INTELLIGENCE **14**, 245–257 (1990)

Genetic Correlations Between Reading Performance and IQ in the Colorado Adoption Project

LON R. CARDON [1]
LISABETH FISHER DILALLA [1]
ROBERT PLOMIN [2]
J.C. DEFRIES [1]
DAVID W. FULKER [1]

[1]*Institute for Behavioral Genetics, University of Colorado, Boulder*
[2]*College of Human Development, The Pennsylvania State University*

A multivariate conditional path model was fitted to general cognitive ability and reading performance data obtained from members of 119 adoptive families and 120 nonadoptive families. Measures include Wechsler-R Full-Scale, Verbal, and Performance IQ scores and Peabody Individual Achievement Test (PIAT) Reading Recognition scores for both parents and 7-year-old offspring. Results of model-fitting analyses provide evidence for moderate phenotypic correlations between the PIAT and IQ measures, substantial heritability for IQ and Reading Recognition, and large genetic correlations among the traits, particularly with respect to Verbal IQ and Reading Recognition. Thus, IQ–academic achievement relationships may be largely due to genetic influences.

The intelligence test developed by Binet and Simon in 1905 was intended as a predictor of classroom achievement of young children (Weinberg, 1989). Although the Binet and subsequent intelligence tests are valid predictors of academic achievement (Dunn & Markwardt, 1970), the etiology of the relationship between tests of mental ability and school achievement has not been investigated extensively. It is reasonable to hypothesize that associations between ability and achievement measures are mediated environmentally, for example, as the educational system strives to foster both ability and achievement. However, genetic

This research was supported in part by grants HD-10333, HD-18426, and HD-19802 from the National Institute of Child Health and Human Development (NICHD), and by grant MH-43899 from the National Institute of Mental Health. The paper was written while the first two authors were supported by training grant HD-07289 from the NICHD.

We would like to thank Rebecca G. Miles for her expert editorial assistance in the preparation of this manuscript.

Correspondence and requests for reprints should be sent to Lon R. Cardon, Institute for Behavioral Genetics, Campus Box 447, University of Colorado, Boulder, CO 80309.

mediation of the ability–achievement association is also plausible—that is, genetic factors that influence scores on measures of intelligence might affect performance on achievement measures as well. The nature of this etiology is an empirical matter.

Although numerous previous studies suggest that the heritability of general cognitive ability is substantial (see reviews by Bouchard & McGue, 1981; Plomin & DeFries, 1980), relatively few studies have investigated the nature of genetic influences on measures of school achievement during middle childhood. One small sibling adoption study reported heritability estimates of .26 and .53 for reading and math achievement, respectively (Scarr & Carter-Saltzman, 1982). Studies of twin samples by Matheny and Dolan (1971) and Harris (1982) yielded heritability estimates ranging from .38 to .68 for a variety of reading achievement measures. Such results suggest that tests of academic achievement as well as intelligence show genetic influence.

The average correlation between IQ tests and various measures of scholastic achievement is approximately .50 (Jensen, 1969). Given this large phenotypic correlation between two variables, both of which appear to be highly heritable, it seems quite possible that individual differences in measures of general cognitive ability and school achievement may be due at least in part to the same component processes.

To our best knowledge, only one multivariate behavioral genetic analysis of IQ and achievement data has been reported previously. Brooks, Fulker, and DeFries (1990) analyzed reading performance data (Peabody Individual Achievement Test [PIAT]; Dunn & Markwardt, 1970) and Full-Scale Wechsler IQ scores obtained from a sample of 86 monozygotic (MZ) twin pairs and 60 same-sex dizygotic (DZ) twin pairs in the Colorado Reading Project. Multivariate analysis of these data yielded substantial heritability estimates for both IQ and PIAT Reading Recognition, .57 and .45, respectively. Moreover, estimates of the phenotypic and genetic correlations between these two measures were .38 and .58, suggesting that the relationship between intelligence and school achievement is largely genetic in origin.

