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READING PERFORMANCE AND GENERAL COGNITIVE ABILITY: A MULTIVARIATE GENETIC ANALYSIS OF TWIN DATA

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Summary—Confirmatory factor analyses of three reading performance measures and full-scale Wechsler IQ data obtained from 146 pairs of twins of average or above average reading ability were conducted. A simple factor model which contained one general reading factor, three specific factors, and a single set of IQ loadings was employed to assess the extent to which phenotypic correlations among the reading measures are due to IQ. The significance of the general reading factor was determined by constraining its loadings to be zero and then computing a χ^2 goodness of fit for the reduced model. The resultant change in χ^2_3 of 114.09 ($P < 0.001$) indicates that there is covariation among the reading measures independent of IQ. This same factor model was then fitted to the genetic, common environmental, and unique environmental covariance components estimated from the twin data, and several hypotheses regarding the structures of the three variance/covariance component matrices were tested. Although deleting the common environmental component from this model did not result in a significant change in χ^2 ($\chi^2_{10} = 9.67$, $P > 0.5$), the removal of the genetic covariance component did ($\chi^2_{10} = 20.26$, $P < 0.05$). Subsequent confirmatory factor analyses of the genetic and unique environmental covariance matrices indicated that the reading factor could not be removed from either matrix without causing a highly significant deterioration in fit. However, the similarity between the genetic and phenotypic factor loadings suggests that the phenotypic factor structure is largely genetic in origin.

INTRODUCTION

Measures of intelligence and reading performance are highly correlated (Strang, 1968). Although the magnitude of this relationship may be somewhat less for children in the early grades (Stanovich, Cunningham & Freeman, 1984), IQ is clearly a major source of variance in reading performance and may account for a substantial proportion of the covariance among various reading measures. Confirmatory factor analysis of twin data facilitates direct tests of the etiology of covariation among variables (Heath, Neale, Hewitt, Eaves & Fulker, 1989).

The primary objective of the present study was to assess the relationship among three measures of reading performance and general intelligence using a twin sample. First, a form of confirmatory factor analysis was employed to test the hypothesis that phenotypic covariance among the reading measures is due to IQ. Second, the genetic and environmental etiologies of the phenotypic relationships were assessed.

METHOD

Subjects

Twin pairs in this study served as control *S*s in the Colorado Twin Study of Reading Disability (DeFries, Fulker & LaBuda, 1987). Twins were ascertained through cooperating school districts within a 150-mile radius of Denver, Colo. Potential control *S*s with no evidence of reading problems based upon an inspection of school records were administered an extensive psychometric test battery. To be included in the final sample, control twins had to be classified as unaffected using a discriminant function analysis of six test scores: Reading Recognition, Reading Comprehension, and Spelling subtests of the Peabody Individual Achievement Test (PIAT) (Dunn & Markwardt, 1970), the Coding-B and Digit Span scaled scores from the Wechsler Intelligence Scale for Children—Revised (WISC-R) (Wechsler, 1974), and the Colorado Perceptual Speed Test (DeFries, Plomin, Vandenberg & Kuse, 1981). This discriminant function correctly reclassified 93.6% of the reading-disabled (RD) *S*s and 92.9% of the non-reading-disabled (NRD) *S*s in an independent sample of 140 RD and 140 NRD *S*s.

Because the reading and IQ test scores of RD *S*s are highly attenuated, only data obtained from the control (i.e. NRD) *S*s in the Colorado Twin Study of Reading Disability were analyzed in the present study. However, some degree of attenuation will also be present in a control group who have been selected for an absence of reading problems. To the extent that such attenuation is present in our samples, environmental influences shared by members of twin pairs may be somewhat underestimated (Neale, Eaves, Kendler & Hewitt, 1989). Zygosity was determined using the diagnostic rules developed by Nichols & Bilbro (1966) which have a reported accuracy of approx. 95%. In questionable cases, blood diagnosis was used. This sample consisted of 146 twin pairs, 86 identical pairs (48 female, 38 male) and 60 same-sex fraternal pairs (28 female, 32 male) ranging in age from 7 yr 8 months to 20 yr 6 months. The average age was 12 yr 6 months.

