Educational Psychology,
Vol. 25, No. 1, February 2005, pp. 55–73

Carfax Publishing
Taylor & Francis Group

A Genetically Sensitive Investigation of the Effects of the School Environment and Socio-Economic Status on Academic Achievement in Seven-Year-Olds

Sheila O. Walker,[a]* Stephen A. Petrill[b] and Robert Plomin[a]
[a]*King's College, UK;* [b]*Pennsylvania State University, USA*

Although it is well established that school characteristics (SCH) and socio-economic status (SES) are associated with academic achievement (ACH), these correlations are not necessarily causal. Because academic achievement shows substantial genetic influence, it is useful to embed such investigations in genetically sensitive designs in order to examine environmental influences more precisely by controlling genetic influence on ACH. In the first study of this kind for academic achievement, data were collected for 1,063 same-sex pairs of seven-year-old MZ and DZ twins for teacher-assessed ACH, UK statistics on SCH, and parent-reported SES. Exclusive of genetic influence on school achievement, shared environment (environmental influences that make siblings similar) accounts for 12% of the variance in academic achievement. SCH accounts for 17% and SES accounts for 83% of this shared environmental variance. Exclusive of genetic and shared environmental influence including SCH and SES, nonshared environment (environmental influences that do not make siblings similar) accounts for 19% of the variance in academic achievement. The importance of nonshared environmental influences on academic achievement leads to the question of what these child-specific experiences might be that are not shared by children in the same family, school, and classroom.

Research in educational psychology has long been directed towards understanding how specific aspects of the environment mediate academic achievement, with the ultimate goal of identifying modifiable environmental risk factors and improving performance. For example, some key aspects of the school environment that have been assessed are distal variables such as class size, ethnicity, percent of students receiving free school meals, and truancy (Ehrenberg, Brewer, Gamoran, & Willms,

---

*Corresponding author. 2708 36th Street NW, Washington, DC 20007, USA. Email: sheila_ohlsson@yahoo.com

ISSN 0144-3410 (print)/05/010055-19
DOI: 10.1080/0144341042000294895

2001; Lytton & Pyryt, 1999; McCallum & Demie, 2001; Rutter, Maughan, Mortimore, Ouston, & Smith, 1983; Sutton & Soderstrom, 1999). Additionally, research suggests that the overall level of school academic attainment is significantly associated with individual pupil achievement (Rutter et al., 1983). In short, a substantial body of research suggests that certain distal aspects of the school environment are associated with school achievement.

However, such environmental research has typically not considered possible genetic confounds in interpreting correlations between environmental measures and academic achievement. In fact, genetics is rarely addressed in educational psychology research even in light of the substantial body of research suggesting genetic influence on academic achievement as well as educationally relevant traits such as cognitive abilities and reading (Patrick, 2000; Petrill & Wilkerson, 2000; Plomin & Walker, 2003). One way in which to investigate more precisely the influence of specific environmental measures on academic achievement is to embed environmental research in a genetic framework such as the twin design, which uses the natural experiment of identical and fraternal twins to assess genetic influence (Plomin & Bergeman, 1991). The motivation for investigating the influence of the environment on academic achievement using a genetically sensitive design stems from a decade of research on the interplay between genetics and environment in research on the family environment (Plomin, 1994). This research began with the observation that genetic factors affect not only developmental outcome measures of children such as their adjustment but also measures of the family environment, a phenomenon that has been called the nature of nurture (Plomin & Bergeman, 1991). Subsequent research using multivariate genetic techniques has shown that associations between specific measures of the family environment and developmental outcomes of children are often mediated in part by genetic factors (for example, Reiss, Neiderhiser, Hetherington, & Plomin, 2000). Such multivariate genetic analyses require child-specific measures of the environment such as measures of parenting specific to each twin in a family. Because SES and SCH are not child-specific they cannot be used in multivariate genetic analyses of this sort, although it is nonetheless useful to embed such measures in genetically sensitive designs in order to examine environmental influences more precisely by controlling for genetic influence. Another benefit of genetically sensitive designs is that, in addition to controlling for genetic influence, they distinguish two types of environmental influence – shared environmental influences that make siblings in a family similar to one another and nonshared environmental influences that do not make siblings in a family similar, as discussed later.

The nature of nurture lies in a process known as genotype–environment (GE) correlation in which children's genetic propensities are correlated with their experiences (Plomin, 1994; Plomin, DeFries, & Loehlin, 1977). That is, because children share heredity as well as family environment with their parents, they can passively inherit environments correlated with their genetic propensities (passive GE correlation). For example, given genetic influence on academic achievement, high-achieving children are likely to have high-achieving parents who provide them with both genes and an environment conducive to the development of strong academic skills. In addition, children evoke parental responses in part for genetic reasons (evocative GE correlation) and children actively create environments that foster their genetic propensities (active GE correlation). As it pertains to academic environment, an evocative GE correlation could occur if a pupil draws the teacher's attention to his or her exceptional talent in science by asking insightful questions and showing excitement about the subject matter, and the teacher responds by proactively encouraging the child's interest and offering an invitation to participate in the school's science club. An active GE correlation could occur if the same pupil chooses to prepare a project to compete in a national science competition.

For distal measures of the school environment such as school resources, passive GE correlation can contribute to associations with children's academic achievement, although evocative and active GE correlation is unlikely. For example, academically achieving parents are likely to be more able and willing to place their children in schools with excellent educational resources. Parental SES might operate in a similar manner. SES shows the strongest and most consistent association with children's school achievement (Cappella & Weinstein, 2001; Ceci & Williams, 1997; Hickman, Greenwood, & Miller, 1995; Lytton & Pyryt, 1999; Mortimore & Blackstone, 1982; Rutter & Madge, 1976; Sutton & Soderstrom, 1999), accounting for as much as half of the variance in performance outcomes. Furthermore, SES correlates substantially with the school environment, as schools in affluent neighbourhoods tend to have additional financial resources for educational programs, higher quality teachers, and more supportive processes for pupils (Fowler & Walberg, 1991). Moreover, higher SES parents not only have greater financial capacity to provide educational resources, but also tend to be more proactively involved in supporting the child through the learning process (Hickman et al., 1995). The final link in the chain of passive GE correlation is evidence for genetic influence on SES (Fulker & Eysenck, 1979; Lichtenstein, Hershberger, & Pedersen, 1995; Tambs, Sundet, Magnus, & Berg, 1989; Taubman, 1976; Teasdale, 1979).

