Published in final edited form as:
Child Dev. 2007 ; 78(3): 972–986. doi:10.1111/j.1467-8624.2007.01044.x.

Why are Hyperactivity and Academic Achievement Related?

Kimberly J. Saudino and
Boston University

Robert Plomin
King's College London

Abstract

Although a negative association between hyperactivity and academic achievement is well documented, little is known about the genetic and/or environmental mechanisms responsible for the association. The present study explored links between parent and teacher ratings of hyperactive behavior problems and teacher-assessed achievement in a sample of 1,876 twin pairs (mean age 7.04 years). The results did not differ across rater, nor were there significant differences between males or females or for twins in the same or different classrooms. Hyperactivity was significantly correlated with achievement. Multivariate model-fitting analyses revealed significant genetic and nonshared environmental covariance between the two phenotypes. In addition, bivariate heritabilities were substantial, indicating that the phenotypic correlations between hyperactivity and achievement were largely mediated by genetic influences.

Children with attention-deficit/hyperactivity disorder (ADHD) are typically academic underachievers. It has been estimated that anywhere from 9% to 80% of children with ADHD have significant learning problems (Frick et al., 1991; Rabiner & Malone, 2004; Rapport, Scanlan, & Denney, 1999). This association is, however, not limited to diagnoses of ADHD in clinical populations. When viewed as a continuously distributed trait consisting of behavioral problems of overactivity, impulsivity, and inattentiveness (Taylor, 1998), hyperactivity also reliably predicts academic underachievement. Dimensional measures of hyperactive problem behaviors in population-based samples are consistently associated with academic achievement such that children who display more hyperactive/inattentive behavior problems tend to perform more poorly in math, reading, language, and global measures of academic achievement (e.g., Adams, Snowling, Hennessy, & Kind, 1999; Barriga et al., 2002; DuPaul, 1991; Fergusson & Horwood, 1995; Merrell & Tymms, 2001; Rapport et al., 1999). Moreover, early hyperactive/inattentive behavior problems are predictive of academic achievement assessed up to 10 years later (Fergusson, Lynskey, & Horwood, 1997; McGee, Prior, Williams, Smart, & Sanson, 2002; Rabiner & Malone, 2004; Rapport et al., 1999). These associations hold when hyperactivity is assessed via parent or teacher ratings of problem behaviors (e.g., Adams et al., 1999; DuPaul, 1991; Goodman & Stevenson, 1989a) or temperament (e.g., Coplan, Barber, & Lagacé-Séguin, 1999; Martin &

Correspondence concerning this article should be addressed to Kimberly J. Saudino at the Psychology Department, Boston University, 64 Cummington St., Boston, MA 02215. Electronic mail may be sent to ksaudino@bu.edu. .

Holbrook, 1985; Newman, Noel, Chen, & Mats-opoulos, 1998); when academic achievement is indexed using standardized tests (Coplan et al., 1999; DuPaul, 1991; Rapport et al., 1999), teacher ratings of progress (Barriga et al., 2002; Martin & Holbrook, 1985; Newman et al., 1998), or report card grades (DuPaul et al., 2004; Fergusson et al., 1997); and when intelligence and family demographics are considered as covariates (Adams et al., 1999; Fergusson, Horwood, & Linskey, 1993; Goodman & Stevenson, 1989a; Rapport et al., 1999).

Although the negative relation between hyperactivity and academic achievement has been well documented, little is known about the factors that mediate this association. Why are hyperactivity and academic achievement related? Two commonly presented explanations for this relation are that frustration associated with achievement difficulties leads to hyperactive behavior problems, or that hyperactive behaviors make it harder for the child to learn within the classroom situation. Behavioral genetics research raises the possibility of a third factor—genetics—accounting for the correlation between hyperactivity and achievement. It is clear that individual differences in both hyperactivity and academic achievement are genetically influenced. Twin studies examining the relative importance of genetic and environmental influences on hyperactivity have consistently shown it to be among the most highly heritable behavior problems in childhood, with heritability estimates as high as 90% (Eaves et al., 1997; Goodman & Stevenson, 1989a, 1989b; Price, Simonoff, Waldman, Asherson, & Plomin, 2001; Saudino, Ronald, & Plomin, 2005; Stevenson, 1992; Thapar, Hervas, & McGuffin, 1995). Similarly, academic achievement is also substantially heritable. Recent research suggests that genetic factors explain more than 50% of the variability in academic achievement (e.g., Bartels, Rietveld, Van Baal, & Boomsma, 2002; Walker, Petrill, Spinath, & Plomin, 2004). It is possible, therefore, that hyperactivity and achievement are associated because of common genetic influences. However, two traits can be highly heritable but not at all genetically correlated. Moreover, individual differences in neither hyperactivity nor achievement are fully explained by genetic factors—both are also influenced by the environment. Consequently, environments that convey risk for developing hyperactive problem behaviors may also influence academic achievement.

