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Heritability of Educational Achievement in 12-year-olds and the Overlap with Cognitive Ability

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In order to determine high school entrance level in the Netherlands, nowadays, much value is attached to the results of a national test of educational achievement (CITO), administered around age 12. Surprisingly, up until now, no attention has been paid to the etiology of individual differences in the results of this national test of educational achievement. No attempt has been made to address the question about the nature of a possible association between the results of the CITO and cognitive abilities, as measured by psychometric IQ. The aim of this study is to explore to what extent psychometric IQ and scholastic achievement, as assessed by the CITO high school entrance test, are correlated. In addition, it was investigated whether this expected correlation was due to a common genetic background, shared or nonshared environmental influences common to CITO and intelligence or a combination of these influences. To this end multivariate behavior genetic analyses with CITO and IQ at ages 5, 7, 10 and 12 years have been conducted. The correlations were .41, .50, .60, and .63 between CITO and IQ assessed at age 5, 7, 10, and 12 respectively. The results of the analyses pointed to genetic effects as the main source of variance in CITO and an important source of covariance between CITO and IQ. Additive genetic effects accounted for 60% of the individual differences found in CITO scores in a large sample of Dutch 12-year-olds. This high heritability indicated that the CITO might be a valuable instrument to assess individual differences in cognitive abilities in children but might not be the right instrument to put the effect of education to the test.

In the Netherlands, nowadays, much value is attached to the results of a national test of educational achievement (CITO), administered around age 12, in order to determine high school entrance level. The results of the test are often used as an independent judgment, besides the teachers' opinion, in advising the parents on the future educational level of their child. So the CITO is used as an aid in choosing the most appropriate type of high school (e.g., academic versus technical). From a historical perspective, this attention for "independent" testing has to do with the possibilities for selection. The establisher of the CITO (Eindtoets Basisonderwijs, 2002) emphasized that this national test of educational achievement has put the effect of education in a particular school to the test besides measuring possible learning potential or cognitive abilities in children (Geldermans, 2001). It was hypothesized that success in scholastic achievement depended on the quality of the elementary school. A large number of articles in Dutch daily newspapers were dedicated to the influences of the school population and school neighborhood on the test results of the pupils. In these articles the influences of socioeconomic status (SES) and ethnic background of the majority of the children at a certain school were considered important factors to classify the school and the future success of the pupils. Several studies agreed on the claim that family variables (e.g., family size, SES, parental involvement, cultural level) influenced the development and educational achievement of children (Christenson et al., 1992; Garcia & Rosel, 2001; Marjoribanks, 1994). If this were true, influences of shared environmental factors on CITO would show up as significant in the classical twin design. Alternatively, parental SES might reflect the parents' cognitive abilities. Heritable influences on cognition would predict CITO scores to be genetically mediated.

Intelligence has been found to explain a significant amount of the variance in educational achievement (Eaves & Darch, 1990; Jensen, 1972). In the Netherlands no attempt has been made to address the question about the nature of a possible association between the results of the CITO and cognitive abilities, as measured by psychometric IQ. Even more striking, no attention has been paid to possible genetic influences on the results of the national test of educational achievement. In emphasizing that the CITO was a test for the level of the school and the classification of children, the CITO-group might have underestimated the true content and value of the results of this test. It could be interesting to establish whether the possible association between intelligence and results of the CITO was based either on overlapping genetic influences, overlapping environmental influences (SES, school population), or both.

Numerous behavior genetic studies have been conducted in which cognition and educational achievement were examined separately. Studies on cognition have yielded the largely consistent result that genetic differences accounted for at least 50% of the observed variability in cognition in adults (e.g., Alarcón et al., 1998, 1999; Bouchard & McGue, 1981; Bratko, 1996; McCartney

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et al., 1990; Posthuma et al., 2000; Rijsdijk et al., 1997, 1998). It has also been well established that the genetic influences on cognitive functioning increase throughout development, whereas influences of common environment decrease (e.g., Alarcón, 1998, 1999; Bartels et al., 2002; Boomsma, 1993; Boomsma & Van Baal, 1998; Fulker et al., 1988; Labuda et al., 1986; Loehlin et al., 1989; McCartney et al., 1990; McGue et al., 1993; Plomin et al., 1997; Skodak & Skeels, 1949; Wilson, 1983). A few longitudinal studies have focused on the influences of genes and environment on cognitive development rather than cognition at specific ages. Results of these studies have proven intelligence to be one of the most stable phenotypes (Colorado Adoption Project [CAP]; e.g., Plomin & DeFries, 1985; Louisville Twin Study; e.g., Wilson, 1983; Eaves et al., 1986; Netherlands Twin Register, Boomsma et al., 1992; 2002; Boomsma, 1998). In the Dutch longitudinal sample this stability in intelligence seemed to be mainly genetically mediated. Environmental factors gave rise to stability as well as change of cognitive functioning over the years (Bartels et al., 2002).