Twin studies are useful in testing hypotheses about genetic and environmental etiology (Plomin, DeFries, McClearn, & McGuffin, 2001). Extant twin research on teacher-assessed academic achievement suggests that genetic influence accounts for roughly half of the variance in teacher-assessed academic achievement (Husén, 1959; Walker, Petrill, Spinath, & Plomin, 2004). Although much emphasis has been placed on the magnitude of nature's contribution to achievement, it is important to note that the remaining half of the variance is explained by nurture. Shared environmental influence, or familial resemblance that cannot be explained by genetics, contributes about one quarter of the variance in teacher-assessed achievement (Husén, 1959; Walker et al., 2004). Shared environmental influence refers to the effect of experiences shared by children growing up in the same family which can include attending the same school or being in the same classroom. Finally, non-shared environmental influences also contribute importantly to individual differences between children in the same family and can include differences in their school experiences, even for twins in the same home, school, or classroom. Nonshared environment, which also contains measurement error, accounts for the remaining quarter of the variance in teacher-assessed achievement (Husén, 1959; Walker et al., 2004).

The purpose of the present study is to address the extent to which shared environmental influence on academic achievement is explained by SCH and SES when genetic influence is controlled. We also considered the independent prediction of academic achievement from SCH and SES. Finally, we investigated the extent to which environmental influences on academic achievement, independent of genetics and shared environmental influence, are nonshared by children in the same family, school, and classroom. We addressed these questions using a large, representative sample of identical and fraternal twins whose academic achievement was assessed by their teachers, using UK government statistics for SCH and parent-reported SES.

Method

Participants

The sampling frame for our study was the Twins Early Development Study (TEDS), a longitudinal population-based study of twins born in England and Wales in 1994 and 1995 (Trouton, Spinath, & Plomin, 2002). After screening for infant mortality, all families identified by the UK Office for National Statistics (ONS) as having twins born during 1994 and 1995 were contacted to take part in TEDS when the twins were about one year old. Subsequently, each family was sent a letter explaining the project along with a return-addressed postcard of interest. Parents who responded were mailed a first-contact booklet explaining the TEDS project in greater detail and requesting background demographic information. It is from this information that socio-economic status is derived in the present study.

Of the 8,119 families who received consent forms when the twins were seven and completing their first year in primary school, 4,690 (58%) agreed to participate in the seven-year study. Of those, 4,278 (91%) agreed to allow us to contact the twins' teachers via postal questionnaire and supplied teacher and school details. Of the 8,538 teacher questionnaires sent, 7,246 (85%) responded for both twins. Of these, 2,186 were dizygotic (DZ) opposite-sex twins, which were not utilized in the analyses—an issue that is addressed in further detail below. This produced a sample of 4,846 twin pairs. Despite attrition, it has been shown that the TEDS sample continues to be reasonably representative in terms of education, parental ethnicity, and employment status, of the UK population of parents of young children (Spinath, Ronald, Harlaar, Price, & Plomin, 2003).

Physical similarity ratings by parents were used to determine the zygosity of the twins. This method was more than 95% accurate when validated with a sample of same-sex pairs using DNA markers (Price et al., 2000). Twins with complete school achievement and SES data within the normal range (achievement ± 3SD) included 2,446 pairs of MZ and DZ same-sex twins. School environment data and Key Stage

2 academic achievement data were not available for 1,383 twin pairs as distal measures of the school environment were available for only about 80% of the schools, and Key Stage 2 academic achievement data was only available for children attending schools with pupils aged 11 and higher (about two-thirds of the sample). Key Stage 2 achievement data is not published for infant schools, or those with students under nine years of age. The final sample was comprised of 243 pairs of identical or monozygotic (MZ) males, 298 pairs of MZ females, 259 pairs of fraternal or dizygotic (DZ) males, and 263 pairs of DZ females.

Measures

Teacher-assessed academic achievement. Teachers' academic achievement assessments were based on UK National Curriculum (NC) criteria for Key Stage 1, which is designed for children aged five to seven (Qualifications and Curriculum Authority, 2000). The NC is the core academic curriculum developed by the Qualifications and Curriculum Authority (QCA) and the National Foundation for Educational Research. NC curriculum criteria are uniform assessment guidelines followed by all teachers within the UK school system. For Key Stage 1, the QCA provides teachers with NC curriculum material, end of key stage scholastic aptitude tests (SATs), and grading keys for three academic categories within mathematics (using and applying mathematics; numbers; shapes, space and measures) and English (speaking and listening; reading; writing). These six measures provided the basis of our analysis of teacher-assessed academic achievement.

Key stage 1 NC scores are comprised of teacher-assessed performance at the end of the key stage, when children are seven years old. The teacher's grading key stipulates five levels of achievement for each academic subject area, each level encompassing a broad range of skills. The child's final NC rating is subject to interpretation, as the teacher determines which rating level provides the best fit given the child's performance. For example, a student receives a rating of 1 for Key Stage 1 Writing if the pupil's writing communicates meaning through simple words and phrases, the pupil begins to show awareness of how full stops are used, and letters are usually clearly shaped and correctly orientated; a rating of 2 indicates that a pupil's writing communicates meaning in both narrative and non-narrative forms, uses appropriate and interesting vocabulary, and shows some awareness of the reader; and a rating of 3 if the pupil's writing is often organised, imaginative, and clear, and the basic grammatical structure is usually correct (*QCA English Tasks Teacher's Handbook*, 2002). A student performing below level 1 would receive a "W", and a student performing above level 3 receives a "4 + ". The assessment of the teacher ultimately determines the final SAT score that is submitted to the QCA at the end of the key stage. The SAT at the end of Key Stage 1 is different from other key stages, as it is the only one in which the teacher bears responsibility for grading the exam (with guidelines provided by the QCA). Key Stage 2, 3, and 4 results (administered when children are 11, 14, and 16, respectively) comprise teacher-assessed classroom performance combined with a cumulative objective, externally graded SAT administered at the end of the key stage. Key Stage 1 teacher assessments are the academic achievement measure used in the current analysis. Final scores lie on a five-point scale ranging from far below average to far above average.

Principal component factor analysis of the six academic measures yielded a first unrotated principal component that accounted for 71% of the variance in teacher-assessed academic achievement (Walker et al., in press). The individual academic subject loadings on the general factor were uniformly high, suggesting that the six scores are well represented by a general academic achievement factor (ACH). This general factor provided the basis for our subsequent analyses. Standardized residual scores that adjust for sex differences were used.