Tests

The reading measures used were subtests of the PIAT. They included Reading Recognition, Reading Comprehension, and Spelling. Reading Recognition (REC) consists of matching like letters, naming letters, and reading individual words aloud; essentially, it measures word decoding skills. Reading Comprehension (COMP) involves deriving meaning from printed words. The *S* is asked to read a sentence silently, then point to an illustration which best represents the meaning of that sentence. Spelling (SPELL) requires correct identification of letters or words. The measure of general cognitive ability was the WISC-R full-scale IQ for *S*s <17 yr and the Wechsler Adult Intelligence Scale—Revised (WAIS-R) (Wechsler, 1981) full-scale IQ for older *S*s.

Analysis

In order to explore the structure of the phenotypic correlations among the reading measures and IQ, the simple factor model shown in Table 1 was employed. In this model, the first factor is identified with IQ. This factor therefore effectively partials out IQ from the remaining variables. After IQ has been partialed out, the remaining partial correlations are explained by a general reading factor and three factors specific to the three reading measures. The factor loadings in the full model were estimated from the phenotypic correlations using confirmatory factor analysis. Trial values for the loadings were chosen and an expected covariance matrix, **E**, computed. This matrix was compared to the observed phenotypic matrix, **P**, using the log likelihood function:

$$\mathrm{F} = N[\log_e(\mathrm{DET}(\mathbf{E})/\mathrm{DET}(\mathbf{P})) + \mathrm{tr}(\mathbf{PE}^{-1}) - k)],$$

where N is the degrees of freedom for *S*s, or 291, and k is the number of variables, or 4. The MINUIT optimization package (Cern, 1977) was used to minimize this function. The change in χ^2 was used to assess the statistical significance of the factors in the model.

The phenotypic covariances among the three reading measures and IQ were then subjected to a multivariate genetic analysis. The observed covariances are assumed to be due to the sum of their genetic and environmental covariances as follows:

$$\mathbf{P} = \mathbf{A} + \mathbf{E}_C + \mathbf{E}_U,$$

where **P** is the phenotypic variance/covariance matrix, and **A**, $\mathbf{E}_C$, and $\mathbf{E}_U$ are the additive genetic, common environmental, and unique environmental covariance component matrices, respectively. The genetic and environmental influences are assumed to be uncorrelated.

In order to examine the genetic and environmental etiology of these phenotypic relationships between reading ability and IQ, two 8×8 covariance matrices—one for the identical (MZ) pairs and one for the fraternal (DZ) pairs—were calculated from the data. The four variables (IQ and three reading measures) exist for each member of a twin pair, thus generating an 8×8 matrix of

Table 1. Factor pattern matrix

	General factors		Specific factors		
Variables	IQ	READING	REC	COMP	SPELL
IQ	x	o	o	o	o
REC	x	x	x	o	o
COMP	x	x	o	x	o
SPELL	x	x	o	o	x

Table 2. Observed phenotypic correlations

	IQ	REC	COMP	SPELL
IQ	1.00	0.38	0.47	0.13
REC		1.00	0.50	0.46
COMP			1.00	0.15
SPELL				1.00

variances and covariances for both MZ and DZ twin pairs. Together with the phenotypic covariances, a comparison of the MZ and DZ cross covariances between pairs in the off diagonals facilitates estimation of the genetic and environmental components (Heath *et al.*, 1989).

The genetic and environmental covariance matrices were fitted to the same factor model used in the phenotypic analysis, i.e. a factor model with a general IQ factor, a reading factor, and a specific factor for each reading measure. This full model provided a starting point to which alternative models could be compared and evaluated according to the changes in χ^2. Again, MINUIT was used when fitting the various models to the data.

RESULTS AND DISCUSSION

The phenotypic correlations among the reading measures and IQ are presented in Table 2. These correlations exhibit the typical positive manifold displayed by a group of cognitive tests. The results obtained from fitting the full model to this phenotypic correlation matrix are depicted in the path diagram shown in Fig. 1. This model did not yield a perfect fit ($\chi^2_1 = 2.41$, $P > 0.1$) because it was fitted under the constraint that specific variances be non-negative. As expected, the IQ factor has a loading of 1.00 on the first variable since the IQ factor and the first variable are equated in this model. However, this factor has only moderate to low loadings on the reading measures. This result suggests that IQ does not explain much of the variance in the reading measures or the covariances between them. In contrast, the loadings from the reading factor tend to be higher, especially the loading of 0.92 on Reading Recognition. Notice that Reading Recognition also has zero specific variance, which indicates that this measure identifies the reading factor once IQ has been partialed out.