Such univariate genetic research cannot address the etiology of the covariance between hyperactivity and academic achievement, which is the provenance of multivariate genetic analyses. These analyses permit exploration of the extent to which genetic and environmental factors overlap across the two domains by examining genetic and environmental sources of *covariance* between the two measures rather than the variance of each measure considered separately (Plomin, DeFries, McClearn, & McGuffin, 2001). Multivariate genetic research exploring the etiology of comorbidity between diagnoses of ADHD and reading disability (RD) suggests that there is a significant genetic overlap between the two disorders (Light, Pennington, Gilger, & DeFries, 1995; Willcutt, Pennington, & DeFries, 2000). For example, Willcutt et al. report a bivariate group heritability of .23 estimating the extent to which proband RD diagnoses are attributable to genetic influences that are common to diagnoses of ADHD. Moreover, they found that 64% of the phenotypic covariance between the two disorders was due to common genetic influence. It remains a question, however, as to whether these results based on extreme selected groups (i.e., using diagnostic criteria) will generalize across the full distribution of scores when hyperactivity and achievement are assessed dimensionally in a nonclinical population. Recent research has suggested that the severity of ADHD, as assessed via quantitative/continuous measures, is particularly important for predicting academic outcomes (DeShazo Barry, Lyman, & Klinger, 2002; McGee et al., 2002). Additionally, given that children with hyperactive behavior problems experience achievement difficulties in a number of academic areas (e.g., math, language, and reading) and that performance across subject areas tend to be highly correlated (e.g., Barriga et al., 2002; Coplan et al., 1999; Rapport et al., 1999), it may be more informative to consider associations with comprehensive measures of achievement rather than focusing on a single subject area. Although no behavioral genetic study has examined the links between hyperactive problem behaviors and academic achievement, a recent twin study examining the effects of disruptive behavior on school grades at age 11 found that there was a substantial overlap in the genetic influences contributing to inattention and global estimates of overall grade performance (i.e., ranging from “much above average” to “much below average”; Johnson, McGue, & Iacono, 2005). These authors, however, focused exclusively on attention problems and did not consider the full range of behavior problems related to hyperactivity (i.e., overactivity, impulsivity, and inattentiveness).

In the present study, we use multivariate genetic methods in a large community sample of young twins to investigate genetic and environmental mediation of associations between individual differences in hyperactive/inattention problem behaviors and early academic achievement. Our focus on early school achievement is important, given that there may be developmental cascades whereby behavior problems in childhood undermine achievement, which in turn influences later behavior problems (Masten et al., 2005). Thus, there may be a snowballing effect, with the association between hyperactivity and achievement increasing over time. Both parent and teacher ratings of hyperactivity are examined. The importance of using multiple informants for the assessment of behavior problems in children has long been emphasized in the phenotypic literature (Achenbach, McConaghy, & Howell, 1987). Correlations between different informants are typically low (i.e., <.30 for parents and teachers), which has been interpreted as indicating that different raters provide unique information about behavior problems because they view the child in different contexts or situations (Achenbach et al., 1987). Although parents provide valuable information about their children’s problem behavior, it has been suggested that teacher reports of hyperactivity may be more valid than maternal reports (Fergusson & Horwood, 1995; Goodman & Stevenson, 1989a; Nadder, Rutter, Silberg, Maes, & Eaves, 2002). Teachers are familiar with a broader range of children and have greater expertise regarding normative child development; moreover, the types of situations in which teachers view children (i.e., highly structured, challenging, large peer groups) are particularly relevant to problem behaviors. Indeed, as compared with parent ratings, teacher ratings of hyperactivity are more highly associated with measures of academic achievement (e.g., DuPaul, 1991; Fergusson & Horwood, 1995; Goodman & Stevenson, 1989a). However, the association between hyperactivity and achievement is not limited to the classroom setting—parent ratings of hyperactivity *do* predict school performance. At question, then, is whether associations between parent-rated (i.e., home) hyperactivity and achievement, and teacher-rated (i.e., school) hyperactivity and achievement arise because of similar mechanisms. Similarly, the inclusion of twin pairs in same and different classrooms in the present study allows us to explore possible teacher/classroom effects on sources of covariance. The extent to which results replicate across informants and contexts informs about the robustness of the effects.

The potential confounding influences of intelligence were also considered in the present study. The fact that the association between hyperactivity and achievement persists after controlling for the effects of intelligence (Adams et al., 1999; Fergusson et al., 1993; Goodman & Stevenson, 1989a; Rapport et al., 1999) suggests that the link between hyperactivity and academic outcome is not simply a result of the association between hyperactivity and general cognitive ability. Nonetheless, hyperactivity, academic achievement, and intelligence are substantially intercorrelated (Fergusson & Horwood, 1995; Fergusson et al., 1993; Rapport et al., 1999) and all are genetically influenced. Previous multivariate genetic analyses have found that genetic factors substantially contribute to the covariance between intelligence and achievement (Bartels et al., 2002; Petrill & Thompson, 1993; Wadsworth, DeFries, Fulker, & Plomin, 1995), and between intelligence and hyperactivity (Kuntsi et al., 2004). It is possible, therefore, that genetic mediation of the association between hyperactivity and achievement could arise indirectly as a result of both variables being genetically correlated with intelligence. To control for this, academic achievement scores were adjusted to remove variance due to general cognitive ability. Thus, the phenotypic association between hyperactivity and academic achievement is independent of general cognitive ability and genetic effects common to general cognitive ability cannot mediate this association.