There have been fewer behavioral genetic studies of scholastic achievement during childhood. However, genetic influences also seemed to be an important factor explaining individual differences in achievement, but the influences of shared environmental factors could not be ruled out (Labuda et al., 1986; Loehlin & Nichols, 1976; Martin & Martin, 1975; Martin, 1975; Nichols, 1965; for a review see Plomin, 1986; Thompson et al., 1991; Willerman et al., 1977).

Multivariate behavioral genetic models have indicated that genetic effects are the primary source of variance underlying the phenotypic correlation between cognition and scholastic achievement (Petrill et al., 1993; Wadsworth et al., 1995a, 1995b). Thompson and colleagues (1991) showed genetic correlations between cognition and achievement tests ranging from .57 to .85, whereas shared environment correlations were essentially zero, and specific environment correlations were low (.00 to .19). Results of the CAP, using related and unrelated sibling pairs, showed that genetic influences accounted for most of the phenotypic covariance among measures of cognitive ability (verbal comprehension and perceptual organization) and achievement (reading recognition and mathematics achievement), with much of the genetic covariation being due to influences shared with verbal ability (Wadsworth et al., 1995a). An extension of the previous study by simultaneously analyzing parent–offspring and sibling data from the CAP yielded the same results (Wadsworth et al., 1995b).

We have studied the development of cognitive abilities and the correlation with educational achievement in a large longitudinal sample of Dutch twins. A previous analysis on the heritability of cognition in this longitudinal sample of Dutch twins at ages 5, 7, 10 and 12, showed an increase in heritability over the years, ranging from 26% at age 5 to 85% at age 12. A decrease in shared environmental influences is observed. Shared environmental influences seem to be significant at age 5 and 7, but not at ages 10 and 12 (for details see Bartels et al., 2002).

The aim of this study was to explore to what extent psychometric IQ and scholastic achievement, as assessed by the Dutch CITO-elementary test, were correlated and whether this correlation was due to genetic influences, shared or nonshared environmental influences common to CITO and intelligence or a combination of these influences. The unique aspect of this study was that the IQ data were collected longitudinally at ages 5, 7, 10, and 12 and that scholastic achievement was assessed at age 12. So we had the possibility to determine whether intelligence measured at age 5, 7, 10 and 12 might be used as a predictor of scholastic achievement at age 12. Since, scholastic achievement and IQ were also assessed at the same age a reliable measure of the association, without confounding effects related to age, could be obtained. Further, the variance found in the results of CITO was disentangled into variance due to genetic influences, variance due to shared environmental influences (environmental influences shared by two members of a twin pair), and variance due to unique environmental influences (environmental influences unique to an individual). If shared environmental influences (C) determined the association, then we expected that IQ5-CITO would show the highest correlation, because C was of significant influence on IQ at age 5. If genetic factors (A) determined the association, then we expected the highest correlation between IQ12 and CITO, because genetic factors were the main source of individual differences of IQ at age 12.

Information on the strength of genetic and environmental influences on the results of the CITO and information on an association between CITO and intelligence at several ages is a valuable contribution to a discussion on the reliability of the CITO. It further gives information on the value of the use of this national test of educational achievement as a predictor of future scholastic success and to determine the quality level of a certain elementary school in comparison to other elementary schools in the country.

Method

Participants

In 2000, the Netherlands Twin Register (NTR; Boomsma et al., 1992; Boomsma, 1998; Boomsma et al., 2002) started collecting the results of a national test of educational achievement (CITO) from all registered 12-year old twins. Eighty-five per cent of all Dutch schools yearly administer this test in the final class of elementary school. The main purpose of this test is to select for different levels of high school education (university preparation vs. advanced elementary education). A standardized CITO score was collected for 1495 children, who took the CITO in 1998, 1999, 2000 or 2001.

Zygosity of this large CITO-sample was determined by DNA or blood group polymorphisms for 306 same-sex twin pairs. For the remaining same sex twin pairs zygosity was determined by discriminant analysis of questionnaire items. The questionnaire items allowed accurate determination of zygosity of nearly 95%. The employment of the discriminant analysis and the use of zygosity questions are described in more detail in Rietveld et al. (2000b). In this sample of 1495 children there were 170 monozygotic female twin pairs (MZF), 113 dizygotic female twin pairs (DZF), 127 monozygotic male twin pairs (MZM), 113 dizygotic male twin pairs (DZM), and 168 dizygotic pairs of opposite sex twin pairs (DOS). There were 9 MZM incomplete twin pairs, 25 DZM incomplete twin pairs, 7 MZF incomplete twin pairs, 17 DZF incomplete twin pairs and 54 DOS incomplete twin pairs. For one child (incomplete twin pair) information on zygosity was missing.

