The genetic and environmental correlation between verbal and spatial intelligence

DENIS BRATKO

The genetic and environmental correlations between measures of verbal and spatial intelligence were estimated using the methodology of multivariate behavioral genetics. Two verbal (word fluency and vocabulary) and two spatial (visualization and spatial orientation) test scores were available for the 71 monozygotic and 78 dizygotic pairs of twins. A multivariate model including additive genetic and within-family environmental factors was specified to detect common sources of variance for the measures of verbal and spatial intelligence. The model fitted data well, and the maximum likelihood estimates of genetic and environmental correlations were calculated. The genetic correlations among measures of verbal and spatial intelligence varied in magnitude and exhibited a pattern similar to corresponding phenotypic correlations. On the other hand, correlations due to the within-family environmental influences were generally small. Thus, it was concluded that phenotypic correlations between measures of verbal and spatial intelligence may be largely due to genetic influences

More behavioral genetic data have been obtained for intelligence than for any other behavioral trait (for a recent review, see Loehlin, Willerman & Horn, 1988; Plomin, 1988; Plomin & Rende, 1991; Rose, 1995 Scarr & Carter-Saltzman, 1988). Majority of that research was based on psychometrically defined intelligence measured by paper-and-pencil tests. Accumulation of the large amount of data obtained by different methods (family, adoption and twin methods) resulted in well established fact, as indicated by several meta-analyses (Bouchard & McGue, 1981; Erlenmayer-Kimling & Jarvik, 1963; Plomin & DeFries, 1980), that genetic variation contributes significantly to individual variation in general intelligence or IQ. Recent model fitting analysis (Chipuer, Rovine & Plomin, 1990) of the covariance structure of the world's IQ data from various behavioral genetic designs, based on the Bouchard and McGue (1981) meta-analysis, indicated that about 50% of the variance of phenotypic IQ is attributable to the genetic influences.

But there is certainly more to characterizing human cognitive ability than could be achieved by the general intelligence or IQ score alone. However, much smaller number of behavioral genetic studies of cognitive abilities dealt with specific cognitive abilities. Two main questions raised in this research were: 1) whether some specific cognitive abilities are less heritable than others? and 2) does the genetic effects for different specific cognitive abilities overlap or independent genetic factors influence different abilities? Behavioral genetic research of specific cognitive abilities usually resulted with heritability estimates ranging from 30-50% (Plomin, DeFries & McClearn, 1990; pp. 393). There is some evidence that verbal and spatial abilities could be more heritable than perceptual speed and memory. DeFries, Johnson, Kuse, McClearn, Polovina, Vandeberg and Wilson (1979) in a widely cited Hawaii Family Study of Cognition administered 15 tests of specific cognitive abilities to the samples of two ethnic groups: 830 families of Americans of European ancestry and 305 families of Americans of Japanese ancestry. Factor analysis of used measures yielded four group factors: verbal (inclu-ding vocabulary and word fluency), spatial (including visualization and spatial rotation), perceptual speed (simple arithmetic and number comparisons), and visual memory (recognition of line drawings, both short-term and long-term). Regressions of offspring on midparent, which may be considered as upper limit of heritability were higher for verbal and spatial factors than for perceptual speed and memory in both ethnic groups. Other family studies also indicate greatest familial resemblance for verbal ability (DeFries, Vandenberg & McClearn, 1976).

Although studies of nuclear families (parent-offspring and/or siblings living together) could be very useful in providing the upper limit of heritability, other behavioral genetic designs are needed to differentiate genetic from

Denis Bratko, Department of Psychology, Faculty of Philosophy, University of Zagreb, I. Lučića 3, 10000 Zagreb, Croatia; E-mail: denis.bratko@ffzg.hr (Correspondence concerning this article should be sent to this address).