Method

Sample

The sample for the present study was derived from twins participating in the Twins Early Development Study (TEDS), an ongoing population-based study whose sampling frame includes all twins born in England and Wales in 1994, 1995, and 1996 (Trouton, Spinath, & Plomin, 2002). Background information regarding pregnancy, birth, and family demographics was obtained when the twins were 18 months old. Twins were assessed at 2, 3, 4, and 7 years of age. The current analyses are based on age 7 data from families in the 1994 and 1995 birth cohorts.

Twin zygosity was determined using parents’ responses on a physical similarity questionnaire, which was shown to be more than 95% accurate when compared with DNA markers (Price, Freeman, Craig, Ebersole, & Plomin, 2000). Using this instrument, we were able to assign zygosity with certainty to 95% of the same-sex twin pairs. DNA analyses were used in cases where zygosity was uncertain. We excluded twin pairs for whom sex, zygosity, behavior problem, or academic achievement data were unavailable. Twin pairs were also excluded where at least one of the twins had a hearing problem; specific medical or genetic condition (e.g., cerebral palsy, Down Syndrome, chromosomal abnormality); or was an outlier for birth weight, time spent in hospital, special care after birth, gestational age, or maternal alcohol consumption during pregnancy. Because of the statistical problems that arise when conducting multivariate analyses with opposite-sex twins (Neale, 2002), we limited our analyses to same-sex twins. The final sample included 452 monozygotic male (MZM) and 523 monozygotic female (MZF) twin pairs, 436 dizygotic male (DZM) and 465 dizygotic female (DZF) twin pairs. The mean age at the time of assessment was 7.04 years (*SD* = 0.23).

Procedure

Families were contacted and asked to participate in the age 7 assessment. Fifty-eight percent (4,707 of the 8,115 original TEDS families) agreed to participate. Despite attrition, the TEDS families continue to be fairly representative of the U.K. population with respect to parental occupation, education, and ethnicity (92% White/Causasian, 2.8% Mixed, 1.7% Asian, 1.2% Black, 0.6% other, and 1.6% missing; Spinath, Ronald, Harlaar, Price, & Plomin, 2003). Moreover, with respect to the present analyses, attrition was unrelated to earlier behavior problems (Saudino et al., 2005). Twins who participated in the age 7 assessment were not significantly different from lost twins in hyperactive behavior problems at age 2 (In year 7: *M* = 2.84, *SD* = 1.91; Not in year 7: *M* = 2.91, *SD* = 1.93; *t* = 1.77, *p* = .08).

Of the families participating in the age 7 assessments, 91% granted permission for us to contact the twins' teachers via postal questionnaire and provided accurate information about the teachers and schools. For the present analyses, 1,197 twin pairs were assessed by the same teacher and 639 twin pairs were assessed by different teachers. Twins were placed in the same or different classes largely because of school policies about separation of twins, which vary widely, and apparently result in a nearly random assignment of twins to same or different teachers. In the full sample, the different teacher group was higher in socioeconomic status (same: *M* = .05, *SD* = .71; different: *M* = .15, *SD* = .74; *t* = 3.66, *p*<.001); however, this difference accounted for <.05% of the variance. In addition, the distribution of MZ and DZ twins is similar across the two teacher groups and mirrors what is expected in the population of twins generally. Similarly, the ratio of males to females is similar across teacher groups (same: 48% male; different: 50% male). Thus, it is likely that assignment to same or different teachers is largely due to random variation.

Measures

Hyperactivity—Hyperactive problem behaviors were assessed using the Hyperactivity–Inattention subscale of the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997), a 25-item questionnaire that is designed to assess behavioral competencies as well as behavior problems in children ages 4–16 years. Although a relatively new measure, the SDQ has been widely used in Europe and has been translated into over 40 languages (see www.sdqinfo.com). Both parents and teachers completed the same version of the SDQ. The Hyperactivity–Inattention subscale consists of 5 items assessing behaviors relating to hyperactivity, inattention, and impulsivity (i.e., restless, fidgeting, easily distracted, thinks before acting, and good persistence/attention span). These items were specifically selected for inclusion in the SDQ because they are the key symptom domains for a Diagnostic and Statistical Manual of Mental Disorders, 4th ed. (DSM—IV) diagnosis of ADHD and ICD–10 diagnosis of hyperkinesis (Goodman & Scott, 1999). Raters were asked to indicate on a

3-point scale (0 *not true*, 1 *somewhat true*, 2 *certainly true*) how well each item described the child's behavior over the past 6 months.