Although the validity of teacher assessments has been questioned (for example, Davies & Brember, 1994; Demaray & Elliot, 1998; Glascoe, 2001; Reeves, Boyle, & Christie, 2001), a review of the literature has concluded that on the whole they are valid (Hoge & Coladarci, 1989). Furthermore, in the TEDS sample, Key Stage 1 teacher-assessed reading correlates .68 with a brief test of early word recognition (Test of Early Word Reading Efficiency; Torgesen, Wagner, & Rashotte, 1999) that we administered via telephone to 5,808 seven-year-olds, thus providing additional support for the validity of teacher assessments (Dale, Harlaar, & Plomin, submitted).

School environment. Distal measures of the environment for each school were obtained from the Department for Education and Skills (DfES), the government body responsible for collecting statistical information from schools in the United Kingdom. A composite measure of the school environment was based on: class size; free school meals; authorized absences; unauthorized absences; percent of students classified as ethnic minority; student–teacher ratio; percent of students on the special educational needs (SEN) register (children with mild learning difficulties); percent of students with SEN statements (children with severe learning difficulties); 2001 Key Stage 2 combined school-level results for English, maths, and science; and percent of students speaking English as a second language. Stepwise regression analysis showed that 2001 Key Stage 2 achievement, percent of students eligible for free school meals, and student–teacher ratio were significant predictors explaining a total of 1.9% of the variance in teacher-assessed academic achievement. These variables were standardized and summed to create a school environment (SCH) scale using unit weights from the stepwise regression, and the resulting scale score was re-standardized.

Socio-economic status. All demographic information was obtained from the first contact booklet. An index of socio-economic status (SES) was created based on a factor analysis of fathers' highest educational qualification, fathers' occupation, mothers' highest educational qualification, mothers' occupation, and age of the mother at birth of eldest child. Principal component factor analysis of these variables yielded a first unrotated principal component that accounted for 50% of the variance, with all five variables loading highly (from .52 to .80). The five variables were standardized, and then summed using unit weights in order to create a general SES composite. Further details on the SES measure are available elsewhere (Pike, Iervolino, Eley, Price, & Plomin, submitted).

Analyses

Phenotypic analyses. Univariate analysis of variance (ANOVA) was conducted for the teacher-assessed academic achievement factor scores in order to investigate mean gender, age, and zygosity differences. Standardized residuals adjusting for age and sex differences were used in subsequent analyses. Correlations were calculated to describe the relationships between ACH, SCH, and SES. The phenotypic analyses provide the data necessary to conduct genetically sensitive analyses.

Univariate genetic analyses. Genetically sensitive analyses of ACH, SCH, and SES were conducted using the twin method, which makes use of the natural experiment provided by monozygotic (MZ) and dizygotic (DZ) twins (Plomin et al., 2001). MZ twins share all of their genes but DZ twins are only 50% genetically similar on average. As such, the greater resemblance of MZ twin pairs relative to DZ pairs provides a rough estimate of half the genetic influence on the variance of the outcome measure and doubling the difference in MZ and DZ twin correlations provides a rough estimate of "heritability". The remaining within-pair similarity is accounted for by the shared environment, defined as environmental influences that make twins similar beyond the similarity induced by heredity. Remaining variance not due to genes or shared environment is referred to as nonshared environment, which also includes measurement error. The twin design is widely accepted as a useful screen for genetic influence, and the strengths and limitations of the method are discussed elsewhere (Martin, Boomsma, & Machlin, 1997; Plomin et al., 2001).

Twin analyses generally yield estimates of anonymous components of variance. That is, the analyses do not identify specific genes or specific environmental factors responsible for the genetic and environmental components of variance. However, the informativeness of the twin method can be increased by incorporating specific genes, a major focus of molecular genetic research (Plomin, DeFries, Craig, & McGuffin, 2003), and by incorporating specific measures of the environment (Plomin, 1994). The present study includes two "measured" environmental variables: SCH and SES. As these variables are school-specific (each school gets one score) and family-specific (each family shares the same score), they are by definition shared environmental variables as they have been measured. The goal of the study is to test whether these measured environmental variables account for a significant amount of the shared environmental variance in teacher-assessed academic achievement at age seven, while simultaneously estimating genetic, shared, and nonshared environmental variance.

Maximum likelihood estimation was used to assess the origins of the relationship between SCH, SES, and ACH. The univariate model decomposes the variance in ACH into additive genetic factors (A) and shared environmental factors (C), as well as measured shared environmental factors (SCH and SES) in order to examine the contribution of such factors to teacher-assessed academic achievement (see Figure 1). Genetic relatedness is 1.0 for MZ twins and .5 for DZ twins. The correlation between shared environmental influences (r_C) is defined to be 1.0 both for MZ and DZ twins. The latent E variable represents nonshared environmental influence, which contributes to differences between twins, and also contains measurement error (Plomin et al., 2001). Because the measured environmental variables in the analyses (SCH and SES) are constrained to be equal for all twins, only MZ and DZ same-sex twins are used, as potential sex differences in the DZ opposite sex group present modeling issues. The estimation of the measured shared environmental variables in addition to A, C, and E is an extension of a similar model applied to the TEDS data (Caspi, Taylor, Moffitt, & Plomin, 2000; Petrill, Pike, Price, & Plomin, in press).

The A, C, and E parameters and their 95% confidence intervals were estimated by applying the structural-equation modelling package Mx (Neale, Boker, Xie, & Maes, 1999) to variance–covariance matrices using listwise deletion. Three fit indices are reported: the χ^2-statistic, Akaike's information criterion (AIC = χ^2—2df; Akaike, 1987), and the root mean square error of approximation (RMSEA) which is the most appropriate fit statistic for large sample sizes.

