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MULTIVARIATE ANALYSIS OF COGNITIVE AND TEMPERAMENT MEASURES IN 24-MONTH-OLD ADOPTIVE AND NONADOPTIVE SIBLING PAIRS

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Summary—The genetic and environmental etiologies of covariation among measures of temperament (the Bayley Infant Behavior Record's Affect and Task Orientation Scales and the first principal component from the New York Longitudinal Study's difficult temperament items) and cognition (the Bayley Mental Development Index [MDI] and the total score on the Sequenced Inventory of Communication Development [SICD]) were assessed at 24 months of age in 70 biologically related and 66 unrelated pairs of siblings in the Colorado Adoption Project. Between- and within-pair mean cross products were equated to expectations using the LISREL multiple-group specification (Fulker, Baker and Bock, 1983) to obtain maximum-likelihood estimates of genetic and environmental factor loadings and specific variances. The full one-factor model, with one general factor and five specific factors, provides a satisfactory fit to the data ($\chi^2 = 27.8$, df $= 30$, $P = 0.58$). Genetic influences are important for the Bayley MDI and SICD language measures, but not for temperament measures. Little or no evidence was found for shared-sibling environmental influences for any of the measures. Various hypotheses regarding genetic and environmental correlation structures were also tested.

INTRODUCTION

Data collected from biologically related and unrelated sibling pairs provide a powerful behavioral genetic design with which to study the etiology of individual differences in behavioral development. This design circumvents the problems associated with twin and parent–offspring designs. For instance, differences in gestational age among twin pairs may yield inflated twin correlations, and analyses of parent–offspring adoption data assume that measures taken during infancy and adulthood are isomorphic. Sibling data have been collected in the Colorado Adoption Project (CAP) and this paper reports the first multivariate analyses of these data to assess the genetic and environmental etiologies of variation and covariation of behaviors during infancy.

Although univariate analyses of data from adoptive and nonadoptive sibling pairs provide measures of the relative importance of genetic and shared environmental influences, multivariate analyses of such data are even more informative. Especially interesting are the possibilities for examining the etiology of covariation among different characters. The multivariate analysis of data from adoptive and nonadoptive sibling pairs tested in the CAP facilitates the investigation of the interrelationships between temperament and cognitive measures at the level of genetic and environmental influences as well as at the phenotypic level.

Data from the present study include five measures, two cognitive tests and three temperament ratings, taken from the CAP sibling sample when each of the children was 24 months old. The cognitive tests are the Bayley Mental Development Index (MDI; Bayley, 1969) and the Sequenced Inventory of Communication Development (SICD; Hedrick, Prather and Tobin, 1975); the temperament ratings are two scales from Bayley's Infant Behavior Record (IBR; Bayley, 1969), Affect and Task Orientation, and a difficult temperament rating from the New York Longitudinal Study (NYLS; Thomas and Chess, 1977). Previously reported CAP results have included parent–offspring analyses of these data. To summarize the findings briefly, evidence for parent–offspring resemblance due to both genetic and environmental influences has been found for the cognitive measures. However, little or no parent–offspring resemblance for the temperament variables has been found. Reports of these analyses and details about the CAP sample have recently been published by Plomin and DeFries (1985).

Twin analyses of the Bayley MDI and the IBR Affect-Extraversion rating from the Louisville Twin Study (LTS) have also been reported. The results from that study indicate that common environmental influences operate at 24 months of age to make twins similar to each other for the Bayley MDI and that genetic factors influence the Affect-Extraversion temperament measure (Buss and Plomin, 1984; Matheny, 1980; Wilson, 1983). Thus, the etiology of individual differences may differ for the Bayley MDI and IBR temperament ratings. The CAP sibling data will provide additional evidence for this hypothesis.

METHOD

Sample

Subjects were sibling pairs selected from the total sample of children participating in the Colorado Adoption Project (CAP). The CAP sample consists of 245 adoptive and 245 nonadoptive matched control families. The children are followed longitudinally and, whenever possible, a younger sibling of the first child recruited into the project is tested at the same ages on the same measures. This report is based on 66 pairs of biologically unrelated siblings, 48 adoptive and 18 adoptive/nonadoptive pairs, and 70 pairs of related nonadoptive siblings.

Measures

Each child participating in the CAP is administered a 2-h test battery near the second birthday; the mean age at test administration is 24.6 months with a standard deviation of 0.52 months. For the current analyses, five measures were selected to represent both the cognitive and temperament domains.