The purpose of the present study was to investigate the genetic and environmental etiologies of individual differences in tests of intelligence and school achievement. More specifically, we explored the relationship between Reading Recognition and intelligence as previously examined by Brooks et al. (1990). However, rather than the twin method used earlier by Brooks et al., our multivariate behavioral genetic analysis employed an adoption design. In addition to a bivariate analysis of PIAT Reading Recognition and Full-Scale IQ, we also undertook a trivariate analysis involving both the Verbal and Performance IQ subscales. A multivariate adoption model (Rice, Carey, Fulker, & DeFries, 1989) was fitted to data from a sample of 119 adoptive and 120 nonadoptive families participating in the Colorado Adoption Project (Plomin, DeFries, & Fulker, 1988) in order to assess the genetic and environment etiologies of the IQ–achievement relationship.

We formulated several predictions regarding the outcome of the study. We expected to find a substantial phenotypic correlation between Full-Scale IQ and Reading Recognition. Moreover, we predicted larger phenotypic correlations between Verbal IQ and Reading Recognition than between Performance IQ and Reading Recognition (see Sattler, 1982). We also expected to obtain substantial heritability estimates for both intelligence and Reading Recognition, congruent with those reported from previous studies. Finally, given the combination of high heritabilities and phenotypic correlations among the measures, we predicted a substantial genetic correlation between intelligence and school achievement, particularly with respect to verbal intelligence.

METHOD

Subjects

The Colorado Adoption Project (CAP) is a longitudinal, prospective study of genetic and environmental determinants of behavioral development. It employs a "full" adoption design in that a variety of measures are administered to both adoptive and biological parents, as well as to the adopted children (DeFries & Plomin, 1978). Adopted children are separated from their biological parents a few days after birth and are placed in their adoptive homes within 1 month. Nonadoptive control families are matched to the adoptive families according to several criteria: age, education, and occupational status of the fathers, gender of the adopted child, and number of children in the family. Detailed descriptions of the CAP sample have been provided by Plomin and DeFries (1985).

The present sample consists of 119 adoptive families and 120 nonadoptive families participating in the CAP. The children in the sample were tested after completion of their first year in elementary school, at an average age of 7.4 years. Data from biological parents are not included in the present sample because the particular measures used in this study were not collected from biological parents.

Although the lack of available biological parent data prevents us from utilizing the full potential of the CAP adoption design, other partial adoption studies of intelligence have yielded results quite consistent with those of more complete adoption designs (see Scarr & Carter-Saltzman, 1982; Scarr & Weinberg, 1983). A slight loss of power to detect genetic effects may result from the absence of direct h^2 estimates provided by biological parent/adopted-offspring correlations. Nevertheless, the data are sufficient to yield adequate estimates of genetic and environmental transmission parameters.

Measures

Standardized intelligence measures used in the study were the Wechsler Adult Intelligence Scale-Revised (WAIS-R) (Wechsler, 1981) and the Wechsler Intelligence Scale for Children-Revised (WISC-R) (Wechsler, 1974). Standard scores from the Reading Recognition subtest (REC) of the Peabody Individual Achievement Test (PIAT) (Dunn & Markwardt, 1970) were obtained from both parents and offspring in the present CAP sample. The WAIS-R, WISC-R, and PIAT Reading Recognition measures appear to be highly isomorphic from childhood to adulthood and, thus, minimize potential contamination of model parameter estimates due to age-based differences in tests (see DeFries, Plomin, & LaBuda, 1987).

Analyses

The multivariate path model of genetic and environmental transmission developed by Rice et al. (1989) was applied to the CAP data. The model employs multivariate conditional paths (VanEerdewegh, 1982) to represent the effects of phenotypic assortment and cross-assortment, which provide identical expectations as correctly specified reverse paths (Fulker, 1988). Figure 1 shows the path diagram of the model as applied to the present sample, in which **h**, **e**, and ½ represent diagonal matrices of the square root of heritability and environmentality, and a diagonal matrix containing ½ in each element, respectively. Full nonsymmetric matrices of mate conditional path parameters (equated across family types), genotype–environment correlations, and maternal and paternal environmental transmission parameters are represented by **D**, **s**, **m**, and **f**, respectively.