Results

Phenotypic Analyses

Phenotypic correlations between teacher-assessed academic achievement (ACH) and the distal school environment measures are shown in the first column of Table 1. Analyses were performed separately for each member of each twin pair. Results were highly similar for both sets of analyses, although Table 1 presents results for just one randomly-selected member of each twin pair. Significant associations were found between ACH and Key Stage 2 school achievement ($r = .13$, $p < .01$), authorized absences ($r = -.10$, $p < .01$), unauthorized absences ($r = -.11$, $p < .01$), student–teacher ratio ($r = .09$, $p < .01$), class size ($r = .07$, $p < .05$), percentage of students speaking English as a second language ($r = -.06$, $p = .05$), percentage of students receiving free school meals ($r = -.12$, $p < .01$), percentage of students eligible for free school meals ($r = -.13$, $p < .01$), percentage of students on the SEN register (moderate behaviour problems; $r = -.07$, $p < .05$), and percentage of students with severe behaviour problems (statements of SEN; $r = -.11$, $p < .01$). It is noteworthy that ethnicity correlated negligibly with ACH. The rest of Table 1 indicates that the SCH variables are only moderately intercorrelated with the exception of: KS2 achievement and authorized/unauthorized absences ($r = -.38$, $-.37$, respectively); KS2 achievement and students receiving/eligible for free meals ($r = -.50$, $r = -.52$, respectively); authorized and unauthorized absences and students receiving/eligible for free meals ($r = .43$ to $.55$); ethnicity and English as a

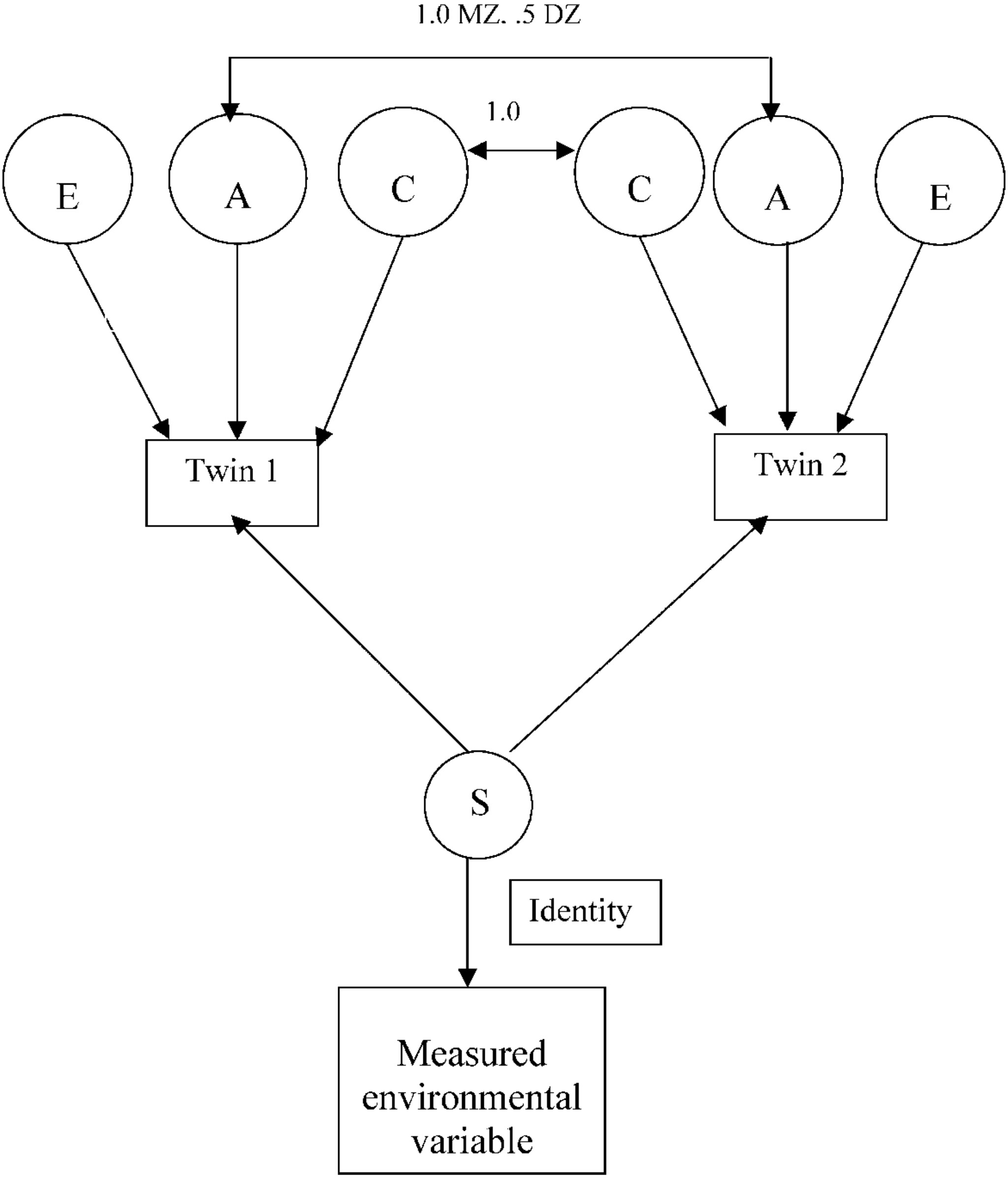

Figure 1. Univariate mediation model estimating genetic (A), shared environmental (C), non-shared environmental (E), and measured shared environmental (S) variables as they relate to target behavioural trait. Rectangles represent the measured behavioral trait, and circles represent latent variables. The pathway from the latent variable to the measured environmental variable is set to identity.

second language (*r* = .74); English as a second language and students receiving/eligible for free meals (*r* = .42 for both); ethnicity and students receiving/eligible for free meals (*r* = .40 for both); students receiving/eligible for free meals and severe

Table 1. Phenotypic correlations between teacher-assessed academic achievement, school-level academic achievement, and school environment variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Teacher-assessed academic achievement factor score	1.00											
2. Key Stage 2 achievement	.13	1.00										
3. Authorized absences	−.10	−.38	−.38	1.00								
4. Unauthorized absences	−.11	−.37	.11	1.00								
5. % Ethnic minority	−.05**	−.12	.10	.37	1.00							
6. Student–teacher ratio	.09	.14	.14	−.12	−.10	−.09	1.00					
7. Class size	.07*	.24	−.14	−.13	.01**	.60	1.00					
8. English as second language	−.06*	−.15	.16	.39	.74	−.13	−.01**	1.00				
9. % Receiving free meals	−.12	−.50	.43	.54	.40	−.20	−.21	.42	1.00			
10. % Eligible for free meals	−.13	−.52	.45	.55	.40	−.20	−.21	.42	.97	1.00		
11. Moderate SEN	−.07*	−.22	.14	.09	−.02**	−.33	−.30	−.002**	.18	.19	1.00	
12. Severe SEN	−.11	−.42	.34	.32	.09	−.24	−.16	.11	.43	.44	.14	1.00

Note. $n = 2575$. All correlations are significant at $p < .01$; *significant at $p < .05$; ** nonsignificant.