The MDI from the Bayley Scales of Infant Development (Bayley, 1969) is used as a measure of general mental development. The total score from the SICD (Hedrick *et al.*, 1975) is used as a measure of language development and also represents the cognitive domain.

Temperament variables include two scales taken from Bayley's IBR (Bayley, 1969), a tester assessment of the infant's test taking behaviours. The two scales were formed according to a factor analysis reported by Matheny (1980) by summing the items with the highest loadings on each of the two factors. Affect-Extraversion conveys a dual nature: It includes emotionality items ('emotional tone,' 'fearfulness') as well as sociability items ('responsiveness to examiner,' 'cooperativeness'). Items loading highest on the Task Orientation factor are 'responsiveness to objects,' 'attention span' and 'goal directedness.' Also included is a parental rating of their child's difficult temperament. This rating is the first principal component derived from items representing the nine dimensions of the NYLS (Thomas and Chess, 1977) and a general item measuring parental perceptions of difficult behavior in their children (for details concerning this measure, see Daniels, Plomin and Greenhalgh, 1984). For each temperament measure, directionality of a variable is indicated by its label, e.g. a high score on the difficult temperament dimension denotes that parents perceived the child as difficult.

The measures just described are reliable, widely used instruments which are generally accepted as representative of their respective domains. Moreover, there is evidence that these measures are interrelated (Plomin and DeFries, 1985; Daniels *et al.*, 1984); however, the etiology of these relationships is unknown.

Analyses

Table 1 presents the phenotypic correlations among the temperament and cognitive variables. With the exception of the correlation between the SICD and Difficult Temperament, the measures

Table 1. Phenotypic correlations among the cognitive and temperament variables

	Affect	Task orientation (TO)	Difficult temperament (DT)	SICD language (SICD)	Bayley (MDI)
Affect	—				
TO	0.56	—			
DT	−0.36	−0.38	—		
SICD	0.30	0.23	−0.14	—	
MDI	0.55	0.56	−0.27	0.43	—

Table 2. Mean-square and cross-product matrices for sibling pairs

	Affect	Task orientation	Difficult temperament	SICD language	Bayley MDI
Related pairs					
Between	64.41				
	9.40	10.32			
	−0.74	−0.35	0.89		
	34.13	11.58	−2.54	99.03	
	5.29	16.14	−4.92	135.33	368.96
Within	45.17				
	8.36	9.91			
	−0.34	−0.40	0.87		
	24.65	7.89	−0.65	55.19	
	27.53	10.21	0.63	52.68	149.79
Unrelated pairs					
Between	38.56				
	1.18	8.79			
	0.27	0.02	0.72		
	18.85	1.21	0.00	67.83	
	19.09	8.78	0.62	69.91	227.45
Within	38.26				
	6.93	9.70			
	−0.48	−0.06	0.84		
	10.53	1.25	−1.15	59.85	
	17.88	4.44	−2.71	66.11	183.08

are moderately intercorrelated. The negative correlations between Difficult Temperament and the other variables are in the expected direction, with more difficult children obtaining lower scores on the other measures.

A major objective of multivariate genetic analysis is to assess the genetic and environmental causes of phenotypic covariation. For the present analysis a multivariate genetic analysis of twin data proposed by Fulker, Baker and Bock (1983) was adapted for application to sibling data. The model examines genetic and environmental influences through a components of covariance approach. Between and within mean-square and cross-product matrices were formed using MANOVA for both biologically related and unrelated sibling pairs, yielding the four matrices shown in Table 2.

Expectations in terms of components of covariance for each of these matrices are formed in accordance with a genetic and environmental model shown in Table 3. In these expectations **A** is the additive genetic covariance matrix, **C** is the common (shared) environmental covariance matrix and **S** is the specific environmental covariance matrix.

In terms of the LISREL model, the four mean cross-product matrices have expectations $\Sigma = \Lambda\psi\Lambda'$, where Λ is a matrix of genetic and environmental factor loadings and ψ is a diagonal matrix of coefficients of the genetic and environmental model shown in Table 3. Various hypotheses can be easily tested with this model simply by changing the factor structure represented in Λ. A more general form of the model involves a correlated factor analysis in which the ψ matrix may be partitioned as follows:

$$\psi = \Gamma\Phi\Gamma'$$

where Φ is the correlation among factors and Γ is a diagonal matrix containing the square roots of the coefficients of the genetic and environmental components presented in the expectations in