A subsample (N = 209 twin pairs) of this NTR sample took part in a longitudinal study of the development of intelligence and problem behavior. For information on the initial sample selection and the IQ assessment at the distinct ages see Bartels et al. (2002). Details on the demographic characteristics of the sample and information on parental occupation can be found in Rietveld et al. (2000a). For at least 190 of the 209 twin pairs results for CITO at age 12 and Full-Scale IQ at age 5, or 7, or 10 or 12 are available.

Procedure

The Dutch CITO-elementary test. Educational achievement was assessed by the Dutch CITO-elementary test (Eindtoets Basisonderwijs, 2002). The CITO consists of 240 multiple-choice items assessing four different intellectual skills: Language, Mathematics, Information Processing, and World Orientation. Each performance scale contains 60 multiple-choice questions. In 2001 the test slightly changed with respect to the distribution of the questions resulting in 60 questions for Mathematics and World Orientation, 90 questions for Language and 30 questions for Information Processing. Together the performance scales result in a standardized score between 501 and 550. The test is usually administered on three consecutive days in January or February when the children are in the final class of elementary school. In the present study the CITO data were collected by mail from the teacher, after informed consent from the parents or by mail from the parents as a question in a questionnaire on the child's behavior at age 12. In all analyses concerning the CITO score the mean was fixed to the population mean (534.5) in order to control for volunteer bias, which in this respect could have been a result from voluntary registration in the Netherlands Twin Register, voluntary sending in the results of the CITO, or voluntary participating in the CITO test (Neale & Cardon, 1992; Neale & Eaves, 1993). The population mean was based on a sample of 657,869 children, who had taken the CITO in the years 1997 till 2001. The mean of our sample (M = 537.88) was slightly, but significantly higher than this population mean (t_{1494} = 15.099, p = .00).

The intelligence tests. At age 5, 7, and 10 the children were tested with the Revised Amsterdamse Kinder Intelligentie Test (RAKIT; Bleichrodt et al., 1984). Six subtests, with age-appropriate items, were employed to assess cognitive functioning. The raw scores were standardized. For further details on this well-known Dutch intelligence test see Rietveld et al. (2000a). At age 12 the twins completed the full version of the WISC-R (in Dutch; Van Haasen et al., 1986). The WISC-R consists of 12 subtests, 6 mainly verbal and 6 mainly non-verbal. The subtest scores are standardized, based on results of same-aged children in the Netherlands and the same standardization is used for boys and girls. For details on the procedure of testing see Bartels et al. (2002).

Data Analyses

Descriptive statistics. Descriptive statistics for full-scale IQ at age 5, 7, 10 and 12 (IQ5, IQ7, IQ10, and IQ12), and the standardized CITO scores were calculated using SPSS/Windows 10. Differences in means and variances of IQ and CITO for boys and girls and monozygotic and dizygotic twins were tested with ANOVA. Twin correlations for the five zygosity groups (MZM, DZM, MZF, DZF, DOS) were calculated to get a first impression of the genetic and environmental influences on the variance in CITO scores. Pearson correlations were used to test the association (phenotypic correlation) between IQ at the four ages and CITO at age 12. MZ and DZ cross-correlations were calculated to get an impression of influences of genes and environment on the covariance between IQ and CITO.

Genetic Modeling. Genetic model fitting of twin data allows for separation of the observed phenotypic variance into its genetic and environmental components. Additive genetic variance (A) is the variance that results from the additive effects of alleles at each contributing genetic locus. Shared environmental variance (C) is the variance that results from environmental events common to both members of a twin pair. Unique environmental variance (E) is the variance that results from environmental effects that are not shared by members of a twin pair. Estimates of the unique environmental effects also include measurement error. To account for this source of variance, E is always specified in the model.

The different degree of genetic relatedness between monozygotic (MZ) and dizygotic (DZ) twin pairs was used to estimate the contribution of these factors to the phenotypic variation in IQ at the four ages and in CITO scores. Similarities for MZ twins are assumed to be due to additive genetic influences plus environmental influences that are shared by both members of a twin pair. Experiences that make MZ twins different from one another are unique environmental influences. Because DZ twins share 50% of their genetic material on average, like other siblings, genetic factors contribute only half to their resemblance. As for MZ twins the shared environment contributes fully. Model fitting to twin data is based on the comparison of the variance-covariance matrices in MZ and DZ twins. Exploiting the known difference in genetic contribution to intra-pair resemblance of MZ and DZ twin pairs, influences of additive genetic, shared environmental and unique environmental factors are estimated using the computer program Mx (Neale, 1999).