Despite it being a brief measure of behavior problems, the SDQ has demonstrated impressive reliability and validity (Goodman, 1997, 2001; Goodman & Scott, 1999). With regard to the Hyperactivity – Inattention subscale, an epidemiological study of over 10,000 British 5- to 15-year-olds found internal consistencies of .77 and .88, and stabilities across 4 – 6 months of .72 and .82, for parent and teacher ratings, respectively; and SDQ Hyperactivity – Inattention subscale scores above 90th percentile were significantly associated with independently-assessed DSV – IV diagnoses of ADHD (Goodman, 2001). Similar results have emerged in a large Australian community sample (Hawes & Dadds, 2004). Moreover, across a variety of samples, scores on the SDQ Hyperactivity – Inattentive scale correlate strongly with clinical assessments of ADHD (Goodman, Renfrew, & Mullick, 2000; Goodman & Scott, 1999; Hawes & Dadds, 2004; Mathai, Anderson, & Bourne, 2004). The SDQ Hyperactivity – Inattention subscale also correlates strongly with the Attention Problems scale on the Child Behavior Checklist (CBCL; Achenbach, 1991) (Becker, Woerner, Hassel-horn, Banaschewski, & Rothenberger, 2004; Goodman & Scott, 1999; Klasen et al., 2000). In fact, the SDQ Hyperactivity – Inattention scale has been shown to be superior for detecting children with hyperactivity problems than its much longer CBCL counterpart (Becker et al., 2004; Goodman & Scott, 1999; Klasen et al., 2000). In the present sample, internal consistency for the Hyperactivity – Inattention subscale was .76 and .85 for parent and teacher ratings, respectively.

Teacher-assessed academic achievement—Teachers' academic achievement assessments were based on U.K. National Curriculum (NC) criteria for Key Stage 1, which is used for children ages 5 – 7 years (Qualifications and Curriculum Authority [QCA] Key Stage 1: Assessment and reporting arrangements, 2000). Assessments were conducted at the end of the first year of primary school (equivalent to Grade 1 in the United States). Key Stage 1 differs from other key stages in that it is the only key stage in which an objective scholastic achievement test is not administered. Instead, teacher judgments of children's specific academic skills, based on the work of the child and NC tests and tasks, determine the achievement scores that are submitted to the QCA at the end of the school year (see Walker et al., 2004 for details). Teachers were provided with NC materials and test guidelines for six academic subjects, three related to mathematics (using and applying mathematics; numbers; shapes, space, and measures) and three related to English (speaking and listening; reading; writing). Performance in each academic area was rated according to 5 levels of achievement (0 = *criteria not achieved, working toward level 1*; 1 = *below NC average*; 2 = *NC average*; 3 = *above NC average*; 4 = *above NC average and at a higher level than level* 3) based on specific academic attainment target criteria outlined in the NC. Each level is indicative of a range of specific skills within that academic area. For example, children at level 1 in mathematics, shapes, space, and measures can describe two-dimensional (2D) and 3D shapes, properties and position, measure and order objects using direct comparison, and order events; whereas children at level 2 use mathematical names for 2D and 3D shapes, describe their properties (e.g., numbers of sides and corners), distinguish between straight and turned movements, understand angle as a measurement of turn, recognize right angles, and are beginning to use common standard and nonstandard units to measure length and mass (Mathematics, National Curriculum for England, Key Stages 1 – 4, 1999).

Mathematics and English composite scores were highly correlated (r = .76) (Spinath, Walker, Saudino, & Plomin, 2005). Moreover, a principal components analysis of the six measures of academic achievement yielded a first unrotated principal component that accounted for 71% of the variance in teacher-assessed academic achievement (Walker et al., 2004). All six measures loaded highly on the general factor, suggesting that the six scores are well represented by a general academic achievement factor. Consequently, a composite measure of general academic achievement, based on all six measures, was formed and used in the following analyses. To control for the influence of general cognitive ability on achievement, we regressed teacher-assessed achievement on test-assessed cognitive ability and used the residuals as a measure of achievement that was independent of cognitive ability.

A review of the literature suggests that teacher-based judgements of academic achievement are generally valid (Hoge & Coladarci, 1989; Newman et al., 1998). This is supported in the TEDS sample, which found that teacher-assessed reading correlated .68 with early word recognition as assessed on the Test of Early Word Reading Efficiency (Torgesen, Wagner, & Rashotte, 1999) administered via telephone (Dale, Harlaar, & Plomin, 2007). Moreover, in TEDS, teacher-assessed achievement correlated .58 with general cognitive ability (Spinath et al., 2005), providing strong evidence of construct validity.