Derivations of the parameter matrices for the present analysis differ somewhat from those reported by Rice et al. (1989) because our matrix respecification permits elimination of the parameter constraints previously required for model identification. The original model required parameterization of **e** and $\mathbf{R_E}$, a matrix of environmental correlations, whereas $\mathbf{R_P}$ (the expected phenotypic correlation matrix) and **s** were subject to constraints imposed by other model parameters, and **f** was derived from the parameter constraints. However, if **m** and **f** are modeled as product matrices **me** and **fe**, and $\mathbf{R_P}$ is estimated as a free symmetric correlation matrix, the **e**, $\mathbf{R_E}$, and product matrix **se** can be derived from extant model parameters.[1] This alteration in parameterization results in fewer overall estimated parameters and does not affect the expected adoptive and nonadoptive covariances derived from the path diagram by Rice et al. (1989). These changes also are equivalent to a multivariate extension of the univariate model outlined by Fulker et al. (1988) and recently described by Cyphers, Fulker, Plomin, and DeFries (1989).

For the present analyses, the multivariate model of parental transmission was first applied as a bivariate model to Full-Scale IQ scores and PIAT Reading Recognition data of CAP parents and offspring. Then, in order to explore the relationship between Reading Recognition and more specific components of

[1] $\mathbf{R_E}$ and **e** are derived as a matrix product, where $\mathbf{eR_Ee} = \mathbf{R_P} - (\mathbf{hR_Gh'} + \mathbf{hse'} + \mathbf{es'h})$. In a similar manner, $\mathbf{se} = \tfrac{1}{2}\mathbf{R_Gh'}\,\{(\mathbf{I} + \mathbf{D'R_P})\mathbf{me'} + (\mathbf{I} + \mathbf{DR_P})\mathbf{fe'}\}\,\{\mathbf{I} - [(\mathbf{I} + \mathbf{D'R_P})\mathbf{me'} + (\mathbf{I} + \mathbf{DR_P})\mathbf{fe'}]\}^{-1}$.