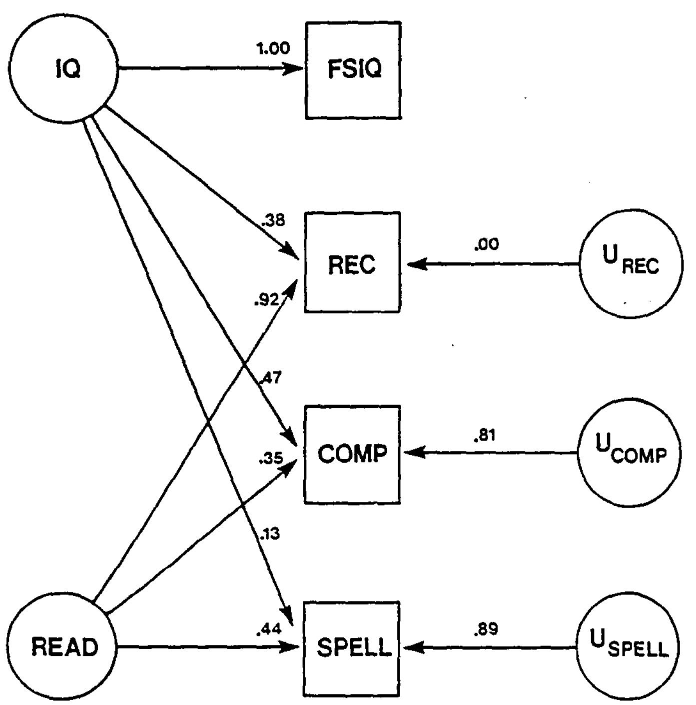

Fig. 1. Factor analysis of phenotypic correlations among Reading Recognition (REC), Reading Comprehension (COMP), Spelling (SPELL), and IQ (FSIQ).

The significance of the reading factor was determined by removing it from the model, re-estimating the remaining loadings, and comparing the χ^2 goodness of fit. The resulting χ^2_3 of 116.5 yielded a highly significant change ($\chi^2_2 = 114.09$, $P < 0.001$). Thus, significant covariation exists among the reading measures independently of IQ.

Correlation matrices for the three components of covariation (genetic, common environmental, and unique environmental) are displayed in Table 3. When the full model was fitted to the corresponding covariance component matrices, the fit was less than adequate $\chi^2_{26} = 42.98$, $P < 0.025$). However, it is against this model that the reduced genetic and common environmental models were compared. Estimates of heritability and environmentality were also computed and can be found in Table 4. Genetic influences account for 21–57% of the phenotypic variance of the individual measures. Estimates of environmentality due to influences common to members of a twin pair range from 7 to 36%, and unique environmental factors account for 25–53% of the total variance.

Results of the model comparisons are presented in Table 5. In the second model, when the genetic component was removed, the change in χ^2 was significant ($\chi^2_{10} = 20.26$, $P < 0.05$). Thus, significant genetic covariance exists among IQ and the three reading measures. In contrast, in the third model, when the common environmental component was removed, the change in χ^2 was nonsignificant ($\chi^2_{10} = 9.67$, $P > 0.5$), probably indicating insufficient statistical power to resolve this component adequately. In fact, the estimates for this source of variation indicated in Table 4 are nontrivial.