Univariate model fitting was carried out to estimate the genetic and environmental components in CITO scores. Per time point (CITO-IQ5, CITO-IQ7, CITO-IQ10 and CITO-IQ12) a bivariate model (Cholesky decomposition) was used to estimate genetic and environmental influences (Figure 1). Rather than decomposing the variance of IQ and CITO into genetic and environmental sources of variance, bivariate genetic analysis decomposes the variance of

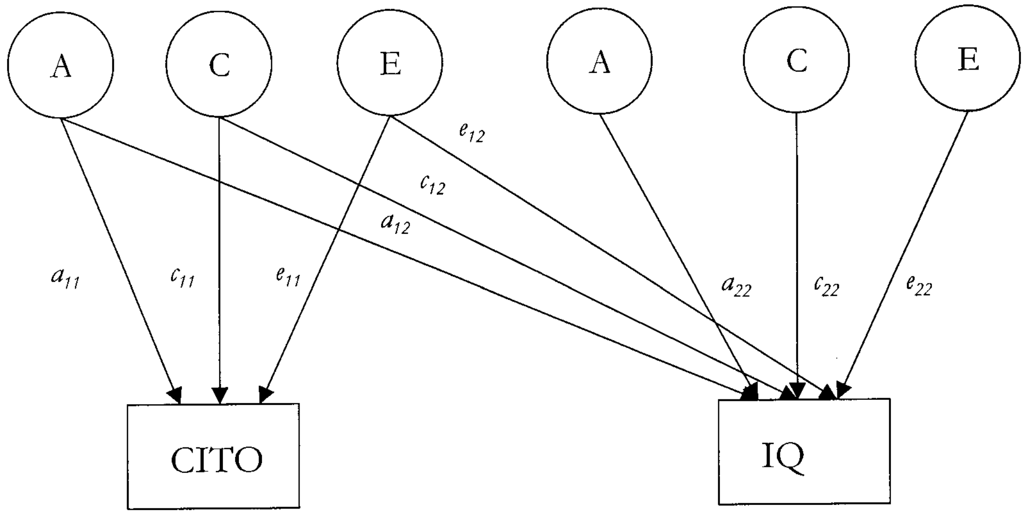

Figure 1
Cholesky decomposition model for CITO and IQ.

each measured variable and the covariance between the measured variables into genetic and environmental sources.

To make optimal use of all available data, the analyses were performed on raw data. Submodels were compared by hierarchic chi square tests. The χ^2 statistic is computed by subtracting –2LL for a reduced model from that for the full model. This resulted in a χ^2 statistic, $\chi^2 = 2LL_0 - (-2LL_1)$. We compared alternative models by means of the principle of parsimony. We began the bivariate model fitting with a full model with additive genetic, shared environmental and unique environmental influences (ACE model), including sex-differences in mean and a free estimate of the degree of genetic relatedness in twins of opposite sex (Model 1). First, we tested whether different genes influence IQ and CITO in boys and girls (Model 2). It was also tested whether the influences of the genes are of different magnitudes in boys and girls (Model 3). Furthermore, we tested whether the influences of unique environment were specific for CITO and IQ (Model 4). After these model reductions it was tested whether the covariance between IQ and CITO is based on a common genetic background, a common source of shared environmental influences or both. Estimates of genetic, shared environmental and unique environmental influences on CITO and the covariance between IQ (four ages) and CITO have been estimated based on the best fitting model.

Results

Descriptive statistics for IQ at the four ages and CITO at age 12 are presented in Table 1. No differences in means were found for boys and girls or monozygotic and dizygotic twins for IQ and CITO. Significant differences in variances between boys and girls were only found for IQ at age 10 $F_{(1, 390)} = 4.326$, $p = .038$. No differences in variances were found for monozygotic and dizygotic twins. Phenotypic correlations between IQ and CITO are presented in Table 3 (upper part). All correlations were significant at the α = .01 level, indicating medium to strong associations between IQ at several ages and CITO. The expected rise in correlation from IQ5 and CITO to IQ12 and CITO was

Table 1
Descriptive Statistics for Full-scale IQ at Different Ages and CITO

		N	Min	Max	Mean	*SD*	Skewness	*SE*	Kurtosis	*SE*
IQ5	M	210	64	139	102.32	13.19	–.164	.168	.281	.334
	F	205	70	142	103.20	13.19	.047	.170	.142	.338
IQ7	M	194	65	139	102.98	14.63	–.079	.175	.001	.347
	F	188	62	145	102.80	14.75	–.176	.177	.076	.353
IQ10	M	195	69	145	107.75	14.40	–.009	.175	.040	.346
	F	197	63	145	106.17	16.59	–.067	.173	–.361	.345
IQ12	M	185	66	138	101.03	13.00	.123	.179	.216	.355
	F	196	61	127	99.08	13.32	–.171	.174	–.018	.346
CITO12	M	702	510	550	538.13	8.61	–.865	.092	.317	.184
	F	793	506	550	537.66	8.70	–.730	.087	.073	.173

observable in the table. This rise was not surprising because of the fact that the CITO was taken at age 12 and was in that sense most comparable to IQ12.