General cognitive ability—A measure of general cognitive ability was obtained using the Similarities, Vocabulary, and Picture Completion subtests from the Wechsler Intelligence Scale for Children, Third edition, U.K. (WISC – III – U.K.; Wechsler, 1992), and the Conceptual Grouping subtest from the McCarthy Scales of Children's Abilities (MCSA; McCarthy, 1972). All subtests were adapted for telephone administration (Petrill, Rempell, Dale, Oliver, & Plomin, 2002). Factor analysis of the four cognitive tests yielded an unrotated principal component accounting for 48% of the variance, with all subtests loading highly on this general factor. To create a single composite measure of general cognitive ability, the subtests were standardized, corrected for age and sex, and summed using unit weightings. This measure was validated in a sample of 52 children, ages 6 – 8 years, by comparing general cognitive ability scores (i.e., telephone-administered test) with performance on an in-person, tester-administered, standardized test of cognitive ability (Petrill et al., 2002). General cognitive ability scores correlated .65 (.72 when corrected for restriction of range) with performance on the Stanford – Binet Intelligence Scale (Thorndike, Hagen, & Sattler, 1986).

Data transformation—To reduce the effects of skewness and sex differences on means and phenotypic variances, scores for hyperactivity – inattention were first log-transformed to correct for positive skew and then standardized within sex. Because twin covariances can be inflated by variance due to age and sex, all scores were residualized for age and sex effects (see McGue & Bouchard, 1984).

Twin Cross-Correlations

The essence of a multivariate analysis of covariance (MANCOVA) is the cross-twin correlation. For the present analyses, the cross-twin correlation involved correlating Twin 1's score on hyperactivity with Twin 2's score on achievement and vice versa. Genetic contributions to the covariance between two measures are implied when the MZ cross-twin correlation is greater than the DZ cross-twin correlation. Twin cross-correlations for all four zygosity groups were calculated using a double entry procedure.

Model-Fitting Analyses

Although the major results of a multivariate twin analysis can be gleaned from twin cross-correlations, model-fitting procedures analyze all of the data simultaneously, provide tests of the fit of models, yield confidence intervals for parameter estimates, and test the fit of alternative models (Plomin et al., 2001). Therefore, bivariate correlated factors models were used to explore the extent to which genetic and environmental effects on hyperactivity overlap with genetic and environmental effects on the academic achievement. All models were fit to observed covariance matrices using Mx structural equation modeling software (Neale, Boker, Xie, & Maes, 2003).

The correlated factors model, depicted as a path diagram in Figure 1, partitions the phenotypic covariance between the hyperactivity and achievement into genetic, shared, and nonshared constituents. The latent variables A1, C1, and E1 refer to the genetic (additive), shared, and nonshared influences on hyperactivity and A2, C2, and E2 refer to the genetic and environmental influences on achievement. The path coefficients, h, c, and e, are standardized partial regressions indicating the relative influence of the latent variables on the phenotypes. Of particular interest in this model are the estimated parameters r_g, r_c, and r_e the genetic, shared environmental, and nonshared environmental correlations, respectively, between hyperactivity and achievement. The genetic correlation indicates the extent to which genetic effects on one measure correlate with genetic effects on another measure, *independent of the heritability of each measure*. That is, the genetic factors that influence two measures can covary perfectly even though the genetic factors on each measure contribute only slightly to the phenotypic variance. Thus, r_g can be 1.0 even though the genetic contribution to the phenotypic correlation is only modest if the heritability of each measure is modest and the same genetic effects operate on each measure. On the other hand, the two measures may be substantially heritable, but the genetic correlation would be zero if the genetic effects on the two measures do not overlap. Similar logic applies to r_c and r_e, the estimated shared and nonshared environmental correlations.

Following tracing rules, the genetic contribution to the phenotypic correlation between hyperactivity and achievement can be calculated as the product of genetic paths linking the two variables (i.e., $[h_1 \times r_g \times h_2]$). Shared and nonshared environmental contributions to the phenotypic correlation are derived in a similar manner. Thus, the phenotypic correlation between the two variables is the sum of the genetic and environmental chains of paths (i.e., $r_{\text{phenotypic}} = [h_1 \times r_g \times h_2]+[c_1 \times r_c \times c_2]+[e_1 \times r_e \times e_2]$). *Bivariate heritability* is the proportion of the phenotypic correlation that is due to genetic factors (i.e., $[h_1 \times r_g \times h_2]/r_{\text{phenotypic}}$).

Parent ratings of hyperactivity

Because previous univariate analyses with this sample found that parent ratings of hyperactivity are prone to contrast effects (Saudino et al., 2005), the parent bivariate model was modified to include a sibling interaction (*i*) on hyperactivity (see Neale & Cardon, 1992). Under this model, each twin's parent rating of hyperactivity is a function of additive genetic effects, shared environmental influences, nonshared environmental influences, *and* the hyperactivity rating of their cotwin. For the parent data, our full model (Model 1) allowed for separate parameter estimates (i.e., h^2, c^2, e^2, r_g, r_c, r_e, and *i*) for males and females. We then fit a series of hierarchical reduced models to test for sex differences. Model 2 equated males and females for sources of covariance between hyperactivity and achievement (i.e., r_g, r_c, r_e). Model 3 equated males and females for the magnitude of genetic and environmental effects in addition to sources of covariance (i.e., h^2, c^2, e^2, and r_g, r_c, r_e). Model 4 equated males and females for all parameters (i.e., h^2, c^2, e^2, r_g, r_c, r_e, and *i*). Because the alternative models are hierarchically related (i.e., one model is nested within the other), the relative fit of each alternative model is determined by the difference in chi-square between the two models, with degrees of freedom (*df*) equal to the difference in degrees of freedom between the two models.