Table 2. Model fitting results for teacher-assessed academic achievement at seven, and measured indexes of the shared environment (SCH, SES, SCH controlled for SES, and SES controlled for SCH)

Variable	h^2	c^2	e^2	SCH^2	SES^2	χ^2	*df*	*p*	AIC	RMSEA
Achievement at age seven:										
SCH mediation	.69	.10	.19	.02		9.43	7	.22	− 4.57	.024
SES mediation	.69	.02	.19		.10	10.09	7	.18	− 3.91	.029
SCH_{ses} mediation	.69	.12	.19	.001		9.81	7	.20	− 4.19	.028
SES_{sch} mediation	.69	.04	.19		.08	12.66	7	.08	− 1.34	.039

Note. $n = 541$; MZ and 522 DZ same-sex pairs from 1994 and 1995 cohorts.

special educational needs ($r = .43$, $r = .44$, respectively); and receiving free school meals and eligibility for free school meals, which correlate .97.

As described earlier, we derived an SCH composite from a regression of the SCH variables on ACH. We examined correlations and partial correlations between ACH, SCH, and SES using one randomly selected member of each twin pair. ACH is significantly ($p < .01$) correlated with SCH ($r = .15$) but the strength of the association is considerably diminished when controlling for SES ($r = .03$). Similarly, ACH is associated with SES ($r = .33$) and the relationship weakens when controlling for SCH ($r = .27$). SCH and SES correlate .30. Results for other twins were highly similar. These results suggest that the relationship between SCH and ACH is mediated substantially by SES.

Genetic analyses. The relationships between teacher-assessed academic achievement, school environment, and SES were examined using the model described in Figure 1. Genetic results (shown in Table 2) suggested substantial heritability and moderate shared and nonshared environment for ACH. The shared environmental component of variance was decomposed into separate measured indexes represented by SCH, SES, and residual shared environmental influence (c^2). Maximum-likelihood estimation suggests that SCH and in particular SES contribute significantly to shared environmental influence beyond that accounted for by genetic, nonshared environmental, and unidentified shared environmental influences.

When SCH is used as the sole index of shared environment (first row of Table 2), it accounts for a modest proportion (17%; .02/.12) of the total shared environmental influence on ACH. In other words, 2% of the total variance in teacher-assessed academic achievement at age seven is accounted for by SCH, and 10% is comprised of non-identified shared environmental variance. Genetic factors account for 69% of the variance, and nonshared environmental factors including measurement error account for 19% of the variance [χ^2 (7) = 9.43, $p = .22$, AIC = − 4.58, RMSEA = 0.024; see Figure 2]. However, when SES is entered as the sole index of shared environment (second row of Table 2), it accounts for the vast majority (83%; .10/.12) of the shared environmental influence on ACH. In other words, the proportion of the total variance in ACH accounted for by SES is 10%, and the remaining 2% is comprised of non-identified shared environmental variance. Estimates of genetic and nonshared environmental variance were unchanged, accounting for 69% and 19% of the variance respectively [χ^2 (7) = 10.09, p = .18, AIC = − 3.91, RMSEA = 0.029].

We also ran the same model using SCH controlled for SES (SCH_{ses}) and SES controlled for SCH (SES_{sch}). An analysis controlling SCH for SES (SCH_{ses}) showed that all of the school environmental variance in teacher-assessed academic achievement is mediated by SES (third row of Table 2). This is evident as SCH_{ses} accounts for none of the shared environmental variance (0% of the total variance) in ACH when SES is controlled. Genetic, nonspecific shared, and nonshared environment explain 69%, 12%, and 19% of the variance in ACH, respectively [χ^2 (7) = 9.81, p = .20, AIC = − 4.19, RMSEA = .028]. In contrast, SCH has a significant relationship with SES as it relates to ACH independent of SCH (fourth row of Table 2). SES_{sch} is reduced from .10 to .08 when SCH is controlled [χ^2 (7) = 12.66, p = .08, AIC = − 1.34, RMSEA = .039]. Thus, SCH and SES overlap in their prediction of shared E effects on ACH, although SES accounts for five times as much variance as ACH.

Discussion

The current study is the first to investigate the relative influence of the school environment (SCH) and socio-economic status (SES) on teacher-assessed academic achievement at age seven while controlling for genetics. Phenotypic analyses validate prior research showing that SCH and SES have significant associations with teacher-assessed achievement. Genetically sensitive analyses, which allow for a more precise estimation of environmental influence, validate SES as the primary shared environmental mechanism that mediates the relationship between the school environment and academic achievement exclusive of the substantial effects of genetics on academic achievement. A further benefit of using a genetically sensitive design is that it points to the importance of nonshared environmental influences that affect children's academic achievement, even for children in the same family, school, and classroom.

The finding that SCH and SES have significant associations with academic achievement is not at all new (Cappella & Weinstein, 2001; Ceci & Williams, 1997; Hickman et al., 1995; Sutton & Soderstrom, 1999). Nor is the finding that SCH and SES are related to one another (Cappella & Weinstein, 2001; Fowler & Walberg, 1991; Rutter et al., 1983). In keeping with extant research, the current study found that SCH and SES were significantly correlated with ACH (.15 and .33, respectively), as well as modestly correlated with each other (.30). Further examination of the relationship between ACH, SCH, and SES showed that when controlling SCH for SES, the correlation with ACH was reduced substantially (from .15 to .03), but when controlling SCH for SES, the correlation showed only a modest decrease (from .33 to .27). These results validate prior research showing a significant