METHOD

Sample

The population was defined as "the same-sex twins born between 1974. and 1977. who live together with their parents in the urban area of Zagreb". The sample consisted of 160 twin-pairs. Compared to most twin studies, a relatively high percentage of contacted pairs were willing to participate in the study (73%). Each twin completed a questionnaire designed by Nichols and Bilbro (1966) to diagnose their zygosity. This questionnaire is frequently used in the studies of adolescent twins, and proved to be at least 95% accurate, when compared to results of the blood sample analyses. The questionnaire included questions about physical similarity and frequency of confusion of the twins by family members and others. 149 twin pairs were classified by this method either as monozygotic or dizygotic, and eleven pairs with doubtful zygosity were excluded from the analysis. Therefore, the final analysis was carried out on 71 monozygotic (36 male and 36 female) and 78 dizygotic (43 male and 35 female) twin pairs. Their ages ranged from 15 to 19 years. Mean age for MZ twins was 17.0 (SD=1.34) and for DZ twins it was 17.4 (SD=1.38). At the time of data collection, all subjects lived together with their parents in the city of Zagreb, Croatia. The data were collected in small groups (two pairs simultaneously) at the Department of Psychology, University of Zagreb.

Measures

The twins were tested by test battery which included measures of two factors of spatial abilities (visualization and spatial orientation) and two factors of verbal abilities (word fluency and vocabulary). Following tests were administered to the subjects: 1) The Surface Development Test (Vz-3) (French, Ekstrom & Price, 1963). This test was used to measure visualization - the ability to manipulate or transform the image of spatial arrangements; 2) The Card Rotation Test (S-1) (French et al., 1963) was used to measure spatial orientation - the ability to perceive spatial patterns or to maintain orientation with respect to objects in space; 3) An adaptation of the Thurstone First Letter Test (Momirović & Kovačević, 1970), which was adapted according to the relative frequency of particular words in the Croatian language, was used to measure word fluency - the facility in producing isolated words, without reference to their meaning. The participants were asked to write as many words as they could recall in a three minute period, beginning with the letter P. This procedure was then repeated with the letter S. The partici-

pant's total score equals the total number of words he/she wrote; 4) The Fourth Subtest of the Multifactor Test Battery (MFBT) (Tarbuk, 1977), which is a Croatian adaptation of the fourth subtest of The General Aptitude Test Battery (GATB). This subtest was used to measure vocabulary - knowledge of the meaning of words. MFBT is a 60 item test, where each item consists of four independent words. The task is to find the pair of words which are either the synonyms or the antonyms.

Reliabilities of these four measures are satisfactory, ranging from .90 to .92. The tests of spatial orientation and word fluency are typical speed tests, while the visualization and vocabulary tests are primarily the tests of strength.

Genetic analysis

The genetic analysis was based on 8 x 8 matrices of observed variances and covariances among the measures of visualization, spatial orientation, word fluency and vocabulary for each of the two cotwins, respectively. These matrices were computed separately for monozygotic and dizygotic twin pairs.

In the behavioral genetic analyses, the three variance components are often estimated: the additive genetic variance (G_A), the environmental variance due to the within family influence (E_w) and the environmental variance due to between family influence (E_b). Since previous univariate analyses of these four measures for the present sample resulted in significant G_A and E_w, and nonsignificant E_b estimates (Bratko, 1996) - the multivariate analysis presented here include only G_A and E_w latent variables. Thus, the basic quantitative genetic model about the structure of phenotypic covariation of measures of verbal and spatial abilities is:

$$P = G_A + E_w,$$

where P is the phenotypic variance/covariance matrix among measures, and G_A and E_w represent the additive genetic and within family environmental variance/covariance matrices, respectively. This model assumes that the total phenotypic variance/covariance matrix in a population (P) can be decomposed into two independent components, G_A and E_w. If the measures of interest (in this case, the measures of verbal and spatial abilities) are genetically independent, then matrix G_A is expected to be diagonal. Similarly, if the environmental factors which contribute to the phenotypic differences are different for different variables, then E_w is expected to be diagonal. Alternatively, this model can be formulated in terms of correlation as follows:

$$R_P = h\, R_{GA}\, h' + e_w\, R_{ew}\, e'_w,$$

where R_p, R_{GA} and R_{ew} represent matrices of phenotypic, additive genetic and within family environmental correlations, and h and e_W are the diagonal matrices containing the square root of heritabilities and environmentalities of the measures. While heritabilities and environmentalities reflect the proportions of phenotypic variance of individual measure that are attributable to the genetic and environmental differences in population, the genetic and environmental correlations (which are the topic of present report) indicate the extent to which individual differences on different tests are due to the same set of genetic and environmental influences.

