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Review

# The prediction of school achievement from a behavior genetic perspective: Results from the German twin study on Cognitive Ability, Self-Reported Motivation, and School Achievement (CoSMoS)

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ABSTRACT

Much phenotypic research aims to identify which individual and familial characteristics explain individual differences in academic achievement. Behavior genetic studies can add informative value by analyzing the sources of this variation. The objective of the present study was to investigate the genetic and environmental origins of academic achievement and of two important and widely accepted predictors of school achievement, i.e. general cognitive ability (CA) and domain-specific self-perceived abilities (SPA). Results are based on cross-sectional data from the German twin study CoSMoS (97 MZ twin pairs, 183 DZ twin pairs; mean age 13.1 years, SD = 0.87). In line with previous research we confirmed the significance of genetic influences for all three variables, yielding heritability estimates between 30% and 62%. Multivariate genetic analyses further indicated that the genetic correlations between the variables were substantial and that SPAs in two school domains (German and Math) correlated with academic achievement for genetic rather than environmental reasons.



## 1. Introduction

Measures of general cognitive ability (*g*) correlate with measures of achievement at approximately 0.50 (e.g., Gustafsson & Undheim, 1996), identifying *g* as the most important single predictor of achievement. More recently, researchers are addressing the question of which constructs explain the remaining 75% of the variance in school achievement. Children's motivational characteristics and especially their self-perceived abilities (SPAs) have been shown to be promising candidates (e.g., Spinath, Spinath, Harlaar, & Plomin, 2006; Steinmayr & Spinath, 2009). In the expectancy-value model by Eccles and colleagues (Eccles (Parsons) et al., 1983; Wigfield & Eccles, 2000) – a well established theory applicable to school contexts – it is presumed that SPAs are the key variables influencing future achievement. Typically, SPAs are assessed by self-reports about how *good* people think they are in a specific domain. Many studies have confirmed moderate relations between SPAs and school achievement within domains, mostly ranging between 0.40 and 0.60 (e.g., Guay, Marsh, & Boivin, 2003; Marsh, Smith, Barnes, & Butler, 1983). So far, intelligence and SPAs have rarely been considered in the same study. Results from such studies (Gose, Wooden, & Muller, 1980; Schicke & Fagan, 1994; Spinath et al., 2006; Steinmayr & Spinath, 2009) converge in that SPAs contributed to the prediction of school achievement after intelligence was controlled, explaining incremental variance between 3% and 8%. Additionally, a substantial portion of variance in school achievement has been explained by what *g* and motivation had in common (Spinath et al., 2006).

Behavior genetic findings indicate that the heritability of intelligence increases from childhood to adulthood (from around 40% in middle childhood to around 60% in adulthood) whereas shared environmental effects show a reverse trend with high influences in early childhood and negligible influences after adolescence (e.g., Plomin, DeFries, McClearn, & McGuffin, 2008; Plomin & Spinath, 2004). With regard to school achievement, heritability estimates of approximately 60% have been reported for different school subjects while estimates for the effects of shared environment have been significantly lower (e.g., Bartels, Rietveld, Van Baal, & Boomsma, 2002; Johnson, McGue, & Iacono, 2006). Results from the Twins' Early Development Study (TEDS, Oliver & Plomin, 2007) suggested that genetic effects contribute to the same extent to continuity and change in academic performance (Kovas, Haworth, Dale, & Plomin, 2007).

At present, behavior genetic findings regarding SPAs are few but the results that have been reported appear to be at odds with theoretical assumptions from the original model in which environmental circumstances – such as parental beliefs, expectations, or

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behaviors – are considered to be the primary sources of children's inter-individual differences in SPAs (Eccles (Parsons) et al., 1983; Wigfield & Eccles, 2000). In TEDS, for example, the reported heritability estimates for a global measure of SPA (combining SPAs in English, Math, and Science in one latent factor) were around 0.50 at ages 9 and 12 whereas shared environmental effects were negligible (Greven, Harlaar, Kovas, Chamorro-Premuzic, & Plomin, 2009; Luo, Haworth, & Plomin, 2010). Multivariate genetic analyses indicated that genetic influences were the primary source of the covariation among intelligence, SPA, and school achievement (e.g., Bartels et al., 2002) and that SPAs predicted school achievement, independently of intelligence, mainly as a result of genetic influences (Greven et al., 2009).

To contribute further to the understanding of the genetic and environmental influences on SPAs as well as genetic and environmental influences on the association between intelligence, SPAs, and achievement, we used a genetically informative design based on a sample of 13-year old German twins. SPAs were operationalized domain-specifically for the school subjects German and Math. This allowed us to explore the genetic and environmental contributions to inter-individual differences in domain-specific SPAs in a German twin sample.