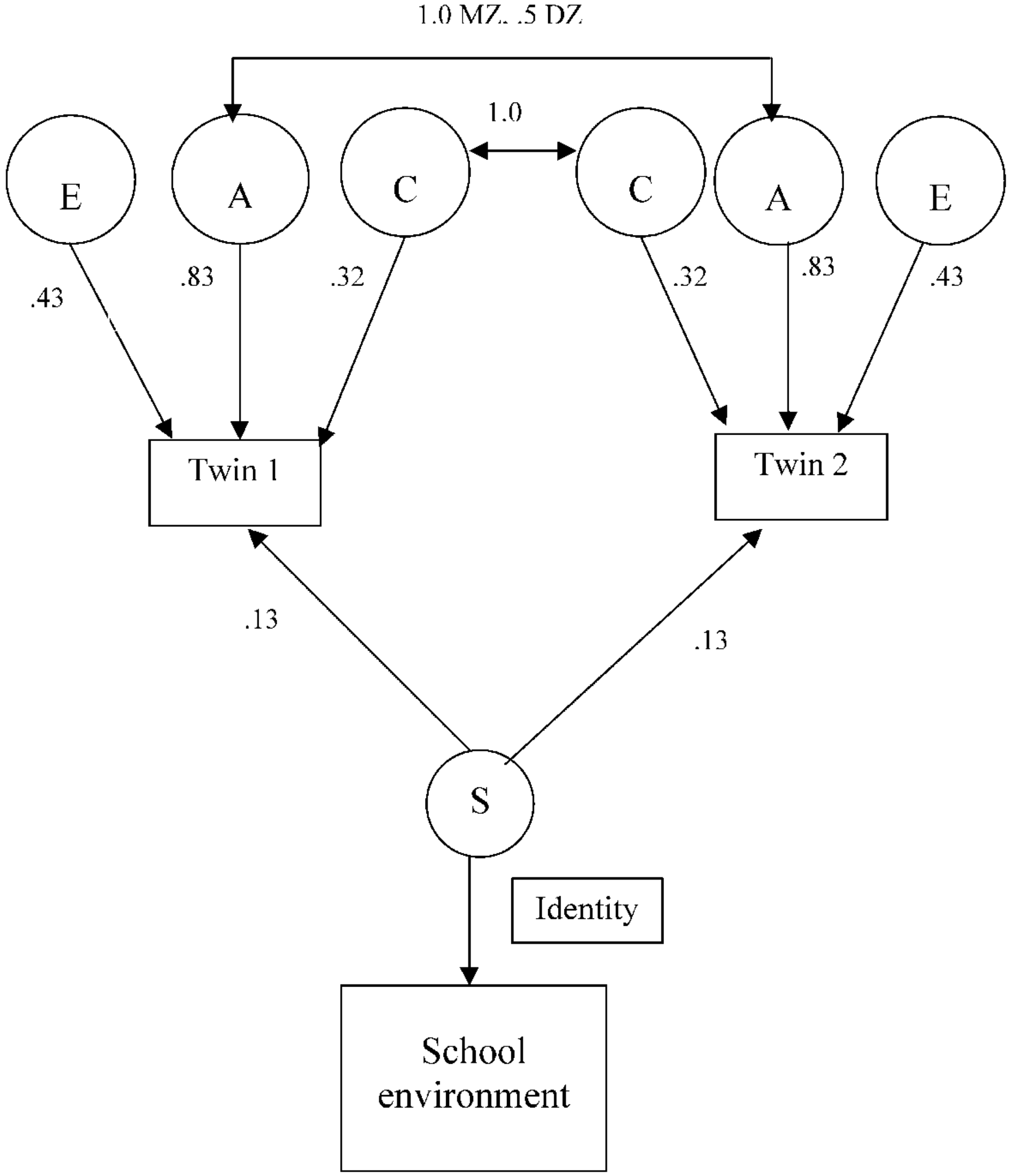

Figure 2. Model-fitting estimates of genetics (A), nonspecific shared environment (C), specific shared environment explained by measured school environment, nonshared environment (E), and measured environment (SCH) for teacher-assessed academic achievement at seven years (ACH). Standardized path coefficients are shown, which must be squared to yield the percentage of variance explained. Thus, A + C + E + S estimates sum to 1.0 (.69 + .10 + .19 + .02 = 1.0). The model assumes that SCH is a separate factor from C.

association between ACH, SCH, and SES and indicate that SES mediates the relationship between teacher-assessed achievement and SCH. However, such phenotypic analyses leave the question of the relative roles of nature and nurture unanswered.

The novel design used in the current study made it possible to re-examine associations between teacher-assessed achievement, SCH, and SES while taking into account the contribution of genetics to achievement. The rationale for taking genetics into account is that it accounts for a very large portion of variance—in the current analysis, genetics account for 69% of the variance in teacher-assessed academic achievement. Exclusive of the effects of genetics, results from the current study suggest that SCH influence on achievement beyond the effects of genetics accounts for 17% of the shared environmental variance and 2% of the total variance at age seven. The significant shared environmental effect of SCH is plausible given that children integrate their experience of the classroom and school into academic performance. For example, good schools tend to have a superior academic ethos and fewer behavior problems (Rutter et al., 1983), and such positive environmental influences help establish a productive learning environment for all pupils. However, SES independently predicted a substantially greater proportion of the shared environmental variance (83%) and the total variance (10%) than SCH alone. This is not surprising, as SES has a broader influence on a child's learning environment than SCH, affecting both home and school characteristics. This dynamic can be explained by the overwhelming effect of SES on the school learning environment, as it influences a wide range of variables such as academic achievement, school resources, teacher and school quality, peer groups, class size, and time spent in school (Cappella & Weinstein, 2001; Harris, 1998; Rutter et al., 1983).The moderate correlation between SCH and SES (.30) combined with the results of the genetically sensitive model imply that environmental aspects of SES mediate the relationship between SCH and teacher-assessed achievement.

Despite the modest effect sizes of SES and SCH on teacher-assessed achievement, it is important to bear in mind that such small environmental influences are significant and can play an important role in the development of long-term behavior patterns. This process may occur through indirect "chain effects" instigated during the school years that accumulate over time (Gray, Smith, & Rutter, 1980). A study structured similarly to the current one highlighting environmental effects controlled for genetics showed that neighborhood deprivation accounted for roughly 5% of the shared environmental variance in behavior problems (Caspi et al., 2000). Though apparently moderate, the magnitude of neighborhood deprivation on psychopathology is similar to that of a traumatic event such as the premature loss of a parent through death or separation (Kendler, Neale, Kessler, Heath, & Eaves, 1992; Kendler et al., 1996). Over the long term, socio-economic settings and school environments, deprived and otherwise, may have similar cumulative characteristics.

Although SES is the strongest shared environmental factor in the current analysis of teacher-assessed academic achievement, the importance of the school environment should not be underestimated. Evidence for effective classroom learning points to the importance of teacher behaviors such as pacing of lessons, class organization, ability to build children's self-esteem, and a focus on academic subjects rather than electives (Good & Weinstein, 1986; Purkey & Smith, 1983). Children exposed to such teaching styles and school climates consistently outperform children at comparably funded schools not exposed to similarly constructive learning environments. In contrast, widely studied and heavily funded aspects of the school environment such as class size, school resources, and other physical factors have been found to play a negligible role in predicting academic success (Purkey & Smith, 1983; Rutter, 1983). What is clear from the research is that even in disadvantaged areas, good schools have the potential to play a positive role in child development (Rutter et al., 1983).