In order to estimate the genetic and environmental covariance and correlations among measures of verbal and spatial abilities, the LISREL (Jöreskog & Sörbom, 1988) model, specified by Neale and Cardon (1993) was applied. This model uses the LISREL multiple group facility and was simultaneously applied to the monozygotic and dizygotic covariance/cross-covariance matrices. The model was based on the following expectations about the contributions to the covariances/cross-covariances between the multiple measures for the monozygotic and dizygotic twin pairs:

$$C_{MZ} = A$$

$$C_{DZ} = 1/2 \ A$$

where C_{MZ} and C_{DZ} represent the observed covariance/cross-covariance matrices for 8 measures (4 tests for the first and the second member of each twin pair, respectively), and A represents the additive genetic covariance matrix. Thus, this model assumes that additive genetic factors are sufficient for explaining the similarities of cotwin scores on measured variables, while environmental influences operate within family and do not contribute to their similarities. It should be recognized that the measurement error is also allocated in the environmental co-

variance matrix. However, due to high reliabilities of the variables, this measurement error is not large.

The full Cholesky decomposition was imposed upon the genetic and environmental covariance matrices. This technique assumes an initial factor to be equivalent of one variable and determines the extent to which it can account for the entire covariance matrix. Subsequently, a second factor is set equal to another variable and used to account for as much of the remaining variance as possible. Finally, in the full Cholesky decomposition the number of genetic and environmental factors equals the number of variables. The chi-square statistic was used to examine the fit of the model to the data, and loadings of the variables on genetic and environmental Cholesky factors were estimated. Carrying out the pre- and post- multiplication of the loadings of the Cholesky factors gives the maximum-likelihood estimates of the genetic and environmental covariance matrices. These covariance matrices were then transformed into the genetic and environmental correlation matrices.

RESULTS

Preliminary analyses

The phenotypic correlations between the measures of visualization, spatial orientation, word fluency and vocabulary are presented in Table 1. All variables are significantly associated, except measures of word fluency and spatial orientation. Considerable correlations are obtained between one measure of the verbal ability (vocabulary) and two spatial tests, and one measure of the spatial ability (visualization) and two verbal measures (word fluency and vocabulary). As expected, the highest correlations are obtained between the two tests of verbal and two of spatial abilities.

Table 1

Phenotypic correlations (*N=298*) among the measures of spatial (visualization and spatial orientation) and verbal abilities (word fluency and vocabulary)

	Visualization	Spatial orient.	Word fluency	Vocabulary
Visualization	1.00			
Spatial orient.	.49**	1.00		
Word fluency	.18**	.04	1.00	
Vocabulary	.37**	.23**	.53**	1.00

** $p < .01$

One of the assumptions of the twin method is that the scores on analyzed variables are comparable for monozygotic and dizygotic twins. Thus, it should be demonstrated that MZ and DZ twins are the part of the same population. Multivariate analysis of variance (MANOVA) testing the mean effects of zygosity for measured variables yieldednonsignificant F-value (multivariate $F(4,296)=.80$; $p=.52$), showing that MZ and DZ twins scored similarly on tests of verbal and spatial abilities. Also, variance/covariance matrices of MZ and DZ twins do not differ significantly χ^2 (10)=14.38; $p=.17$). Hence, this basic assumption for the twin method was fulfilled.