Twin correlations for the five zygosity groups for CITO and the univariate model fitting results are presented in Table 2a and b. Fifty-seven per cent of the individual differences in CITO could be explained by additive genetic influences. Shared environmental influences explained 27% and nonshared environmental influences explained 16% of the total variance respectively. Univariate model fitting showed no presence of sex-differences in heritability for CITO.

Twin cross-correlations for monozygotic (MZ) and dizygotic (DZ) twins were calculated separately to explore the genetic and environmental influences on the observed association between CITO and IQ. As can be seen in Table 3, the MZ cross-correlations over time were higher than the DZ cross-correlations over time, suggesting that the observed significant association between CITO and IQ at four ages was at least partly due to genetic factors. The MZ correlations, though, were not twice as high as the DZ correlation which indicated influences of shared environment as well. Further, when the correlations of the adjoining age-intervals were compared (CITO-IQ5; CITO-IQ7; CITO-IQ10; CITO-IQ12) the increased difference between MZ and DZ correlations, from age 5 to age 10, suggested an increase in the genetic contribution to the association in this age interval. The 95% confidence intervals for MZ and DZ twins showed an overlap. Model fitting results were necessary to sort out the strength of genetic and shared environmental influences.

Model fitting of the bivariate Cholesky Decomposition for CITO with IQ at the four ages are presented in Table 4. As expected from the univariate model-fitting procedure, no sex-differences were found (models 2 and 3). Further, the estimated genetic and shared environmental correlations indicated overlapping influences for genetic and shared environmental effects on CITO and IQ. For CITO-IQ5, CITO-IQ7, and CITO-IQ10 the unique environmental influences could be reduced to the variable specific influence only (Model 4). For CITO-IQ12, however, some overlap in nonshared environmental influences was observed. For CITO-IQ5 and CITO-IQ7 no difference was observed between a model with a common factor for additive genetic influences or a model with a common factor for shared environmental influences. Both models did not significantly worsen the fit. However, model reduction to a common factor for both additive genetic and shared environmental influences did change the χ^2 significantly. For CITO-IQ10 both the additive genetic and the shared environmental influences could be reduced to a common factor influencing CITO and IQ10. For CITO-IQ12, the full model could be reduced to a model with a common factor for shared environmental influences.

The percentage of variances explained by additive genetic, shared environmental and unique environmental influences based on the full model (ACE without sex-differences) are presented in Table 5. From age 5 to age 10,

Table 2a

Twin Correlations for CITO at Age 12

	MZF[a]	DZF	MZM	DZM	DOS
CITO	.85 (.80–.89)[b]	.47 (.30–.61)	.83 (.77–.88)	.56 (.42–.67)	.55 (.44–.65)

Note: [a] MZF = monozygotic female, DZF = dizygotic female, MZM = monozygotic male, DZM = dizygotic males, DOS = dizygotic opposite sex
[b] 95% confidence intervals

Table 2b

Univariate Model Fitting Results for CITO at Age 12

Model	−2LL	*df*	ΔX^2	Δdf	*p*	A[d]	C	E
ACE + sd[c]	10410.65	1491						
ACE	10411.11	1494	.46	3	.93	.57 (.44–.71)	.27 (.13–.39)	.16 (.13–.19)
AE	10424.19	1495	13.8	1	.00			
CE	10494.41	1495	83.3	1	.00			

Note: [c] model with sex-differences in the strength of the additive genetic, shared environmental and nonshared environmental influences
[d] A represents additive genetic influences, C represents shared environmental influences, and E represents nonshared environmental influences.

Table 3

Phenotypic Cross-correlations for IQ at Four Ages and CITO, Calculated for the Complete Dataset and MZ and DZ Cross-correlations

		IQ5	IQ7	IQ10	IQ12
Total Sample	CITO	.41 *(.31–.50)*	.50 *(.40–.58)*	.60 *(.52–.66)*	.63 *(.55–.69)*
MZ	CITO	.45 *(.12–.53)*	.47 *(.27–.62)*	.55 *(.36–.68)*	.52 *(.32–.65)*
DZ	CITO	.37 *(.23–.48)*	.37 *(.24–.48)*	.37 *(.24–.48)*	.50 *(.39–.59)*