Table 3. Expectations for mean-square and cross-product matrices

Related Between = 1.5A + S + 2C
Related Within = 0.5A + S
Unrelated Between = A + S + 2C
Unrelated Within = A + S

A = additive genetic covariance, C = common environmental covariance, S = specific environmental covariance

Table 4. Structure of the Γ matrices

Related Between =

$$
\begin{bmatrix}
\sqrt{1.5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \sqrt{1.5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \sqrt{1.5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \sqrt{1.5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \sqrt{1.5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \sqrt{2.0} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \sqrt{2.0} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \sqrt{2.0} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sqrt{2.0} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sqrt{2.0} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0
\end{bmatrix}
$$

Related Within = diagonal [$\sqrt{0.5}$ 0.0 1.0].
Unrelated Between = diagonal [1.0 $\sqrt{2.0}$ 1.0].
Unrelated Within = diagonal [1.0 0.0 1.0].
*Note—The Related Within, Unrelated Between and Unrelated Within matrices take the same form as the Related Between matrix with the values indicated in brackets forming the main diagonal.

Table 3. The corresponding Γ matrices are shown in Table 4. The first step in the present analysis uses a one-factor model, i.e. one general factor and five specifics for each of the genetic and environmental components. This structure of Λ is illustrated in Table 5, where each λ represents a factor loading and the matrix Φ is set to identify (I).

The program LISREL IV (Jöreskog and Sörbom, 1978) is used to fit the model to the data and obtain a maximum-likelihood estimate of the loadings λ. The Λ matrix in this application is three 5×6 matrices joined side by side forming a 5×18 matrix, each 5×6 matrix representing the factor structure for **A**, **C** and **S** components, respectively. Covariance matrices for **A**, **C** and **S** are calculated by multiplying each component matrix by its transpose. Univariate estimates of heritability, common environmentality and specific environmentality, as well as correlation matrices, were calculated from these component covariance matrices. The diagonal elements of **A**, **C** and **S** give the components of variance for each measure. Dividing through by the total variance yields the proportion of variance due to **A** as the heritability (h^2), that due to **C** as common environment (c^2), and that due to **S** as specific environment (s^2), where $h^2 + c^2 + s^2 = 1.0$.

RESULTS

The one-factor model fits very well, with a chi square value of 27.8 and 30 df ($P = 0.58$). The LISREL estimates for the matrix were used to calculate the univariate heritabilities and environmentalities presented in Table 6. Only the SICD language measure and the Bayley MDI show evidence for genetic influences. The proportions of variance due to specific environmental influences are substantial but, surprisingly, there is no evidence that shared family environmental influences account for much variance for any of these measures.

To test the significance of the estimates in Table 6, the fits of two reduced models were compared to that of the full model. The first model set the genetic matrix (**A**) equal to zero and the resulting change in chi square was significant, indicating that the genetic covariance matrix is nonzero ($\chi^2 = 26.6$, $P < 0.01$). The second reduced model set the common environment matrix (**C**) to zero

Table 5. Structure of the Λ matrix

$$
\Lambda = \quad \overbrace{}^{\Lambda_A} \qquad \overbrace{}^{\Lambda_C} \qquad \overbrace{}^{\Lambda_S}
$$

$$
\begin{bmatrix}
\lambda_{a1} & \lambda_{as1} & 0 & 0 & 0 & 0 & \lambda_{c1} & \lambda_{cs1} & 0 & 0 & 0 & 0 & \lambda_{s1} & \lambda_{ss1} & 0 & 0 & 0 & 0 \\
\lambda_{a2} & 0 & \lambda_{as2} & 0 & 0 & 0 & \lambda_{c2} & 0 & \lambda_{cs2} & 0 & 0 & 0 & \lambda_{s2} & 0 & \lambda_{ss2} & 0 & 0 & 0 \\
\lambda_{a3} & 0 & 0 & \lambda_{as3} & 0 & 0 & \lambda_{c3} & 0 & 0 & \lambda_{cs3} & 0 & 0 & \lambda_{s3} & 0 & 0 & \lambda_{ss3} & 0 & 0 \\
\lambda_{a4} & 0 & 0 & 0 & \lambda_{as4} & 0 & \lambda_{c4} & 0 & 0 & 0 & \lambda_{cs4} & 0 & \lambda_{s4} & 0 & 0 & 0 & \lambda_{ss4} & 0 \\
\lambda_{a5} & 0 & 0 & 0 & 0 & \lambda_{as5} & \lambda_{c5} & 0 & 0 & 0 & 0 & \lambda_{cs5} & \lambda_{s5} & 0 & 0 & 0 & 0 & \lambda_{ss5}
\end{bmatrix}
$$

*Note—The subscripts a_1–a_5, c_1–c_5, and s_1–s_5 represent the general factor loadings for each of the five variables. The subscripts as_1–as_5, cs_1–cs_5, and ss_1–ss_5 represent the specific factor loadings for each of the five variables.