After that, analyses of variance (ANOVA) testing the mean effect of sex and age (5 age groups, approximately of the same size) were performed for the measures of visualization, spatial orientation, word fluency and vocabulary, respectively. ANOVAs yielded significant sex effects for visualization $F(1, 297)=26.58$; $p<.01$, spatial orientation $F(1, 297)=54.34$; $p<.01$ and word fluency $F(1,297)=11.22$; $p<.01$. Male scored higher on visualization (male - $M=32.12$; female- $M=24.35$) and spatial orientation (male - $M=127.91$; female - $M=96.83$) while females scored higher on word fluency (male - $M=47.15$; female - $M=53.47$). Age effects were significant (older subjects scored higher) for visualization $F(4, 293)=3.99$; $p<.01$, word fluency $F(4, 293)=6.56$; $p<0.1$ and vocabulary $F(4, 293)=4.65$; $p<.01$.

Because twins are perfectly correlated for age, and in our sample for sex as well, twin correlations can be inflated to the extent that the measures of interest correlate with age and sex. To correct for the possible main effect of age and sex, as well as for age by sex interaction, raw scores were residualized prior to genetic analyses by the regression technique (McGue & Bouchard, 1984). These

residuals were then standardized to equalize the variances of the different variables to unity. Correlations between raw scores and scores transformed in such a way were for MZ twins .91, .89, .92, and .99 for visualization, spatial orientation, word fluency and vocabulary, respectively. Same correlations for DZ twins were .98, .93, .97, and .95 for visualization, spatial orientation, word fluency and vocabulary, respectively.

Distributions of the scores transformed in such a manner were than examined for deviations from normality. Smirnov-Kolmogorov tests yielded nonsignificant z-values for all of the measures (visualization - $z=1.09$; $p=.18$; spatial orientation - $z=1.17$; $p=.13$; word fluency - $z=.52$; $p=.95$; vocabulary - $z=.84$; $p=.49$).

Genetic analysis

Testing the model based on the full Cholesky decomposition yielded non-significant chi-square $\chi^2(52) =62.97$; $p = .14$), thus it was concluded that model accounted for the data reasonably well. The parameter estimates, as well as standard errors of these estimates, are given in Table 2. If there is no covariance between genetic and environmental effects on different abilities, then it should be expected that off-diagonal elements in Table 2 equals zero. On the other hand, significant off-diagonal estimate indicates that genetic and environmental influences on different measures of verbal and spatial intelligence are more or less related. It is obvious that majority of the off-diagonal estimates on Cholesky genetic factors are significant, while environmental off-diagonal estimates are mostly nonsignificant.

Table 2

Maximum-likelihood estimates of the genetic and environmental loadings of the measures of spatial (visualization and spatial orientation) and verbal abilities (word fluency and vocabulary) on the Cholesky factors (standard errors of the estimates are given in parenthesis)

| | Cholesky factor | | | | | | | |
| | Genetic | | | | Environmental | | | |
	I	II	III	IV	I	II	III	IV
Visualization	.89*				.43*			
	(.05)				(.04)			
Spatial orientation	.45*	.69*			.18*	.54*		
	(.07)	(.06)			(.06)	(.04)		
Word fluency	.21*	-.08	.84*		.08	.00	.52*	
	(.08)	(.09)	(.06)		(.06)	(.06)	(.04)	
Vocabulary	.44*	.02	.51*	.62*	.02	.05	.09	.44*
	(.07)	(.08)	(.07)	(.05)	(.05)	(.05)	(.05)	(.04)

Chi-square for the model = 62.97; $p=.14$;
* $p < .05$ (estimated by the t-values)

Table 3

Genetic and environmental correlations among the measures of spatial (visualization and spatial orientation)
and verbal abilities (word fluency and vocabulary) estimated from the full Cholesky decomposition

	Genetic correlations				Environmental correlations			
	VZ	SO	WF	VOC	VZ	SO	WF	VOC
Visualization	1.00				1.00			
Spatial orientation	.54	1.00			.31	1.00		
Word fluency	.24	.05	1.00		.15	.05	1.00	
Vocabulary	.48	.28	.65	1.00	.05	.12	.20	1.00

The estimates from the full Cholesky model were transformed into the maximum-likelihood estimates of the genetic and environmental correlations among measures of verbal and spatial intelligence, which are presented in Table 3.