Table 4

Bivariate Model-Fitting Results for CITO-IQ

	MODEL	–2LL	*df*	χ^2	Δdf	compared to model	*p*
CITO-IQ5	Model 1. ACE, H_{free}, sex differences in parameter estimates	13540.560	1883				
	Model 2. ACE sex differences	13540.576	1884	.016	1	1	.90
	Model 3. ACE no sex differences	13547.738	1893	7.162	9	2	.62
	Model 4. ACE E:variable-specific factors only	13548.158	1894	.42	1	3	.52
CITO-IQ7	Model 1. ACE, H_{free}, sex differences in parameter estimates	13412.527	1850				
	Model 2. ACE sex differences in parameter estimates	13412.546	1851	.019	1	1	.89
	Model 3. ACE no sex differences	13417.961	1860	5.415	9	2	.78
	Model 4. ACE E:variable-specific factors only	13417.962	1861	.001	1	3	.92
CITO-IQ10	Model 1. ACE, H_{free}, sex differences in parameter estimates	13447.831	1860				
	Model 2. ACE sex differences in parameter estimates	13447.837	1861	.006	1	1	.94
	Model 3. ACE no sex differences	13462.791	1870	14.954	9	2	.09
	Model 4. ACE E:variable-specific factors only	13462.798	1871	.007	1	3	.93
CITO-IQ12	Model 1. ACE, H_{free}, sex differences in parameter estimates	13210.245	1849				
	Model 2. ACE sex differences in parameter estimates	13210.343	1850	.01	1	1	.92
	Model 3. ACE no sex differences	13220.468	1859	10.125	9	2	.34
	Model 4. ACE E:variable-specific factors only	13225.776	1860	5.308	1	3	.00

Table 5

Percentage of Variance and Covariance Explained by A, C and E, Based Best Fitting Model, with 95% Confidence Intervals and Genetic and Shared/Nonshared Environmental Correlations

			A[a]	C	E
Variance					
	Model *4*	CITO	.57 *(.44–.72)*	.27 *(.13–.39)*	.16 *(.13–.19)*
		IQ5	.22 *(.01–.46)*	.55 *(.32–.72)*	.23 *(.17–.32)*
	Model *4*	CITO	.56 *(.44–.70)*	.28 *(.14–.40)*	.16 *(.13–.19)*
		IQ7	.40 *(.11–.73)*	.29 *(.00–.54)*	.31 *(.22–.43)*
	Model *4*	CITO	.58 *(.45–.72)*	.26 *(.13–.39)*	.16 *(.13–.19)*
		IQ10	.50 *(.26–.79)*	.30 *(.02–.52)*	.20 *(.15–.28)*
	Model *3*	CITO	.55 *(.43–.68)*	.29 *(.16–.40)*	.16 *(.13–.19)*
		IQ12	.51 *(.31–.73)*	.33 *(.13–.52)*	.15 *(.11–.22)*
Covariance					
	Model 4	CITO-IQ5	.40 *(.00–.92)*	.60 *(.08–1.00)*	—
	Model 4	CITO-IQ7	.75 *(.32–1.00)*	.25 *(.00–.68)*	—
	Model 4	CITO-IQ10	.83 *(.53–1.00)*	.17 *(.00–.47)*	—
	Model 3	CITO-IQ12	.41 *(.19–.64)*	.51 *(.28–.70)*	.09 *(.01–.16)*
Correlation					
	Model 4	CITO-IQ5	.42	.58	—
	Model 4	CITO-IQ7	.74	.42	—
	Model 4	CITO-IQ10	.90	.35	—
	Model 3	CITO-IQ12	.47	1.00	.47

Note: [a] A represents additive genetic influences, C represents shared environmental influences, and E represents nonshared environmental influences.

the expected increase in heritability of IQ could be seen. This increase was previously found in these data (Bartels et al., 2002). Furthermore, additive genetic effects explained around 60% of the individual differences in CITO. 24% of the variance in CITO could be explained by shared environmental influences, while unique environmental influences explained 16%. This pattern of influences was identical to the results of the univariate analysis.

Overlap in genetic and shared environmental factors for CITO and IQ is indicated by the genetic and shared environmental correlations in the lower part of Table 5. Covariance between CITO and IQ at the four ages could be mainly explained by additive genetic factor for CITO-IQ7 and CITO-IQ10 (Table 5). The covariance between CITO-IQ5 and CITO-IQ12 was accounted for by additive genetic factors as well as shared environmental factors. As for the most important covariance, CITO-IQ12, it was indicated that the same shared environmental influences influence both CITO and IQ at that age. Some nonshared environmental influences on the covariance between CITO and IQ 12 were observed. These influences suggested idiosyncratic experience specific for age 12.

In summary, additive genetic as well as shared environmental effects were of significant influence on the observed association between CITO and IQ at four ages. Heritabilities of IQ rose from age 5 to age 10 and the heritability of CITO was around 60%.