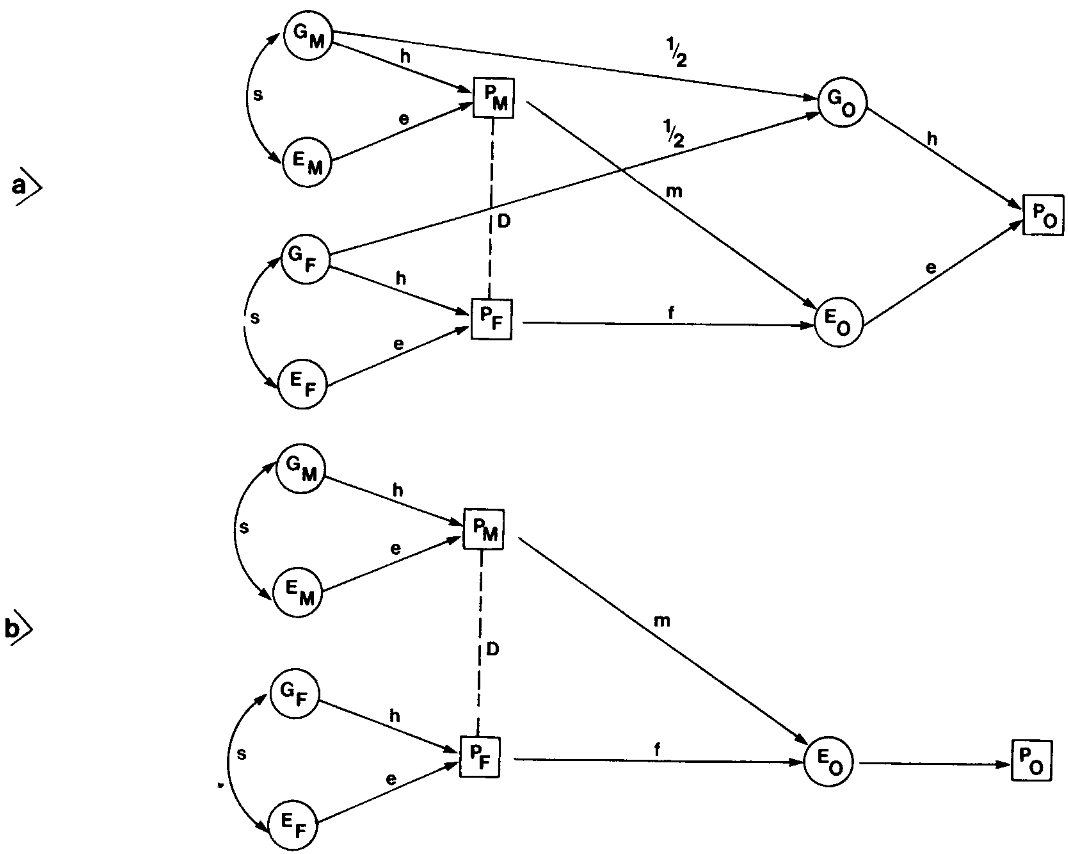

FIG. 1. Path models of genetic and environmental transmission using conditional path representation of assortment in: (a) nonadoptive control families and (b) adoptive families. [After "Multivariate Path Analysis of Specific Cognitive Abilities in the Colorado Adoption Project: Conditional Path Model of Assortative Mating" by T. Rice, G. Carey, D.W. Fulker, and J.C. DeFries, 1989, *Behavior Genetics*, Vol. 19, pp. 198,199].

intelligence, the Verbal and Performance IQ scores and the Reading Recognition data were fitted to a trivariate model of parental transmission.

The bivariate and trivariate path models were fitted to observed variance/covariance matrices of the adoptive and nonadoptive families. For the bivariate case, the observed statistics form two 6×6 matrices, one for adoptive mothers, fathers, and offspring and one for the members of nonadoptive families. A 9×9 matrix is formed for each family type when based on the trivariate model of REC data and Verbal and Performance IQ scores. The observed correlation matrices are presented in Appendix A.

The model was fitted to the data using maximum-likelihood estimation by the MINUIT package of numerical optimization routines (CERN, 1977). The following maximum-likelihood function was minimized:

$$F = \sum_{i=1}^{m} (N_i - 1.0)\,[\ln |\mathbf{E}_i| - \ln |\mathbf{S}_i| + \mathrm{tr}(\mathbf{S}_i\mathbf{E}_i^{-1}) - p_i],$$

where m is the number of observed and expected covariance matrices; p_i is the order of the ith matrix; and $\mathbf{S}_i$ and $\mathbf{E}_i$ are the observed and expected covariance matrices having $(N_i - 1.0)$ degrees of freedom. This function is distributed asymptotically as a chi-square statistic having the following degrees of freedom:

$$\mathrm{df} = \sum_{i=1}^{m} [p_i(p_i + 1)/2] - n,$$

where n is the number of estimated parameters. Function differences between full and reduced models also yield χ^2 values, which have degrees of freedom equal to the difference in number of parameters estimated by the two models. The full model was initially fitted to the observed matrices, and then reduced models were explored in order to test the significance of the parameter estimates.

RESULTS

Bivariate Model

The χ^2 test of goodness of fit for the full bivariate model has 22 degrees of freedom (42 observations minus 20 parameters). The χ^2 value of 37.70 obtained from fitting the model significantly exceeds its 22 degrees of freedom ($p <$ .025); however, given that the chi-square statistic is quite sensitive when applied to large samples (see Mulaik et al., 1989), the lack of fit may be due to the size of the present sample. A Bentler Noncentrality Normed Fit Index (Bentler, 1988) of .92 suggests an acceptable fit to the data independent of sample size. The estimated phenotypic correlation coefficient ($\mathbf{R_P}$) between PIAT Reading Recog-

TABLE 1
Parameter Estimates Resulting from Fit of Full and Reduced Models to Full-Scale IQ (IQ) and PIAT Reading Recognition (REC) Data