These estimates show a very interesting pattern of genetic and environmental correlations. As can be seen from Table 3, the highest genetic correlations are obtained between two tests of verbal and two of spatial abilities. But even within these two kinds of measures, genetic influences only partly overlap (there is a considerable part of genetic variance which is not common for the two verbal and two spatial tests). The genetic correlation between one measure of spatial intelligence (visualization) and one of verbal intelligence (vocabulary) is especially interesting, for it shows that genetic effects of these different abilities partly overlap. On the other hand, environmental correlations are generally low. The only two correlations worth mentioning are those between two measures of verbal (r_E =.20) and two measures of spatial abilities (r_E =.31), indicating slight within-family environmental influences to the phenotypic correlations among these variables. While genetic effects on measures of verbal and spatial intelligence partly overlap, within family environmental influences are largely specific for the particular ability.

If we compare the estimates of genetic and environmental correlations among measures of verbal and spatial intelligence with the corresponding phenotypic correlations - we can see that phenotypic correlations follow the pattern of genetic, not the pattern of environmental correlations. Thus it seems that observed correlations between measures of verbal and spatial intelligence are largely due to genetic influence, or in other words, due to the overlapping of their genetic effects.

DISCUSSION

Results from the reported multivariate behavioral genetic analysis provide further evidence about the impor-

tance of genetic influences for the etiology of individual differences in various specific cognitive abilities. The methodology employed yields estimates of the extent to which genetic and environmental effects are correlated for the measures of verbal and spatial intelligence. These estimates indicate that the genetic correlations among measures of verbal and spatial intelligence are substantial, except that between the spatial orientation and word fluency. The high genetic correlations among similar abilities (two spatial and two verbal tests) are logical and expected. Theoretically more interesting are the genetic correlations between verbal and spatial abilities. Findings that genetic effects of some measures of verbal and spatial abilities are substantially correlated (e.g. visualization and vocabulary) and others are not (e.g. spatial orientation and word fluency) indicate that some measures of verbal and spatial abilities may have common biological basis while others do not. For this reason, future research on specific cognitive abilities should consider more finely differentiated abilities, and even more important, include the information processing variables which are related to the intelligence (Baker, Vernon & Ho, 1991; Ho, Baker & Decker, 1988; McGue, Bouchard, Lykken & Feuer, 1984). The reason why the genetic correlation is higher for visualization and vocabulary than for spatial orientation and word fluency may be that the first two measures are likely to be more g-loaded. For example, correlations of visualization, vocabulary, spatial orientation, and word fluency with the first unrotated component extracted from these four measures are .75, .79, .61 and .61, respectively. Visualization and vocabulary are also more heritable in Croatian population than spatial orientation and word fluency. The heritabilities of these abilities estimated from this sample were 63%, 49%, 52% and 61% for visualization, spatial orientation, word fluency and vocabulary, respectively (Bratko, 1996). Thus, is could be that more g-loaded measures are likely to have higher heritabilities (Jensen, 1987; Vernon, 1989), and are likely to have higher genetic correlations. This hypothesis is in accordance with the observation that phenotypic correlations of measures of ver-

bal and spatial abilities follow the pattern of genetic, not the pattern of the environmental correlations. Together with the finding that each of the four analyzed tests has massive heritable component (Bratko, 1996), this result indicates that the phenotypic correlations among measures of verbal and spatial intelligence are due to the correlations of their genetic effects.[1]