Table 6. Univariate estimates of heritability, common environmentality, and specificity environmentality

	h^2	c^2	s^2
Affect	0.00	0.13	0.87
Task orientation	0.01	0.01	0.98
Difficult temperament	0.02	0.00	0.98
SICD language	0.46	0.03	0.51
Bayley MDI	0.61	0.06	0.33

Table 7. Specific environment correlations

	Affect	Task orientation (TO)	Difficult temperament (DT)	SICD language (SICD)	Bayley (MDI)
Affect	—				
TO	0.35	—			
DT	−0.10	−0.05	—		
SICD	0.57	0.28	−0.08	—	
MDI	0.52	0.25	−0.07	0.41	—

and the resulting chi square was not significantly different from that for the full model ($\chi^2 = 7.84$, $df = 10$, $P > 0.50$); thus, the covariance matrix of shared environmental influences can be dropped from the model. In other words, these results support the finding that common environmental influences are not important causes of variation or covariation for these variables.

The results of fitting the one-factor model to the data indicate significant genetic influences on the two cognitive measures, no common environmental influences, and specific environmental influences on all five of the variables. To estimate the genetic correlation between the cognitive measures (the extent to which the same genes influence both measures) and the specific environmental correlations among all of the measures, another model was tested. This model allowed only the SICD language and Bayley MDI scores to load on the general genetic factor, set the common environment matrix to zero, and allowed one general factor and five specifics for unshared environmental influences. This model also fits well, with a chi square of 45.2 and 43 df ($P < 0.38$). The resulting estimate of the genetic correlation between the SICD and MDI is 0.89, suggesting that many of the same genes cause individual differences in the two behaviors. In contrast, as shown in Table 7, the specific environment correlations among the variables are somewhat lower.

In summary, the results of this first multivariate analysis of adoptive and nonadoptive sibling data indicate significant genetic influence on the two cognitive tests examined; moreover, to a substantial degree the same genetic influences affect both measures. Common environment has little effect on any of the measures examined, but specific environment is important for each of the measures.

DISCUSSION

The results of this first multivariate analysis of data from adoptive and nonadoptive sibling pairs are somewhat surprising for two reasons. First, because of the results from the LTS, we expected to find that shared family environment would have more of an effect on sibling similarity for the measures that we examined. One explanation can be found in the differences in testing procedures. In the LTS, twin pairs are tested on the same day and are perhaps affected by daily circumstances that occur before they enter the laboratory. Both members of the twin pair would share these experiences which could influence test performance. The CAP sibling pairs, who are on average born and tested approximately 3 years apart, would not be influenced by this type of shared environmental influence. Of course, shared prenatal and early postnatal environmental influences may also cause higher twin correlations. The hypothesis that twins share environmental influences to a greater extent than do nontwin siblings receives support within the LTS: Twin-sibling correlations in infancy for the Bayley MDI are only half the magnitude of the twin correlations (Wilson, 1983). Twin-sibling data within the LTS have not as yet been reported for measures other than the MDI.

Second, we expected to find that a two-factor model would fit the data, with one-factor representing the cognitive domain and one representing the temperament domain. However, when we fitted such a model, the fit was extremely poor ($\chi^2 = 87.6$, df = 30, $P < 0.001$). Examination of the genetic matrix clearly reveals that the same genetic influences are affecting the two cognitive measures. This corroborates the results of another CAP analysis which reported that the SICD at 24 months is related to parental general cognitive ability (Thompson and Plomin, 1987). However, relatively little genetic variance or covariance is evident for the temperament measures. It is of interest to note that the structure of the specific environmental correlation matrix (see Table 7) is highly congruent with that of the phenotypic correlation matrix presented in Table 1; thus, the observed interrelationships among these variables may be due primarily to specific environmental influences. It is possible that events idiosyncratic to each test session are influencing the infant's test performance on all of the measures. For instance, if a specific event influences an individual infant's mood, this might affect the test results for that individual only. Such unique environmental influences could thus structure both the specific environmental and phenotypic correlation matrices.

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