Thus, having arrived at a reasonably parsimonious genetic and environmental model which includes only the genetic and unique environmental components, the etiology of the reading factor was assessed. First, when we omitted the reading factor from the genetic covariance component, the result was a highly significant change in χ^2 ($\chi^2_3 = 26.31$, $P < 0.001$). Likewise, when the reading

Table 3. Correlation matrices for the three components of covariation estimated from the full model

	IQ	REC	COMP	SPELL
Genetic				
IQ	1.00	0.58	0.71	0.56
REC		1.00	0.78	0.99
COMP			1.00	0.77
SPELL				1.00
Common environmental				
IQ	1.00	0.76	0.99	−0.39
REC		1.00	0.84	0.31
COMP			1.00	−0.26
SPELL				1.00
Unique environmental				
IQ	1.00	−0.01	0.02	0.10
REC		1.00	0.26	0.23
COMP			1.00	0.07
SPELL				1.00

Table 4. Estimates of heritability and environmentality from the full model

	Phenotype			
	IQ	REC	COMP	SPELL
Heritability	0.57	0.45	0.27	0.21
Common environmentality	0.18	0.07	0.19	0.36
Unique environmentality	0.25	0.48	0.53	0.43

Table 5. Model comparisons

Model	χ^2	d.f.	χ^2 change	d.f.	Comparison
(1) Full model	42.98*	26			
(2) Common and unique environmental (no genetic)	63.24**	36	20.26*	10	2 vs 1
(3) Genetic and unique environmental (no common)	52.65*	36	9.67	10	3 vs 1
(4) No genetic reading factor	78.96***	39	26.31***	3	4 vs 3
(5) No unique environmental reading factor	73.22***	39	20.57***	3	5 vs 3

*$0.01 < P < 0.05$; **$0.001 < P < 0.01$; ***$P < 0.001$.

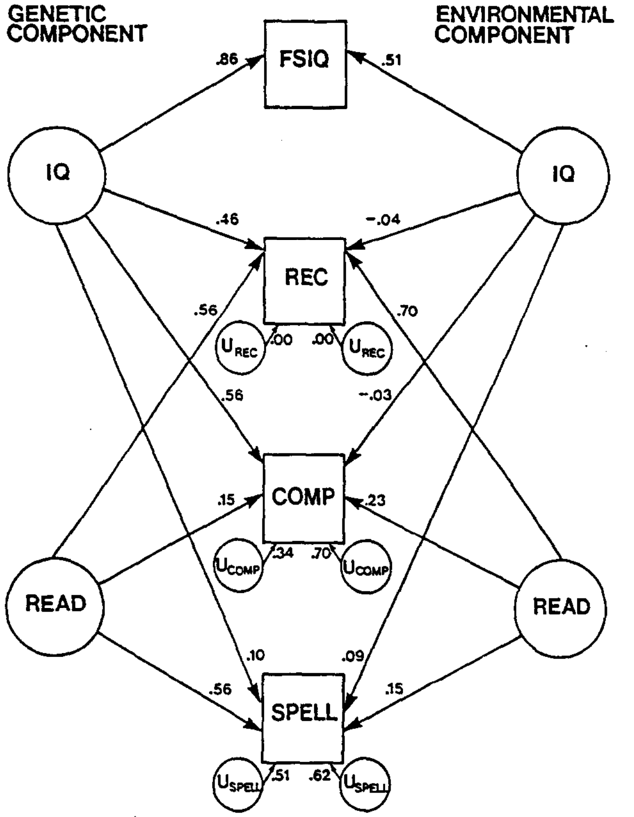

Fig. 2. Standardized factor loadings obtained from fitting the most parsimonious model to genetic and unique environmental covariance matrices.

factor was omitted from the covariance matrix due to unique environmental influences, the change in χ^2 indicated a highly significant deterioration in fit ($\chi^2_3 = 20.57$, $P < 0.001$). These results suggest that both genetic and unique environmental covariances exist among the reading measures independently of IQ.

The factor loadings for the final model are depicted in Fig. 2. The factor loadings in the genetic component are very similar to those shown in Fig. 1 for the phenotypic model. In fact, the rank order of the loadings is almost identical. In contrast, there is a somewhat different pattern for the environmental component—each test has only one major loading, either involving a general or a specific factor. Thus, the environmental pattern appears to be largely specific in character.

In conclusion, results of a confirmatory factor analysis of IQ and reading performance data obtained from a sample of 146 pairs of twins indicate that there is significant covariation among the reading measures independent of general intelligence. Moreover, results of a multivariate genetic analysis of these data suggest that the phenotypic factor structure is largely genetic in origin.

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