The theoretically most interesting interpretation of the observed genetic correlations is the pleiotropy effect. One of the basic rules in genetics, both human and animal, is that single gene usually affects more than just a single phenotype (Plomin et al., 1990; pp. 53). The concept of pleiotropy refers to this multiple effect of a gene. There is no doubt that individual differences in complex human behavioral characteristics like intelligence, are affected by many individual genes (for a review on the quantitative genetic theory, see Falconer, 1981). The pleiotropy interpretation of the substantial genetic correlations obtained between some measures (e.g. between visualization and vocabulary) would predict that some of the individual genes involved in determination of individual differences in these abilities are the same. It should be mentioned that genetic correlation could also result from temporary linkages due to the recent admixtures of population or non-random mating. However, these linkages are soon broken up by recombination. Thus, the pleiotropy is theoretically the most useful way of conceptualizing stable genetic correlations between different behavioral characteristics. The present data demonstrate that the correlated genetic influences contribute to the observed phenotypic correlation between measures, showing that the biological mechanism involved in determination of the individual differences in some measures of verbal and spatial intelligence may partly be the same, while for other measures it is clearly different.

REFERENCES

BAKER, L.A., VERNON, P.A., & HO, H. Z.(1991). The genetic correlation between intelligence and speed of information processing. *Behavior Genetics, 21,* 351-367.

BOUCHARD, T. J. JR., & McGUE, M.(1981). Familial studies of intelligence: A review. *Science, 212,* 1055-1059.

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[1] The phenotypic correlations between two measures if the function of the genetic and environmental correlations between them, as well as the individual heritability and environmentality of the each particular variable. Thus, it is possible that two measures exhibit high genetic correlation and that heritability of each measure is low. In that case, in spite of the high genetic correlation, the genetic contribution to the phenotypic correlation would be low (Neale & Cardon, 1992). However, this is not the case in reported analysis.

BRATKO, D.(1996). Twin study of verbal and spatial abilities. *Personality and Individual Differences, 21,* 621-624.

CHIPUER, H. M., ROVINE, M. J., & PLOMIN, R. (1990). LISREL modeling: Genetic and environmental influences on IQ revised. *Intelligence, 14,* 11-29.

DEFRIES, J. C., & FULKER, D. W.(1986). Multivariate behavioral genetics and development: An overview. *Behavioral Genetics, 16,* 1-10.

DEFRIES, J. C., JOHNSON, J. C., KUSE, A. R., MCCLEARN, G. E., POLOVINA, J., VANDE-BERG, S. J., & WILSON, J. R.(1979). Familial resemblance for specific cognitive abilities. *Behavioral Genetics, 16,* 1-10.

DEFRIES, J. C., PLOMIN, R., & LABUDA, M. C.(1987). Genetic stability of cognitive development from childhood to adulthood. *Developmental Psychology, 23,* 4-12.

DEFRIES, J. C., VANDEBERG, S. J., & MCCLEARN, G. E.(1976). The genetics of specific cognitive abilities. *Annual Review of Genetics, 10,* 179-208.

DETTERMAN, D. K., THOMPSON, L.A., & PLOMIN, R.(1990). Differences in heritability across groups differing in ability. *Behavioral Genetics, 20,* 369-384.

ERLENMAYER-KIMLING, L., & JARVIK, L. F. (1963). Genetics and intelligence: A review. *Science, 142,* 1477-1479.

FALCONER, D. S.(1981). *Introduction to quantitative genetics.* London: Longman.

FRENCH, J. W., EKSTROM, J .B., & PRICE, L. A.(1963). *Kit of reference tests for cognitive factors.* New Jersey: Princeton, Educational Testing Service.

HO, H. Z., BAKER, L. A., & DECKER, S. N.(1988). Co-variation between intelligence and speed of cognitive processing: Genetic and environmental influences. *Behavior Genetics, 18,* 247-261.

JÖRESKOG, K. G., & SÖRBOM, D.(1988). *LISREL VII: A Guide to the Program and Applications.* Chicago: SPSS, Inc.

JÖRESKOG, K.G.(1973). Analysis of covariance structures. In P. R. Krishnaiah, (Ed.), *Multivariate Analysis III* (pp. 1-33). New York: Academic Press.

KAUFMAN, A. S.(1975). Factor analysis of the WISC-R at 11 age levels between 6.5 and 16.5 years. *Journal of Consulting and Clinical Psychology, 43,* 35-147.