Finally, an important finding from the present study concerns the importance of nonshared environmental influence, which can only be discovered in a genetically sensitive design which controls for both genetic and shared environmental influences. Nonshared environment accounts for about one-fifth of the total variance in the present study. Merely being in the same physical environment does not necessarily serve to make children more similar, as differential perceptions of a similar environment can lead to different experiences (Plomin, 1994). For example, although two children share the same classroom and teacher, they may have extremely different views of how fun and interesting the classroom is on a daily basis, and also may have dissimilar perceptions of their individual relationships with the teacher. Nonshared environment has been almost entirely overlooked in genetically sensitive studies of academic achievement, yet it is a critical piece of the puzzle of understanding how the classroom environment shapes child outcomes, explaining as much variance as shared environment. Identification of such child-specific influences on achievement requires the use of measures of the school environment that are specific to each child rather than general to the entire school. The issue of nonshared school environment is being explored in the next phase of the TEDS project with the twins at nine years old.

The current study is not without its limitations. As discussed in the Methods section, the validity of teacher assessments has been questioned. Evidence does exist that teacher assessments contain some level of bias, if discrepancies with test scores are counted as a sign of bias (Davies & Brember, 1994; Reeves et al., 2001). However, a meta-analysis of the literature suggests that teacher assessments are largely valid (Hoge & Coladarci, 1989). Moreover, although we did not obtain data about the reliability or validity of teacher assessments in the current study, the high correlations for twins—even when rated by different teachers—provide strong evidence for both reliability and validity (Walker et al., 2004). Furthermore, test scores are not without their own biases (Good & Salvia, 1988; Livingstone, 1995; Marks, 1990; Sharpley & Edgar, 1986). Moreover, teachers—particularly those within the UK following National Curriculum guidelines for assessments rather than purely subjective ratings—may actually have a broader perspective on students' performance than measures of test-taking performance. Teachers also assess performance over an extended period of time in the real-world context of the classroom, rather than in the limited environment of achievement tests. In short, teacher assessments may enhance the long-term predictive power of achievement tests, and may be viewed as a strength as well as a limitation of the current study.

Another limitation of our study is the use of distal measures of the school environment to predict academic achievement. As it was not possible to collect qualitative data from each classroom given the scale of the TEDS study, we used data deemed by the UK government to be the best quantitative representation of the thousands of school environments that the school authority is responsible for monitoring. Although the use of distal data may be viewed as a shortcoming, there is substantial evidence that such factors do play a role in overall academic performance (Lytton & Pyryt, 1999; McCallum & Demie, 2001; Rutter et al., 1983; Sutton & Soderstrom, 1999). We believe that the distal measures on which SCH is based, as non-specific as they may be, provide a basic level of insight into a pupil's day-in and day-out surroundings within the school setting.

Acknowledgements

We thank the parents of the twins in the Twins Early Development Study (TEDS) for making this study possible. TEDS is supported by a program grant from Medical Research Council of the United Kingdom.

References

Akaike, H. (1987). Factor analysis and the AIC. *Psychometrika*, *52*, 317–332.

Cappella, E., & Weinstein, R. (2001). Turning around reading achievement: Predictors of high school students' academic resilience. *Journal of Educational Psychology*, *93*, 758–771.

Caspi, A., Taylor, A., Moffitt, T. E., & Plomin, R. (2000). Neighbourhood deprivation affects children's mental health: Environmental risks identified in a genetic design. *Psychological Science*, *11*, 338–342.

Ceci, S. J., & Williams, W. M. (1997). Schooling, intelligence, and income. *American Psychologist*, *52*, 1951–1058.

Dale, P. S., Hamaar, N., & Plomin, R. (submitted). A comparison of two nonconventional procedures for the research assessment of reading skills in 7 year-olds..

Davies, J., & Brember, I. (1994). The first mathematics SATs at KS1. *British Educational Research Journal*, *20*, 35–40.

Demaray, M. K., & Elliot, S. N. (1998). Teachers' judgement of students' academic functioning: A comparison of actual and predicted performances. *School Psychology Quarterly*, *13*, 8–24.

Ehrenberg, R. G., Brewer, D. J., Gamoran, A., & Willms, J. D. (2001). Class size and student achievement. *Psychological Science in the Public Interest*, *2*, 1–30.

Fowler, W. J., & Walberg, H. J. (1991). School size, characteristics, and outcomes. *Educational Evaluation and Policy Analysis*, *13*, 189–202.

Fulker, D. W., & Eysenck, H. J. (1979). Nature and nurture: Environment. In H. J. Eyseick (Ed.) *The structure and measurement of intelligence.* New York: Springer-Verlag.

Glascoe, F. P. (2001). Can teachers' global ratings identify children with problems? *Developmental and Behavioral Pediatrics*, *22*, 163–168.

Good, R. H., & Salvia, J. (1988). Curriculum bias in published, norm-referenced reading tests: Demonstrable effects. *School Psychology Review*, *17*, 51–60.

Good, T. L., & Weinstein, R. (1986). Schools make a difference. *American Psychologist*, *41*, 1069–1077.

Gray, G., Smith, A., & Rutter, M. (1980). School attendance and the first year of employment. In L. Hersov and I. Berg (Eds) *Out of school: Modern perspectives in truancy and school refusal* (pp. 343–370). Chichester, UK: Wiley.

Harris, J. R. (1998). *The nurture assumption: Why children turn out the way they do.* New York: The Free Press.

Hickman, C. W., Greenwood, G., & Miller, M. D. (1995). High school parent involvement: Relationships with achievement, grade level, SES, and gender. *Journal of Research and Development in Education*, *28*, 125–134.

Hoge, R. D., & Coladarci, T. (1989). Teacher-based judgments of academic achievement: A review of the literature. *Review of Educational Research*, *59*, 297–313.

Husén, T. (1959). *Psychological twin research.* Stockholm: Almqvist and Wiksell.

Kendler, K. S., Neale, M. C., Kessler, R. C., Heath, A. C., & Eaves, L. J. (1992). Childhood parental loss and adult psychopathology in women. A twin study perspective. *Archives of General Psychiatry*, *49*, 109–116.

Kendler, K. S., Neale, M. C., Prescott, C. A., Kessler, R. C., Heath, A. C., Corley, L. A., & Eaves, L. J. (1996). Childhood parental loss and alcoholism in women: A causal analysis using twin-family design. *Psychological Medicine*, *26*, 79–95.