Teacher ratings of hyperactivity

Prior univariate analyses of teacher-rated hyperactivity (Saudino et al., 2005) and teacher-assessed academic achievement (Spinath et al., 2005) indicated that data from same and different teacher groups yielded significant differences in the magnitude of genetic and environmental variance. Therefore, for the teacher data, the full model (Model 1) allowed for separate parameter estimates for males and females within the two teacher groups (i.e., same teacher: males and females; different teacher: males and females). To test for sex differences, we fit models that equated males and females for sources of covariance (Model 2) and for sources of variance and covariance (Model 3) *within* each teacher group. To test for teacher differences, we fit models that equated same and different teacher groups for sources of covariance (Model 4) and for sources of variance and covariance (Model 5) *within* each sex. Each of these alternative models is nested in Model 1. Similarly, Model 3 is nested in Model 2, and Model 4 is nested in Model 5. The relative fits of these nested models can be evaluated by the difference in chi-square between the two models. However, because they are not hierarchically related, models testing sex differences cannot be directly compared with models testing teacher differences (e.g., Model 3 vs. Model 5). In this case, Akaike's Information Criterion (AIC) was computed for both models (see Neale & Cardon, 1992 for formula) and the model with the lowest AIC was judged to be the better fitting model.

Results

Phenotypic Correlations

Parent – teacher agreement for hyperactivity ratings—Correlations between parent and teacher ratings of hyperactivity indicate a moderate agreement between raters ($r = .39$, $p<.001$). As would be expected, there was no difference between parent – teacher agreement for same and different teacher groups (same teacher r = .38, p<.001; different teacher r = .38, p<.001).

Associations between hyperactivity and achievement—Table 1 presents the phenotypic correlations between hyperactivity and achievement and general cognitive ability and achievement, by gender and rater. Although achievement and general cognitive ability were moderately correlated (r = 41, p<.001), the two variables were differentially associated with ratings of hyperactivity. As can be seen in Table 1, hyperactive behavior problems were more strongly related to academic achievement than general cognitive ability. Moreover, after controlling for the modest effect of "*g*" on achievement, the associations between achievement and hyperactivity remained significant and were only slightly lower in magnitude. Thus, general cognitive ability does not contribute substantially to the covariance between hyperactivity and achievement. In all subsequent analyses, the term "achievement" refers to achievement adjusted for general cognitive ability.

Both parent and teacher ratings of hyperactivity were significantly associated with academic achievement. Children with higher hyperactivity scores tended to have lower levels of academic achievement. Consistent with previous findings (e.g., DuPaul, 1991; Fergusson & Horwood, 1995; Goodman & Stevenson, 1989a), this association was slightly stronger for teacher ratings. For males, the correlation between parent-rated hyperactivity and achievement was significantly lower than that for the same teacher group (z = −2.58, p<.01), but not for the different teacher group (z = −1.42, *ns*). For females, the correlation based on parent ratings of hyperactivity was significantly lower than that for both same (z = −4.25, p<.01) and different (z = −4.15, p<.01) teacher groups. Overall, there were no significant differences between the phenotypic correlations for males and females, or across same and different teacher groups. Moreover, the correlations between achievement and general cognitive ability did not significantly differ for high hyperactivity (i.e., top 10%) and the rest of the population (Parent rated hyperactivity: high r = .36, others r = .41, z = .95, p = .34; same teacher ratings of hyperactivity: high r = .40, others r = .40, z = 0.1, p = .92; different teacher ratings of hyperactivity: high r = .52, others r = .38 z = 1.9, p = .06), suggesting that the hyperactivity – achievement relation was not driven by highly hyperactive children.

Twin Cross-Correlations

As has been previously found in analyses of TEDS data (Saudino et al., 2005; Spinath et al., 2005; Walker et al., 2004), twin intraclass correlations for hyperactivity and achievement suggest genetic influences (see Table 2). There was very little difference between the intraclass correlations for unadjusted achievement scores and those for scores that were residualized for general cognitive ability—indicating that there is substantial genetic influence on achievement that is independent of "*g*" (see Spinath et al., 2005, for model-fitting analyses of the relation between "*g*" and achievement in TEDS).

