<0.001
Paper Folding	1.61	0.55	0.48	1.34	0.51	0.45	0.51	0.52	0.49	0.47	<0.001
Hidden Patterns	1.76	0.56	0.51	1.01	0.45	0.38	0.54	0.48	0.53	0.22	<0.001
Lines and Dots	1.35	0.66	0.34	1.49	0.92	0.24	0.38	0.62	0.38	0.76	0.01
Identical Pictures	1.78	0.47	0.58	1.11	0.52	0.36	0.58	0.44	0.57	0.43	<0.001
Delayed	1.15	0.43	0.45	1.72	1.13	0.21	0.67	0.50	0.53	0.08	0.01
Immediate	1.10	0.86	0.12	1.28	0.82	0.22	0.17	0.84	0.17	0.73	0.25
Mean			0.45			0.34			0.47		

Note: Degrees of freedom are 42-47 for dfb MZA, 45-50 for dfw MZA, 22-24 for dfb DZA and 23-25 for dfw DZA.
Data from [19].

Table 4 - Mean squares, intraclass correlations and results of genetical model analysis for Comprehensive Ability Battery

Variable	MZA			DZA			Parameter estimates			p-value for test of	
	MSB	MSW	r	MSB	MSW	r	G	E	h	General model	No genetic effect
Verbal	1.63	0.32	0.67	1.41	0.46	0.51	0.65	0.30	0.68	0.59	<0.001
Number	2.01	0.41	0.66	0.97	0.63	0.21	0.69	0.39	0.64	0.36	<0.001
Space	1.62	0.42	0.59	1.60	0.45	0.56	0.64	0.40	0.61	0.31	<0.001
Speed of Closure	1.07	0.57	0.31	1.49	0.65	0.40	0.39	0.56	0.41	0.33	0.033
Perceptual Speed	1.23	0.53	0.40	1.27	0.40	0.52	0.39	0.50	0.44	0.24	<0.001
Induction	1.21	0.49	0.42	1.69	0.84	0.34	0.55	0.51	0.52	0.30	<0.001
Flexibility of Closure	1.31	0.66	0.33	1.32	0.91	0.18	0.36	0.68	0.35	0.88	0.135
Associative Memory	1.79	0.58	0.51	0.84	0.77	0.04	0.51	0.56	0.48	0.34	<0.001
Meaningful Memory	1.41	0.60	0.40	1.70	0.99	0.26	0.54	0.63	0.46	0.52	0.032
Memory Span	1.22	0.71	0.26	1.39	0.71	0.32	0.32	0.69	0.32	0.64	0.156
Spelling	1.59	0.34	0.64	1.49	0.51	0.49	0.65	0.33	0.66	0.64	<0.001
Mechanical Ability	1.02	0.35	0.49	2.33	1.89	0.10				0.00	<0.001
Word Fluency	1.51	0.39	0.59	1.78	0.33	0.68	0.68	0.37	0.65	0.07	0.104
Mean			0.48			0.35			0.52		

Note: Degrees of freedom are 39-46 for dfb MZA, 41-48 for dfw MZA, 24-26 for dfb DZA, and 25-27 for dfw DZA.

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test that there is no genetic effect. Parameter estimates are reported only when the general model statistically fitted the mean squares.

For the H-B, the general model fit the mean square data for all the H-B subtests with the exception of Word Beginnings and Endings and, with the exception of Immediate Visual Memory, the genetic variance component was significant. On average, the proportion of the variance associated with genetic factors appears to be largest for the Spatial Ability tests and least for Visual Memory, but there are very significant exceptions for specific individual tests. It is worth noting that for some tests (eg, Pedigrees, Paper Folding), while the MZA and DZA correlations are comparable, significant genetic effects were observed. This reflects the relatively small size of the DZA sample so that the DZA correlation does not significantly deviate from one half the MZA correlation as implied by the general model.

Results for the CAB are very similar to the H-B as shown by a comparison of the means in the two tables. The general model fit all the CAB subtests with the exception of Mechanical Ability. With the exception of Word Fluency, Memory Span and Flexibility of Closure, the genetic component was statistically significant. The high MZA correlation, relative to the DZA correlation for Mechanical Ability, suggests that this trait may be emergenic [10,12]. The model just barely fit Word Fluency. Word Fluency is the most similar measure in the CAB battery to Word Beginnings & Endings in the H-B, suggesting that the higher DZA than MZA correlation for both tests is real for this sample. Indeed, this effect is found in a number of the speeded tests in both batteries (eg, Things, Subtraction and Multiplication, Perceptual Speed). No explanation for this phenomenon is currently available. The proportion of variance associated with genetic factors appears to be largest for Verbal Ability tests on the CAB with no group showing an especially low level, although the Memory Span subtest shows the lowest heritability.

In order to compare the present results with those for twins reared together, the meta-analysis of the literature on special mental abilities presented by Nichols has been updated [18]. We present results for the four major domains of special mental abilities, Verbal, Spatial, Perceptual Speed and Accuracy and Memory. In order to enhance the comparisons, we have added MZA and DZA correlations from the Wechsler Adult Intelligence Scale subtests [14] from the twin reared apart study where they are relevant. The names of the specific subtests used in the MZA and DZA samples are given in the note section of each table.