		Full Model		Reduced Model	
		REC	IQ	REC	IQ
h					
	REC	.71		.60	
	IQ		.42		.62
e					
	REC	.59		.80	
	IQ		.85		.79
$\mathbf{R_G}$					
	REC	1.00	1.00	1.00	0.90
	IQ		1.00		1.00
$\mathbf{R_E}$					
	REC	1.00	0.04	1.00	0.15
	IQ		1.00		1.00
$\mathbf{R_P}$					
	REC	1.00	0.45	1.00	0.43
	IQ		1.00		1.00
D[a]					
	REC	0.17	−0.13	0.11	−0.12
	IQ	0.13	0.21	0.11	0.20
m					
	REC	0.05	−0.03		
	IQ	−0.03	0.16		
f					
	REC	−0.34	0.26		
	IQ	0.22	−0.10		
s					
	REC	−0.05	0.14		
	IQ	−0.05	0.14		
		$\chi^2(22) = 37.70, p < .025$		$\chi^2(30) = 47.06, p < .05$	

[a]Rows, Mothers; Columns, Fathers

nition and IQ is .45. In contrast, the estimated genetic correlation ($\mathbf{R_G}$) between these two measures is unity, suggesting that individual differences in Reading Recognition and tests of general intelligence are due to the same genetic influences (see DeFries et al., 1987 for a discussion of alternative interpretations of high genetic correlations). The environmental correlation between the measures is .04, which also suggests that the phenotypic IQ/REC correlation is not due to environmental factors.

The maternal and paternal cultural transmission parameters (**m** and **f**) and the genotype–environment correlations (**s**) were dropped from the full model in an effort to obtain a more parsimonious explanation of the observed correlations.

The absence of the **m, f,** and **s** parameters results in a model in which the product matrices $\mathbf{eR_Ee'}$ and $\mathbf{hR_Gh'}$ sum to form the phenotypic correlation matrix $\mathbf{R_P}$. Comparison of this model with the full model indicated no significant loss of fit ($\chi^2(8) = 9.63, p > .25$). Parameter estimates from the full and reduced models are presented in Table 1.

In order to test the significance of the genetic parameters, further reduction of the model was attempted by dropping the **h** and $\mathbf{R_G}$ matrices. This model revealed an unacceptable loss of fit ($\chi^2(3) = 18.05, p < .001$). Therefore, the reduced model with the parameters listed in Table 1 was accepted as being most parsimonious. In general, parameter estimates from this reduced bivariate model are similar to those of the full model, yet more compatible with our expectations. The phenotypic correlation between REC and IQ is .43 and the heritability (h^2) estimates for Reading Recognition and Full-Scale IQ are .36 and .38, respectively. The estimated genetic correlation of .90 again indicates that the proportion of individual differences representing shared variance between these two measures is largely due to the same genetic influences.

Trivariate Model

Given the previous evidence that reading performance is more highly related to verbal skills than nonverbal aspects of intelligence (Bowers, Steffy, & Tate, 1988), a trivariate model was fitted to Verbal and Performance IQ and PIAT Reading Recognition data. The χ^2 goodness of fit for the full trivariate model has 48 degrees of freedom (90 observed statistics minus 42 parameters). The trivariate model fit the data well ($\chi^2(48) = 52.08, p > .25$), indicating that the genetic and environmental parameters better explain the joint transmission of Reading Recognition with both Verbal and Performance IQ than with only full scale intelligence.

A reduced model was fit to the trivariate data as in the bivariate analysis. This model, with **m, f,** and **s** parameters constrained to be zero, also fit the data well ($\chi^2(66) = 76.312, p > .10$) and did not result in a significant change in fit from the full model ($\chi^2(18) = 24.24, p > .10$). However, the genetic parameters could not be dropped from the reduced model without a significant loss of fit ($\chi^2(6) = 27.19, p < .001$). Thus, the reduced model with the genetic parameters included was accepted as most parsimonious. Table 2 shows the parameter estimates obtained from fitting both the full and reduced trivariate models.

The phenotypic correlations among the measures are moderate, ranging from .27 between Reading Recognition and Performance IQ to .46 for REC and Verbal IQ. Heritability estimates are .38 for REC, .36 for Verbal IQ, and .41 for Performance IQ. The genetic correlation between Reading Recognition and Verbal IQ is .96, whereas that between REC and Performance IQ is only .45. As hypothesized, these estimates indicate a much stronger genotypic relationship between Reading Recognition and Verbal IQ than between Reading Recognition and Performance IQ.