More important to our research question regarding sources of covariance between hyperactivity and achievement are the twin cross-correlations. Across all ratings of hyperactivity (i.e., parent, same teacher, different teacher), the MZ twin cross-correlations exceed those of DZ twins, suggesting that genetic factors contribute to the phenotypic correlation between hyperactivity and achievement. Moreover, the MZ twin cross-correlations are nearly as great as the phenotypic correlations, suggesting that genetic factors contribute substantially to the phenotypic correlation. In addition, the pattern of MZ>DZ twin cross-correlations is similar for both males and females, and hence it appears that the factors that mediate the association between hyperactivity and achievement do not differ across sex. Again, the results were very similar for cross correlations using unadjusted achievement scores, providing further evidence that general cognitive ability does not contribute substantially to the covariance between hyperactivity and achievement. Nonetheless, in the following model-fitting analyses, we use the residualized measure of achievement to control the potential confounding influences of intelligence and to allow us to examine sources of covariance between hyperactivity and achievement independent of cognitive ability. Although not presented, model-fitting analyses on unadjusted achievement scores produced nearly identical results in terms of sources of covariance between hyperactivity and achievement.

Model-Fitting

Parent ratings of hyperactivity—

Table 3 presents the model-fitting results for the bivariate analyses of the association between parent-rated hyperactivity and achievement. Although the full model estimating separate parameters for males and females (Model 1) fits the data well, it was possible to equate males and females for all parameters without a significant decrement in fit (Model 4). It was also possible to further simplify the model by eliminating shared environmental influences on hyperactivity (Model 5). No other parameters could be eliminated without worsening the fit of the model. These results indicate that males and females did not significantly differ in the magnitude of genetic or environmental variances, or in the sources of covariance between parent-rated hyperactivity and achievement. Parameter estimates from both the full model and the best-fitting reduced model (Model 5) are also presented in Table 3. As can be seen, there is a moderate negative genetic correlation between hyperactivity and achievement. As indicated earlier, genetic correlations indicated the extent to which genetic effects on one trait correlate with genetic effects on another, independent of heritability. For example, an $r_g = -.41$ indicates that roughly 40% of the genetic effects on hyperactivity overlap with genetic effects on academic achievement. The negative value indicates the direction of the relation, in that overlapping genetic influences that result in high hyperactivity scores also result in low academic achievement. Although more modest in magnitude, nonshared environmental influences also negatively covary across hyperactivity and achievement.

Teacher ratings of hyperactivity—

Bivariate model-fitting results for teacher ratings of hyperactivity and achievement are presented in Table 4. Again, the full model fit the data well, but it was possible to fit more parsimonious models. Tests of sex differences indicated that males and females could be equated for sources of covariance between hyperactivity and achievement (Model 2), and for sources of both variance and covariance (Model 3). Thus, within each teacher group, males and females could be equated for all parameters. Tests of teacher differences found that within each sex, same and different teachers could be equated for sources of covariance (Model 4), but both teacher groups could not be equated for all parameters (Model 5). Hence, although the same and different teacher groups do not differ in the magnitude of genetic and environmental correlations between hyperactivity and achievement, they do differ for estimates of genetic and environmental variance. Of the five models fit to the teacher data, Model 3, which equates males and females but estimates parameters separately by teacher group, was the best-fitting model according to the AIC criterion. As was the case with the parent data, this model could be further simplified by eliminating shared environmental influences on hyperactivity (Model 6).

Table 4 also presents parameter estimates for both the full model and the best-fitting reduced model for the teacher data. Teacher-group differences in genetic and environmental variances for hyperactivity and academic achievement in TEDS have been discussed elsewhere (i.e., Saudino et al., 2005; Spinath et al., 2005), but briefly, when twins are rated by the same teacher, heritability is higher for hyperactivity and lower for achievement; shared environmental variance higher for achievement; and nonshared environmental variance lower for both variables. More specific to our question regarding sources of covariance, the teacher results are remarkably similar to those of parent-rated hyperactivity. For both same and different teacher groups there was a moderate negative genetic correlation, and a modest negative nonshared environmental correlation, between hyperactivity and achievement. Approximately 50% of the genetic effects and 20% of the nonshared environmental effects on hyperactivity overlap with those on academic achievement.

Bivariate heritabilities—Genetic and nonshared environmental contributions to the phenotypic correlation between hyperactivity and achievement are depicted in Figure 2. The results are similar across all three rater groups. Although the genetic correlations between hyperactivity and achievement were moderate for all three rater groups, the *phenotypic* correlations are almost entirely due to common genetic influences. Thus, the bivariate heritiabilities are substantial. For example, the bivariate heritability between parent-rated hyperactivity and academic achievement was .91, indicating that 91% of the phenotypic correlation was due to overlapping genetic factors. Nonshared environmental factors explained the remaining 9% of the phenotypic correlation. Similarly, the bivariate heritabilities for same and different teacher groups were .89 and .81, respectively.

Discussion

Why are hyperactivity and academic achievement related? The present results clearly indicate that the correlation between hyperactive behavior problems and academic achievement arises primarily due to common genetic influences. Genetic factors explained over 80% of the phenotypic covariance between the two domains (i.e., bivariate heritability). This finding was consistent across sex, rater, and context. Moreover, because academic achievement scores were adjusted for general cognitive ability, the genetic association between hyperactivity and achievement is not simply a reflection of genetic correlation between hyperactivity and intelligence or achievement and intelligence.