The results for Verbal Ability measures are shown in Table 5 in the form of a stem-and-leaf display. The stem-and-leaf display has the virtue of presenting all the actual data in an easily interpretable form and effectively illustrates the wide variation in results yielded by brief mental ability tests. The Falconer [6] method of estimating heritability, $2(r_{mz} - r_{dz})$, yields a lower estimate (twins reared together data = 0.36; twins reared apart data = 0.28) than the model-fitting approach. The difference between the reared-apart and the reared-together twins of each type directly estimates the shared environmental effect. The MZ data yields a figure of 0.23 and the DZ data yields a figure of 0.19. The Falconer method, $(2r_{dz}) - r_{mz}$, yields a higher estimate of shared environmental effects (0.38). These results most likely reflect, in part, the influence of assortative mating for Verbal Abilities [4].

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Table 5 - Stem-and-leaf displays of twin intraclass correlations for measures of verbal ability for MZT, MZA and DZT, DZA twin pairs

	MZT twins		DZT twins	
	Stem	Leaf	Stem	Leaf
	9	0	9	
	8	1 1 2 3 3 3 3 5 6 6 6 7 7 8 9	8	1
	7	2 3 4 5 6|6|7 8 9 9	7	0 4
	6	3 3 4 5 6 8 9 9	6	2 3 4 6 7 7 8 8 9 9
	5	2 3 8	5	0 1 2|2|3 3 6 6 7 7 7 7 8
	4	1 3 4	4	2 2 3 3 4 4 5 6 7
	3	3	3	1 3 5 5
	2		2	2 3 4 7 8
	1	3 8	1	5
	0		0	
Weighted mean r		0.74		0.56
Number of samples		43		45
Mean sample size (pairs)		67	89	

	MZA twins		DZA twins	
	Stem	Leaf	Stem	Leaf
	9		9	
	8		8	
	7		7	
	6	0 3	6	
	5		5	4
	4	1 4 6|9	4	9
	3		3	|6
	2		2	2 9 9
	1		1	
	0		0	
Mean r		0.51		0.37
Number of cases		49		25

Note: The stem unit is 0.1. The stem entry 8 followed by a leaf entry of 0 therefore indicates a correlation coefficient of 0.80. Each digit in a sequence of "leaves" indicates a different correlation coefficient.
The median correlation is indicated by "|".

Table 6 shows the stem-and-leaf display for Spatial Ability measures. The Falconer estimates of heritability (twins reared together = 0.48; twins reared apart = 0.44) are much closer to the model-fitting results for the same abilities than the Verbal Ability data. The estimates of shared environmental effects based on comparing MZT vs MZA and DZT vs DZA correlations are 0.10 and 0.08. The reared-together data yield a slightly higher estimate of 0.15. These results are consistent with the much lower estimates of assortative mating for spatial abilities than verbal abilities [4].

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Table 6 - Stem-and-leaf displays of twin intraclass correlations for measures of spatial ability for MZT, MZA and DZT, DZA twin pairs

	MZT twins		DZT twins	
	Stem	Leaf	Stem	Leaf
	9	1	9	
	8	0 1 5 7 8	8	
	7	0 1 1 2 2 2 4 5 6 7 8 9	7	2
	6	0 0 0|1|2 3 5 5 7 8 8 9 9	6	0 7
	5	1 2 4 5 5 8 8 9 9 9	5	3 3 3 4 7 8
	4	2 3 3 3 5 6 8 8 9	4	1 1 2 3 3 4 4 4 5 5 5 6 8 9
	3	5 7	3	3 3 3 4 5 5 6 6 6 8|8 8 9 9
	2	1 8 9	2	0 0 0 1 2 5 5 5 7 8 9
	1		1	0 5 6 9
	0		0	
			−0	2
			−1	2
Weighted mean r		0.63		0.39
Number of samples		55		54
Mean sample size (pairs)		88		70
	MZA twins		DZA twins	
	Stem	Leaf	Stem	Leaf
	9		9	
	8		8	
	7	2	7	
	6	7	6	
	5	1 1|2|9	5	6
	4	1 8	4	5
	3	3	3	4 8|9|
	2		2	3
	1		1	6 8
	0		0	6
Mean r		0.53		0.31
Number of cases		49		25

Note: The stem unit is 0.1. The stem entry 8 followed by a leaf entry of 0 therefore indicates a correlation coefficient of 0.80. Each digit in a sequence of "leaves" indicates a different correlation coefficient.
The median correlation is indicated by "|".
MZA and DZA twin tests include: Card rotations, Cubes, Vandenberg Mental Rotations, Paper Form Board, Paper Folding, Hidden Patterns, CAB-Space, WAIS Block Design.