LaBUDA, M. C., DeFRIES, J. C., & FULKER, D.(1987). Genetic and environmental covariance structures among WISC-R subtests: A twin study. *Intelligence, 11,* 233-244.

LOEHLIN, J. C., WILLERMAN, L., & HORN, J. M.(1988). Human behavior genetics. *Annual Review of Psychology, 39,* 101-133.

MARTIN, N. G., & EAVES, L. J.(1977). The genetical analysis of covariance structure. *Heredity, 38,* 79-95.

MCCARTNEY, K., HARRIS, M. J., & BERNIERI, F.(1990). Growing up and growing apart: A developmental meta-analysis of twin studies. *Psychological Bulletin, 107,* 226-237.

MCGUE, M., & BOUCHARD, T. J. Jr.(1984). Adjustment of twin data for the effects of age and sex. *Behavior Genetics, 14,* 325-343.

McGUE, M., BOUCHARD, T. J. JR., LYKKEN, D. T., & FEUER, D.(1984). Information processing abilities in twins reared apart. *Intelligence, 8,* 569-608.

MOMIROVIĆ, K., & KOVAČEVIĆ, V.(1970). *Evaluacija diagnostičkih metoda [Evaluation of the diagnostic methods].* Zagreb: Republički zavod za zapošljavanje.

NEALE, M. C., & CARDON, L. R.(1992). *Methodology for genetic studies of twins and families.* NATO ASI Series: Behavioral and Social Sciences - Vol. 67, Cluwer Academic Publishers, Dordrecht.

NICHOLS, R. C., & BILBRO, W. C.(1966). The diagnosis of twin zygosity. *Acta Genetica, 16,* 265-275.

PEDERSEN, N. L., McCLEARN, G. E., PLOMIN, R., & FRIBERG, L.(1985). Separated fraternal twins: Resemblance for cognitive abilities. *Behavior Genetics, 15,* 407-419.

PLOMIN, R., & DeFRIES, J. C.(1981). Genetics and intelligence: Recent data. *Intelligence, 4,* 15-24.

PLOMIN, R.(1988). The nature and nurture of cognitive abilities. In R. J. Sternberg (Ed.), *Advances in psychology of human intelligence* (205-231). New Jersey: Lawrence Erlbaum Associates Publishers, Hilsdale.

PLOMIN, R., DeFRIES, J. C., & FULKER, D.(1988). *Nature and nurture during infancy and early childhood.* New York: Cambridge University Press.

PLOMIN, R., DeFRIES, J. C., & McCLEARN, G. E.(1990). *Behavioral genetics: A primer.* New York: W.H. Freeman & Company.

PLOMIN, R., & RENDE, R.(1991). Human behavioral genetics. *Annual Review of Psychology, 42,* 161-190.

ROSE, R.(1995). Genes and human behavior. *Annual Review of Psychology, 46,* 625-654.

SCARR, S., & CARTER-SALTZMAN, L.(1988). Genetics and intelligence. In Sternberg (Ed.) *Handbook of human intelligence,* (pp.792-896). New York: Cambridge University Press.

TAMBS, K., SUNDET, J. M., & MAGNUS, P.(1984). Heritability analysis of the WAIS subtests: A study of twins. *Intelligence, 8,* 283-293.

TAMBS, K., SUNDET, J. M., & MAGNUS, P.(1986). Genetic and environmental contribution to the covariation between the Wechsler Adult Intelligence Scale (WAIS) subtests: A study of twins. *Intelligence, 8,* 283-293.

TARBUK, D.(1977). Test 4/MFBT-Rječnik (Subtest 4/MFBT-Vocabulary). Priručnik za psihologijsko ispitivanje s pomoću multifaktorske baterije testova: forma P-1 [Manual for the psychological assessment with the Multifactor test battery: form P-1]. Zagreb: Republička samoupravna interesna zajednica za zapošljavanje.

VANDEBERG, S. G.(1965). Innate abilities, one or many? A new method and some results. *Acta Geneticae Medicae et Gemellologiae, 14,* 41-47.