## 2. Method

### 2.1. Participants

The sampling frame was the German twin study CoSMoS, which was initiated in 2005. So far, three measurements with two-year periods in between have been completed (see Spinath & Wolf, 2006, for details of the sampling procedure).

The data in this analysis were collected in the 2009 assessment. They consisted of 280 pairs of twins who participated in at least two of the three surveys and included 97 pairs of monozygotic (MZ), 94 pairs of dizygotic (DZ) same-sex twins, and 89 pairs of dizygotic opposite-sex twins (mean age = 13.1, SD = 0.87, 51.9% female). Zygosity was assessed by questionnaire, a method that typically yields accuracies around 95% (Price et al., 2000).

### 2.2. Measures and procedure

#### 2.2.1. General cognitive ability

Cognitive ability (CA) was assessed via telephone by trained experimenters to ensure adherence to the standardized start and stop criteria (cf. Petrill, Rempell, Dale, Oliver, & Plomin, 2002). The test battery consisted of two verbal (*general knowledge* including 18 items and 25 *vocabulary items*) and two nonverbal (*figural classification* and *figural reasoning* consisting of 25 items each) scales adapted from the German Cognitive Ability Test (KFT 4–12 + *R*; Heller & Perleth, 2000) and the Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991). A factor analysis of the four cognitive ability scales clearly favored a general factor model with the first factor accounting for 51% of the variance.

#### 2.2.2. Self-perceived abilities

The questionnaire assessing SPAs was completed at the participants' homes either in paper-and-pencil or on-line format. Children's SPAs for Math and German were assessed by means of three items each. Children were asked to indicate on a 5-point scale ranging from very good (1) to *not good at all* (5) how good they thought they were in the following activities*: number puzzles or text task, mental arithmetic and multiplying/dividing* (Math) and *reading, writing and orthography* (German). Internal consistencies for the SPA scales were good to satisfactory (Cronbach's alpha of 0.82 (Math) and 0.70 (German)).

#### 2.2.3. School achievement

Mid-term and full-term school grades served as indicators for school achievement in Math and German. Because the mark indicating excellence in the German system is 1, coding of grades was reversed so that higher values represent better performances.

## 3. Results

### 3.1. Phenotypic analyses

The scores of CA, SPAs and achievement were regressed on age and sex (McGue & Bouchard, 1984). Standardized residual scores were then used in a latent-factor model of CA (with the four cognitive tests as indicators), SPAs (with the three SPA items per subject as indicators), and achievement (with mid-term and full-term school grades as indicators) separately for Math and German. The phenotypic latent-factor model corresponded with the genetic common-pathway model displayed in Fig. 1. Incomplete data was handled using the expectation maximization algorithm implemented in SPSS 18, since the missing data pattern was completely at random (Little & Rubin, 2002).

Table 1 lists the latent factor correlations calculated with Mx (Neale, Boker, Xie, & Maes, 2004) as well as the loadings of the specific measures on the latent factors.

All phenotypic correlations (except the one between CA and SPA German) were modest to moderate and comparable for Math and German ($r = 0.23–0.46$, $p < 0.01$; $r = 0.41–0.47$, $p < 0.01$, respectively). All factor loadings were moderate to high indicating that the common variance among the measures was adequately captured by the latent factors.

### 3.2. Genetic analyses

Genetic analyses were based on the standard assumptions of the classical twin design (CTD; Plomin et al., 2008; for a detailed description of the design and its application refer to Spinath & Johnson, 2011). In this basic quantitative genetic model, the observed phenotypic trait variance is partitioned into additive genetic (A), non-additive genetic (D), shared environmental (C), and nonshared environmental (E) variance components where D and C are confounded in the CTD and therefore cannot be estimated simultaneously (Ozaki, Toyoda, Iwama, Kudo, & Ando, 2011). Whether D or C is estimated in a particular model depends on the pattern of MZ and DZ twin similarities, calculated as intraclass correlations (ICC). Shared environmental influences are assumed if MZ twins are less than twice as similar as DZ twins. In contrast, dominance can be assumed if MZ twin intraclass correlations exceed half the DZ correlations.

#### 3.2.1. Intraclass correlations

Twin similarity was calculated as ICCs based on scale scores for CA, SPA Math and SPA German as well as school achievement in Math and German. As can be seen in the last two columns of Table 1, ICCs for MZ twins exceeded DZ ICCs for all measures, indicating the contribution of additive genetic influences. For CA and achievement, MZ correlations were less than twice the DZ correlations, suggesting some contribution of shared environmental effects. Finally, ICCs for CA and achievement were generally higher than for SPAs, thus nonshared environmental influences appeared to be of greater importance for SPAs than for the former variables.

#### 3.2.2. Model-fitting analyses

We applied maximum-likelihood model fitting procedures using Mx (Neale et al., 2004) to estimate the relative contributions of genetic and environmental influences on the latent variables CA,