Discussion

Previous studies indicated that in addition to several environmental variables, intelligence seemed to be an explaining factor for the variance in scholastic achievement (Eaves & Darch, 1990; Jensen, 1972). Behavior genetic studies also established that genetic effects were the primary source of variance underlying the observed association between cognition and achievement (Petrill et al., 1993; Thompson et al., 1991; Wadsworth et al., 1995a, 1995b).

Additive genetic effects accounted for 60% of the individual differences found in CITO scores in a large sample of Dutch 12-year-olds. This high heritability indicates that the CITO might be a valuable instrument to assess individual differences in cognitive abilities in children but might not be the right instrument to put the effect of education to the test. The finding of significant additive genetic and shared environmental influences is in line with previous studies on individual differences in scholastic achievement (Labuda et al., 1986; Loehlin & Nichols, 1976; Martin & Martin, 1975; Martin, 1975; Nichols, 1965; for a review see Plomin, 1986; Thompson et al., 1991; Willerman et al., 1977).

The primary aim of this study was to establish if a significant association existed between cognitive abilities and a national test of educational achievement (CITO) in a Dutch sample and to establish the background mechanism of this possible phenotypic correlation. Further the predictive value of IQ for scholastic achievement was examined. To this end multivariate behavior genetic analyses with CITO and IQ at age 5, 7, 10 and 12 were conducted. The results point to genetic effects as the main source of variance in CITO score and an important source of covariance between CITO score and IQ. Beside genetic influences, shared environment shows significant influences on the variance of CITO and IQ and the covariances at all ages. Further, based on correlation between IQ5 and CITO and taking the results of the bivariate model fitting into account IQ5 seems to be an accurate indicator for CITO at age 12. However, the association is not strong enough to completely predict outcomes of the CITO at age 12 from cognitive ability at age 5. Despite the wealth of evidence for small but significant sex-differences in cognitive abilities (for a review see Helgeson, 2002) no sex-differences for CITO or IQ were found. CITO scores were available for 702 boys and 793 girls, resulting in means of 538.13 and 537.66 respectively.

Remarkable is the drop in genetic influences on the covariance between CITO and IQ at age 12. A possible explanation is based on the results of the longitudinal study previous conducted with this sample (Bartels et al., 2002). In this longitudinal study a common genetic factor was found, which influenced cognitive ability at all ages. So it can be hypothesized that the genes that influence stability in IQ also influence the covariance between CITO and IQ at ages 5, 7, 10 and 12. The longitudinal study in cognitive abilities showed that shared environmental influences were partly explained by a common factor and partly by age specific factors. The covariance between CITO score and IQ at age 12 however, can be based on several time specific influences. For instance, age specific shared environmental influences explain a large part of the covariance between CITO and IQ at age 12. So the fact that CITO is measured at age 12 and analyzed in combination with IQ assessed at age 12, makes this bivariate analyses more sensitive than the bivariate analyses for CITO and IQ at previous ages.

Focusing on genetic influences as the overlapping factor for the association, the large CITO database creates opportunities for future research on the genetics of cognition. Because of the fact that the CITO has been used for a long time, scores for parents and their twins are available in the CITO database. Furthermore, administering an intelligence test is time consuming and in order to get more insight into the genetic background of cognition large sample sizes are necessary. Especially since the CITO is a nationwide standardized test, the use of the database and the possibilities to recruit parents, siblings and normal controls for genetic studies would boost power to finally find genes influencing cognitive abilities.

Focusing on shared environmental influences as the main overlapping factor for the association between CITO and IQ, it is interesting to focus on the exact nature of these environmental influences. In general, family environment (SES) is considered to be the main factor of shared environmental influences. However, studies nowadays, also emphasize aspects outside the family environment, like friends or being a member of a sports club, which may also cause similarities between two children of a twin pair. Obviously in measuring scholastic achievement and cognitive abilities and taking the Dutch school system into account, one may also consider the school environment as an important source of shared environmental influences. Information on "same or different" teachers indicated that out of a large sample of 12-year-old twin pairs (n = 1164) 63% of twins are taught by the same teacher, whereas 37% go to separate classes. This ratio makes teacher or classroom environment a shared environmental influence for the majority of the children. Since, in the Dutch school system children move to a different teacher each school year, this results in a lack of continuity in this particular aspect of shared environment. So, these shared but age-specific experiences within the classroom may be represented by the age-specific factors as specified significant in a previous longitudinal study (Bartels et al., 2002). Further indication to consider the classroom and teacher as shared environment is given by preliminary results on twin correlations for CITO in the same large sample of 12-year-old-twin pairs. The twin correlation for CITO in twins taught by the same teacher (MZ = .85; DZ = .63) indicate higher influences of shared environment than the twin correlations for CITO in twins taught by different teacher (MZ = .78; DZ = .29). It should be noted that because only a minority of the twins go to separate classes the zygosity groups to calculate these twin correlation are still small. The collection of CITO data and data on "different or same" teacher is a continuous process at the NTR, so more insight in this matter can be gained in the future. The unique environment was found to explain only a small portion of the variance of CITO. It further seems to be of no influence on the association between CITO and IQ, except for the association between CITO and IQ12. The finding of the influence of nonshared environmental influences on this covariance indicates that, besides measurement error, pure idiosyncratic experiences are of importance for individual differences in cognitive abilities and CITO at age 12. Furthermore, the finding of a significant influence on the association between CITO and IQ at age 12 only, underlines the transient nature of these idiosyncratic experiences. This transient nature of nonshared environmental influences was previously found in a longitudinal study on the development of intelligence (Bartels et al., 2002).