Table 7 shows the stem-and-leaf display for Perceptual Speed and Accuracy ability measures. The Falconer estimates of heritability are 0.42 and 0.16. The inconsistency of these results are due to the high DZA correlations for speed tests discussed earlier and perhaps the small number of tests (sampling variation). The estimates of shared environmental effects based on comparing MZT vs MZA and

Table 7 - Stem-and-leaf displays of twin intraclass correlations for measures of perceptual speed and accuracy for MZT, MZA and DZT, DZA twin pairs

	MZT twins		DZT twins	
	Stem	Leaf	Stem	Leaf
	9		9	
	8	0 2	8	
	7	0 2 4 6 6 6 9	7	
	6	1 3 4 4 4 7 7|8	6	1 3 3 9
	5	1 1 9	5	0 2 2 5 5 6
	4		4	0 1 2 5|9|
	3		3	2 2 3 6
	2		2	4 5
	1		1	
	0		0	
Weighted mean r		0.70		0.49
Number of samples		20		21
Mean sample size (pairs)		81		68

	MZA twins		DZA twins	
	Stem	Leaf	Stem	Leaf
	9		9	
	8		8	
	7		7	
	6	6	6	
	5	8	5	2 8
	4	0	4	
	3	4	3	2
	2		2	4
	1		1	
	0		0	
Mean r		0.50		0.42
Number of cases		49		25

Note: The stem unit is 0.1. The stem entry 8 followed by a leaf entry of 0 therefore indicates a correlation coefficient of 0.80. Each digit in a sequence of "leaves" indicates a different correlation coefficient.
The median correlation is indicated by "|".
MZA and DZA twin tests include: H-B Lines & Dots (Elithorn Mazes), PMA Identical Pictures, CAB-Perceptual Speed, WAIS Digit Symbol.

DZT vs DZA correlations are 0.20 and 0.07. The reared-together data yields a somewhat higher estimate of 0.28. With regard to the magnitude of the heritability, the reared-together data are consistent with the MZA data and with the low level of assortative mating for Perceptual Speed and Accuracy [4].

Table 8 - Stem-and-leaf displays of twin intraclass correlations for measures of memory ability for MZT, MZA and DZT, DZA twin pairs

	MZT twins		DZT twins	
	Stem	Leaf	Stem	Leaf
	9		9	
	8		8	
	7	1	7	
	6	2 3 9	6	
	5	3 7 8	5	3 8
	4	0 3 4 5 7|9	4	5 6 9 9
	3	6 9	3	0 3 3 3|4 5
	2		2	3 9
	1	7	1	
			0	1
			–0	8
Weighted mean r		0.51		0.35
Number of samples		16		16
Mean sample size (pairs)		82		83

	MZA twins		DZA twins	
	Stem	Leaf	Stem	Leaf
	9		9	
	8		8	
	7		7	
	6	2	6	
	5	1	5	
	4	0|5	4	
	3		3	2
	2	6	2	1|2 6
	1	2	1	
	0		0	4 8
Mean r		0.39		0.19
Number of cases		49		25

Note: The stem unit is 0.1. The stem entry 8 followed by a leaf entry of 0 therefore indicates a correlation coefficient of 0.80. Each digit in a sequence of "leaves" indicates a different correlation coefficient.
The median correlation is indicated by "|".
MZA and DZA twin tests include: WAIS Digit Span, CAB Assoc. Mem., CAB Meaningful Mem., CAB Memory Span, H-B Delayed Visual Mem., H-B Immediate Visual Mem.

Table 8 shows the stem-and-leaf display for Memory ability measures. The Falconer estimates of heritability are 0.32 and 0.40. These estimates are in excellent agreement with the MZA estimate of 0.39. The heritability of Memory test appears to be lower than the other special mental abilities. The estimates of shared environmental effects based on comparing MZT vs MZA and DZT vs DZA correlations are 0.12 and 0.16. The reared-together data yield an estimate of 0.19. It should be noted that the Memory tests are less reliable than all other tests in the batteries.

DISCUSSION

For all the special mental abilities, except three (Immediate Visual Memory - H-B, Memory Span - CAB and Flexibility of Closure - CAB), a genetic component was needed to statistically account for the twin data. The two special mental ability batteries given at different times during the assessment week clearly replicate each other. Under the present formulation, the relatively large DZA correlations have been accounted for by statistical variability (ie, the DZA correlations are not significantly greater than one half the MZA correlation). Alternative explanations are obviously possible and are being explored (eg, similar twins are more likely to identify each other, simultaneous assessment leads to similarity, etc). In any case, it will be difficult to account for the MZA correlations without reference to the influence of genetic factors.

The comparisons of the reared-apart and reared-together correlations for Verbal, Spatial, Perceptual Speed and Accuracy, and Memory tests confirm the results of the model-fitting in general, but suggest lower heritabilities. The comparisons also highlight the important role of shared environmental factors as determinants of special mental abilities. These results are in striking contrast with the clear indication, from the same reared-apart sample, that shared environmental factors are at best of minor importance in the personality domain [22] and cardiovascular domain [8]. These data also show that only modest weight should be given to the results of any single study with modest sample sizes utilizing only one or a few brief subtests.

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