TABLE 2
Parameter Estimates Resulting from Fit of Full and Reduced Models to Verbal IQ (VIQ), Performance IQ (PIQ) and PIAT Reading Recognition (REC) Data

		Full Model			Reduced Model		
		REC	VIQ	PIQ	REC	VIQ	PIQ
h							
	REC	.73			.62		
	VIQ		.43			.60	
	PIQ			.63			.64
e							
	REC	.54			.79		
	VIQ		.83			.80	
	PIQ			.76			.77
R_G							
	REC	1.00	1.00	0.38	1.00	0.96	0.45
	VIQ		1.00	0.28		1.00	0.51
	PIQ			1.00			1.00
R_E							
	REC	1.00	0.01	0.12	1.00	0.16	0.15
	VIQ		1.00	0.48		1.00	0.40
	PIQ			1.00			1.00
R_P							
	REC	1.00	0.48	0.28	1.00	0.46	0.27
	VIQ		1.00	0.46		1.00	0.44
	PIQ			1.00			1.00
D[a]							
	REC	0.19	−0.24	0.08	0.18	−0.23	0.08
	VIQ	0.08	0.33	−0.16	0.07	0.32	−0.17
	PIQ	0.00	0.11	−0.00	−0.00	0.12	−0.00
m							
	REC	0.01	0.16	−0.20			
	VIQ	−0.02	−0.04	0.30			
	PIQ	0.12	−0.16	0.15			
f							
	REC	−0.39	0.18	0.12			
	VIQ	0.19	−0.00	−0.09			
	PIQ	0.27	0.05	−0.15			
s							
	REC	−0.13	0.19	0.05			
	VIQ	−0.12	0.19	0.05			
	PIQ	−0.13	0.12	0.02			
		$\chi^2(48) = 52.08, p > .25$			$\chi^2(66) = 76.31, p > .10$		

[a]Rows, Mothers; Columns, Fathers

DISCUSSION

The results of fitting a multivariate path model of parental transmission to Reading Recognition scores and Wechsler IQ data from the Colorado Adoption Project suggest a genetic etiology for the relationship between measures of general intelligence and school achievement. Moreover, the genetic correlation between Reading Recognition and Verbal IQ appears to be substantially greater than that between reading and Performance IQ. In contrast, environmental influences are specific to each measure and contribute little to the IQ–academic achievement relationship.

The results of our bivariate and trivariate analyses strongly suggest that hereditary influences cause the phenotypic resemblance between verbal intelligence and reading performance. The heritability estimates of the traits obtained from the fit of the reduced trivariate model, .38 for Reading Recognition and .36 for Verbal IQ, are consistent with estimates obtained from other studies of school-age children with their parents (Scarr & Carter-Saltzman, 1982) and from twin studies (Harris, 1986).

Parameter estimates obtained from the fit of the reduced trivariate model permit quantification of the extent to which phenotypic correlations between Reading Recognition and the IQ measures are due to genetic and environmental factors. The ratios of the elements of the genetic component product matrix ($\mathbf{hR_Gh'}$) to the corresponding elements of the $\mathbf{R_P}$ matrix reveal that 78% of the phenotypic correlation between Reading Recognition and Verbal IQ (r = .46) and 67% of that between Reading Recognition and Performance IQ (r = .27) are due to hereditary influences. These proportions, in combination with the estimates of large genetic correlations and small environmental correlations that were generated by all models fit to the data, converge to suggest substantial genetic commonality between measures of intelligence and verbal scholastic achievement.

Several main conclusions emerge from the study. First, one particular measures of school achievement, Reading Recognition, appears to be about as heritable as general intelligence. Second, Reading Recognition and general intelligence are moderately correlated phenotypically and the correspondence between these measures is predominantly genetic in origin. That Brooks et al. (1990) obtained a similar result from an analysis of twin data strongly supports this conclusion. Finally, Reading Recognition is more highly correlated with verbal intelligence than with nonverbal intelligence at the phenotypic level and the difference is even more pronounced at the level of the genotype. This finding suggests that heritable determinants of verbal ability scores are applicable both to school performance and to verbal intelligence, but that somewhat different mechanisms may be responsible for cognitive skills unrelated to those measured by tests of verbal abilities.