Cognitive abilities seem to be an explaining factor for the variance in scholastic achievement as measured with the CITO. The association between CITO and IQ is both mediated by underlying genetic and shared environmental influences. Furthermore, it is clear that genetic background accounts for almost 60% of the individual differences found in CITO scores in a large sample of 12-year-olds. The large heritability indicates that the CITO is a valuable instrument to measure capacities in cognition in children but may not be the correct instrument to put the effect of education in a specific school to the test.

A previous study by Thompson and colleagues (1991) reported genetic correlations in the range of .57 to .85, which is in line with the genetic correlations in this study. However, in this study shared environmental correlation ranging from .35 to 1.00 are found, while in previous studies this correlation was essentially zero (Thompson et al., 1991).

With the unique databases of CITO in mind, future studies could be very valuable. For instance, influences of classroom and teacher as a source of shared environmental influences could be sorted out by comparing twins attending the same class with twins attending separate classes. Furthermore, with the value put on the results of the CITO nowadays, it is important to sort out the background of the individual differences in the test results. Another valuable future study could focus on comparison of the decomposition of the variance in CITO scores measured in different cohorts. Daily newspapers mostly devote their articles to the reliability of the national test of educational achievement. Questions are raised about the measurement procedure and the non-standardized preparation of the children. There is no control on the amount of practice prior to the actual days of testing. Opponents of the CITO often use these arguments in discussing the value of the test. The high correlation between MZ twins, which can be regarded as an alternative measure of test–retest reliability, suggests that reliability of the CITO test is good to excellent.

In the USA it has been proven that supplementing teachers' opinions with standardized screening test results is needed to ensure accurate decision-making (Glascoe, 2001). The teacher's opinion may be biased by formal expectations (Demaray & Elliot, 1998), knowledge of the child's SES (Lichtenstein, 1984), or risk factors for difficulties such as language spoken at home (Glascoe, 2001). These previous studies emphasize the importance of independent testing in order to advice parents on the future educational level of their children. The current study on CITO and IQ at four ages may give rise to a valuable discussion on the reliability and appropriateness of the CITO as a measure for the quality level of a certain elementary school in comparison to other elementary schools in the country.

Limitations of the Study

It is known that academic achievement or educational attainment is a phenotype on which nonrandom mating occurs. Besides the so-called passive elements of mate selection (e.g., type and length of education, social class, area of residence), active personal preferences for physical and psychological attributes, including IQ, may play a role in mate selection. This will induce positive assortative mating. Assortative mating is important for genetic research for two reasons. First, assortative mating increases genetic variance in a population. In other words, positive assortative mating increases variance in that the offspring differ more from the average than they would if mating were random. Even if spouse correlations are modest, assortative mating can greatly increase genetic variability in a population, because its effects accumulate generation after generation. Assortative mating is also important because it affects estimates of heritability. Positive assortative mating increases the resemblance between dizygotic twins because it renders the parents of these twins more similar compared to the situation where assortative mating is absent. Identical or monozygotic twins, however, are already at the point of maximum genetic resemblance, and are thus unaffected by positive assortative mating (Plomin et al., 2000). Based on the comparison of MZ correlations and DZ correlations, an increased DZ correlation will result in decreased estimates of heritability, when estimating C. It is possible that in our study the estimate of shared environmental influences is inflated by assortative mating.

Strong assortment effects have been shown for cognitive abilities (Mascie-Taylor, 1989; Nagoshi et al., 1987; Philips et al., 1988; Tambs et al., 1989). The extension of the classical twin design to include parental measurements can be used to disentangle sources of variation that are confounded in the classical twin design and explicitly assess the roles of mate selection in the determination of scholastic achievement (Eaves et al., 1989). In future research, information on CITO scores for the parents of the twins should be collected from the unique database of CITO to sort out the presence and strength of assortative mating in these traits.

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