Lichtenstein, P., Hershberger, S. L., & Pedersen, N. L. (1995). Dimensions of occupations: Genetic and environmental influences. *Journal of Biosocial Science*, *27*, 193–206.

Livingstone, D. W. (1995). For whom The Bell Curve tolls. *Alberta Journal of Educational Research*, *41*, 335–341.

Lytton, H., & Pyryt, M. (1998). Predictors of achievement in basic skills: A Canadian effective schools study. *Canadian Journal of Education*, *23*, 281–301.

Marks, D. (1990). Cautions in interpreting district-wide standardized mathematics achievement test results. *Journal of Educational Research*, *83*, 349–354.

Martin, N., Boomsma, D., & Machlin, G. (1997). A twin-pronged attack on complex traits. *Nature Genetics*, *17*, 387–392.

McCallum, I., & Demie, F. (2001). Social class, ethnicity and educational performance. *Educational Research*, *43*, 147–159.

Mortimore, J., & Blackstone, T. (1982). *Disadvantage and education.* London: Heinemann.

Neale, M. C., Boker, S. M., Xie, G., & Maes, H. (1999). *Mx: Statistical modeling* (5th ed.). Box 980126 VCU, Richmond VA 23298: Department of Psychiatry.

Patrick, C. L. (2000). Genetic and environmental influences on the development of cognitive abilities: Evidence from the field of developmental behavior genetics. *Journal of School Psychology*, *38*, 79–108.

Petrill, S. A., Pike, A., Price, T., & Plomin, R. (in press). Chaos in the home and socioeconomic status are associated with cognitive development in early childhood: Environmental risks identified in a genetic design. *Developmental Psychology.*

Petrill, S. A., & Wilkerson, B. (2000). Intelligence and achievement: A behavioral genetic perspective. *Educational Psychology Review*, *12*, 185–199.

Pike, A., Iervolino, A. C., Eley, T. C., Price, T., & Plomin, R. (submitted). Environmental risk and young children's cognitive and behavioral development.

Plomin, R. (1994). *Genetics and experience.* Thousand Oaks, CA: Sage Publications, Inc.

Plomin, R., & Bergeman, C. S. (1991). The nature of nurture: Genetic influences on "environmental" measures. *Behavioral and Brain Sciences*, *14*, 373–427.

Plomin, R., DeFries, J. C., Craig, I., & McGuffin, P. (2003). *Behavioral genetics in the postgenomic era.* Washington, DC: APA Books.

Plomin, R., DeFries, J. C., & Loehlin, J. C. (1977). Genotype–environment interaction and correlation in the analysis of human behaviour. *Psychological Bulletin*, *85*, 309–322.

Plomin, R., DeFries, J. C., McClearn, G. E., & McGuffin, P. (2001). *Behavioral genetics* (4th ed.). New York: Worth Publishers.

Plomin, R., & Walker, S. O. (2003). Genetics and educational psychology. *British Journal of Educational Psychology*, *73*, 3–14.

Price, T. S., Freeman, B., Craig, I. W., Petrill, S. A., Ebersole, L., & Plomin, R. (2000). Infant zygosity can be assigned by parental report questionnaire data. *Twin Research, 2000,* 129–133.

Purkey, S., & Smith, M. (1983). Effective schools: A review. *Elementary School Journal*, *83*, 427–452.

Qualifications and Curriculum Authority. (2000). *QCA Key Stage 1*: *Assessment and reporting arrangements*. England: The Stationery Office, Department for Education and Employment. London.

Qualifications and Curriculum Authority. (2002). QCA English Tasks Teacher's Handbook. London: The Stationery Office, Department for Education and Employment.

Reeves, D. J., Boyle, W. F., & Christie, T. (2001). The relationship between teacher assessments and pupil attainments in standard test tasks at Key Stage 2, 1996–98. *British Educational Research Journal*, *27*, 141–160.

Reiss, D., Neiderhiser, J. M., Hetherington, E. M., & Plomin, R. (2000). *The relationship code: Deciphering genetic and social patterns in adolescent development.* Cambridge, MA: Harvard University Press.

Rutter, M. (1983). School effects on pupil progress: Research findings and policy implications. In L. Shulman & G. Sykes (Eds.), *Handbook of teaching and policy* (pp. 3–41). New York: Longman.

Rutter, M., & Madge, N. (1976). *Cycles of disadvantage.* London: Heinemann.

Rutter, M., Maughan, B., Mortimore, P., Ouston, J., & Smith, A. (1983). *Fifteen thousand hours: Secondary schools and their effects on children.* London: Open Books.

Sharpley, C. F., & Edgar, E. (1986). Teachers' ratings vs. standardized tests: An empirical investigation of agreement between two indices of achievement. *Psychology in the Schools*, *23*, 106–111.

Spinath, F. M., Ronald, A., Harlaar, N., Price, T. S., & Plomin, R. (2003). Phenotypic 'g' early in life—On the etiology of general cognitive ability in a large population sample of twin children aged 2–4 years. *Intelligence*, *31*, 195–210.

Sutton, A., & Soderstrom, I. (1999). Predicting elementary and secondary school achievement with school-related and demographic factors. *Journal of Educational Research*, *92*, 330–338.

Tambs, K., Sundet, J. M., Magnus, P., & Berg, K. (1989). Genetic and environmental contributions to the covariance between occupational status, educational attainment, and IQ: A study of twins. *Behavior Genetics*, *19*, 209–222.

Taubman, P. (1976). The determinants of earnings: Genetics, family and other environments: A study of white male twins. *American Economic Review*, *66*, 878–870.

Teasdale, T. W. (1979). Social class correlations among adoptees and their biological and adoptive parents. *Behavior Genetics*, *9*, 103–114.

Torgeson, J. K., Wagner, R. K., & Rashotte, C. A. (1999). *Test of Word Reading Efficiency*. Austin, TX: Pro-Ed.

Trouton, A., Spinath, F. M., & Plomin, R. (2002). Twins Early Development Study (TEDS): A multivariate, longitudinal genetic investigation of language, cognition and behaviour problems in childhood. *Twin Research*, *5*, 444–448.

Walker, S., Petrill, S. A., Spinath, F. M., & Plomin, R. (2004). Nature, nurture and academic achievement: A twin study of teacher ratings of 7 year-olds. *British Journal of Educational Psychology 74,* 323–342.