Although the present analysis is limited to reading achievement after the first year in school, its results, if replicated for other ages and other measures, carry far-reaching implications for educational theory. First, these results, as well as other studies of older children, suggest that school achievement measures are just as heritable as are scores on IQ tests. These are not merely statistically significant genetic effects—they account for over a third of the total variance. Although genetically conditioned characteristics are not immutable, this finding contrasts sharply with the widespread assumption that achievement tests solely assess what has been taught rather than characteristics of the learner. The second finding may be of even greater significance: The association between tests of achievement and intelligence is largely due to genetic factors. It has been known for a long time that IQ and school achievement measures are substantially correlated. However, the typical correlation of .50 means that there are many cases of bright children who do not achieve and vice versa. The present results imply that the two domains are nearly perfectly correlated in terms of genetic influence and that heredity is largely responsible for the phenotypic association. One implication is that the genetic covariance between achievement and mental ability can cloud the picture of educational progress as assessed by achievement measures. A more positive implication can be seen when the other side of the finding of genetic covariance is examined. That is, environmental factors are largely responsible for the *uncorrelated* components of IQ and achievement measures. Thus, the environmental impact of education lies in promoting that part of achievement which is independent of intelligence.

REFERENCES

Bentler, P.M. (1988). Comparative fit indexes in structural models. *UCLA Statistics Series #9*.

Bouchard, T.J., & McGue, M. (1981). Familial studies of inheritance: A review. *Science, 212*, 1055–1059.

Bowers, G.B., Steffy, R., & Tate, E. (1988). Comparison of the effects of IQ control methods on memory and naming speed predictors of reading disability. *Reading Research Quarterly, 23*, 304–319.

Brooks, A., Fulker, D.W., & DeFries, J.C. (1990). Reading performance and general cognitive ability: A multivariate genetic analysis of twin data. *Personality and Individual Differences, 11*, 141–146.

CERN (1977). *MINUIT: A system for function minimization and analysis of parameter errors and correlations*. Geneva, Switzerland: CERN.

Cyphers, L.H., Fulker, D.W., Plomin, R., & DeFries, J.C. (1989). Cognitive abilities in the early school years: No effects of shared environment between parents and offspring. *Intelligence, 13*, 369–386.

DeFries, J.C., & Plomin, R. (1978). Behavioral genetics. *Annual Review of Psychology, 29*, 473–515.

DeFries, J.C., Plomin, R., & LaBuda, M.C. (1987). Genetic stability of cognitive development from childhood to adulthood. *Developmental Psychology, 23*, 4–12.

Dunn, L.M., & Markwardt, F.C. (1970). *Examiner's Manual: Peabody Individual Achievement Test*. Circle Pines, MN: American Guidance Service.

Fulker, D.W. (1988). Path analysis of genetic and cultural transmission in human behavior. In B.S. Weir, E.J. Eisen, M.M. Goodman, and G. Namkoong (Eds.), *Proceedings of the Second International Conference on Quantitative Genetics*. Sunderland, MA: Sinauer Associates.

Fulker, D.W., DeFries, J.C., & Plomin, R. (1988). Genetic influence on general mental ability increases between infancy and middle childhood. *Nature, 336,* 767–769.

Harris, E.L. (1982). Genetic and environmental influences on reading achievement: A study of first- and second-grade children. *Acta Geneticae Medicae et Gemellologiae, 31,* 64–116.

Harris, E.L. (1986). The contribution of twin research to the study of the etiology of reading disability. In S.D. Smith (Ed.), *Genetics and learning disabilities.* Omaha: College-Hill Press.

Jensen, A.R. (1969). How much can we boost IQ and scholastic achievement? *Harvard Educational Review, 39,* 1–123.

Matheny, A.P., Jr., & Dolan, A.B. (1971). A twin study of genetic influences in reading achievement. *Journal of Learning Disabilities, 10,* 99–102.

Mulaik, S.A., James, L.R., Van Alstine, J., Bennett, N., Lind, S., & Stilwell, C.D. (1989). Evaluation of goodness-of-fit indices for structural equation models. *Psychological Bulletin, 105,* 430–445.

Plomin, R., & DeFries, J.C. (1980). Genetics and intelligence: Recent data. *Intelligence, 4,* 15–24.

Plomin, R., & DeFries, J.C. (1985). *Origins of individual differences in infancy: The Colorado Adoption Project.* Orlando, FL: Academic.

Plomin, R., DeFries, J.C., & Fulker, D.W. (1988). *Nature and nurture during infancy and early childhood.* Cambridge: Cambridge University Press.

Rice, T., Carey, G., Fulker, D.W., & DeFries, J.C. (1989). Multivariate path analysis of specific cognitive abilities in the Colorado Adoption Project: Conditional path model of assortative mating. *Behavior Genetics, 19,* 195–207.

Sattler, J.M. (1982). *Assessment of children's intelligence and special abilities* (2nd ed.). Boston: Allyn & Bacon.

Scarr, S., & Carter-Saltzman, L. (1982). Genetics and intelligence. In R.S. Sternberg (Ed.), *Handbook of human intelligence.* Cambridge: Cambridge University Press.

Scarr, S., & Weinberg, R.A. (1983). The Minnesota Adoption Studies: Genetic differences and malleability. *Child Development, 54,* 260–267.

VanEerdewegh, P. (1982). *Statistical selection in multivariate systems with applications in quantitative genetics.* Unpublished doctoral dissertation, Washington University, St. Louis, MO.

Wechsler, D. (1974). *Manual for the Wechsler Intelligence Scale for Children-Revised.* New York: Psychological Corporation.

Wechsler, D. (1981). *Manual for the Wechsler Adult Intelligence Scale-Revised.* New York: Psychological Corporation.

Weinberg, R.A. (1989). Intelligence and IQ: Landmark issues and great debates. *American Psychologist, 44,* 98–104.

APPENDIX A

Observed Correlation Matrices with Variances on the Diagonal for Adoptive (AM, AF, AO) and Nonadoptive Families (CM, CF, CO) in the CAP (FS, Full-Scale IQ; V, Verbal IQ; P, Performance IQ; REC, PIAT Reading Recognition)

Full-Scale IQ

AMFS	AMREC	AFFS	AFREC	AOFS	AOREC	CMFS	CMREC	CFFS	CFREC	COFS	COREC
120.15	0.43	0.35	0.18	0.07	−0.11	111.45	0.41	0.08	−0.03	0.21	0.17
	42.27	0.33	0.35	0.01	−0.06		20.03	0.17	0.06	0.18	0.25
		130.27	0.54	0.09	−0.00			120.10	0.54	0.22	0.28
			33.92	0.03	−0.08				39.70	0.12	0.16
	$n = 119$			117.34	0.28		$n = 120$			133.92	0.34
					50.17						67.08

Verbal IQ

AMV	AMREC	AFV	AFREC	AOV	AOREC	CMV	CMREC	CFV	CFREC	COV	COREC
107.40	0.48	0.40	0.22	0.11	−0.09	106.31	0.43	0.15	−0.02	0.22	0.27
	42.27	0.36	0.35	0.00	−0.06		20.03	0.12	0.06	0.16	0.25
		124.17	0.61	0.14	−0.04			121.16	0.55	0.20	0.28
			33.92	0.04	−0.06				39.70	0.11	0.16
	$n = 119$			133.33	0.27		$n = 120$			148.64	0.39
					50.17						67.08

Performance IQ

AMP	AMREC	AFP	AFREC	AOP	AOREC	CMP	CMREC	CFP	CFREC	COP	COREC
130.53	0.26	0.22	0.09	−0.03	−0.07	128.97	0.25	−0.10	−0.07	0.17	−0.02
	42.27	0.21	0.38	0.02	−0.06		20.03	0.16	0.06	0.16	0.25
		137.45	0.35	0.03	0.05			138.35	0.36	0.18	0.19
			33.92	0.01	−0.06				39.70	0.08	0.16
	$n = 119$			141.24	0.21		$n = 120$			150.38	0.16
					50.17						67.08