Although genetic factors explain most of the phenotypic correlation between hyperactivity and achievement, the genetic correlation between the two variables was more moderate. Approximately 40 – 50% of the genetic effects on hyperactivity overlap with those on academic achievement. The finding of very high bivariate heritabilities might seem puzzling in light of the more moderate genetic correlations between hyperactivity and achievement; however, this will be the case whenever two variables are substantially heritable but only modestly correlated. In other words, despite the fact that genetic factors largely mediate the phenotypic association between the two variables, there is substantial genetic variance on hyperactivity that is independent of genetic variance on achievement, and vice versa. Nonetheless, although only 40 – 50% of the genetic effects overlap across the two domains, it is these overlapping genetic factors that result in the phenotypic correlation between hyperactivity and achievement.

Our finding of genetic covariance between hyperactivity and achievement is consistent with Johnson et al.'s (2005) recent finding that genetic factors contribute to the covariance between the more narrowly defined phenotype of attention problems and school grades (more broadly estimated) at age 11. As was the case in the present study, Johnson et al. also found no sex differences in genetic and environmental sources of covariance. This consistency across related, yet different, phenotypes, and across age groups, each reflecting critical time points in children's academic careers (i.e., the start of formal education and the transition between elementary and high school) attests to the robustness of the effect.

The findings may be even more robust. The present analyses considered associations between hyperactivity and a comprehensive measure of achievement that comprised both mathematics and English skills. Our rationale was that children with hyperactive behavior problems typically experience achievement difficulties across a number of academic areas (i.e., the deficit is not specific to any one content area). In TEDS, mathematics and English scores were highly correlated (.76). Moreover, prior multivariate analyses found a substantial genetic overlap ($r_g = .74$) between mathematics and reading scores (Kovas, Narlaar, Petrill, & Plomin, 2005). Consequently, analyses of specific content areas were unlikely to yield results significantly different from the overall achievement score. Although not presented here, this was in fact the case. Analyses (available from the first author) conducted separately for mathematics and English mirrored each other and those found for our comprehensive measure, both in terms of the best models to describe the data and in the magnitude of the genetic correlations.

The shared genetic etiology of hyperactivity and achievement raises important questions regarding the mechanisms that bring about this genetic association. The association between hyperactivity and achievement could arise indirectly as a result of genes influencing one phenotype, which in turn influence the other phenotype. For example, it is sometimes posited that hyperactive behavior is the result of academic frustration within the classroom. That is, children appear inattentive, restless, and distractible because they are experiencing academic difficulties (McGee & Share, 1988). Thus, genes that influence variation in academic achievement could indirectly influence hyperactivity simply because hyperactive behavior is a consequence of experiencing academic difficulties. Two lines of evidence argue against this. First, the association between hyperactivity and achievement is not limited to the classroom setting. Although, as found in the present study, the correlations between hyperactivity and achievement are typically higher for teacher ratings, as we and others have demonstrated, parent ratings of hyperactivity nonetheless predict school performance (e.g., DuPaul, 1991; Fergusson & Horwood, 1995; Goodman & Stevenson, 1989a). The fact that parent ratings of hyperactivity at home are related to achievement is meaningful in that it argues against the notion that hyperactive behavior is simply due to academic difficulties at school. Second, hyperactivity assessed *prior* to, or at the beginning of, school entry predicts later academic achievement (e.g., Merrell & Tymms, 2001; Newman et al., 1998). For example, in the Dunedin Multidisciplinary Health and Development Study, children identified as hyperactive at preschool age displayed a pattern of poor cognitive skills and low levels of reading ability at a 12-year follow-up (McGee, Partridge, Williams, & Silva, 1991). Thus, hyperactive behavior problems are often evident before, not consequent to, the child experiencing academic problems. It is more likely that the direction of effect goes the other way. Recent phenotypic analyses (Rapport et al., 1999) found that the relation between ADHD and scholastic achievement was mediated through two pathways, one cognitive (vigilance and memory) and one behavioral (classroom performance), prompting the authors to conclude that ADHD may influence academic achievement because of its impact on classroom performance and specific cognitive abilities. Indeed, a Head Start study of preschoolers found that hyperactivity at the beginning of the school year significantly predicted classroom learning competencies at the end of the year (Fantuzzo, Bulotsky, McDermott, Mosca, & Lutz, 2003). Thus, it is possible that an indirect genetic association between hyperactivity and achievement arises because the cognitive and behavioral manifestations of genetically influenced hyperactivity make it harder for the child to learn within the classroom situation and/or harder for teachers to teach the hyperactive child (Newman et al., 1998). The issue of direction of effects (i.e., hyperactivity → achievement, vs. achievement → hyperactivity) can be addressed through cross-lagged quantitative genetic analyses. We plan to look at this issue using longitudinal data obtained when the twins are 10 years of age (which includes web-based test data for achievement as well as teacher ratings).

It is also possible that the genetic association between hyperactivity and achievement arises directly through pleiotropic genetic effects (i.e., genes that affect more than one phenotype). That is, there may be a shared genetic liability such that some of the genes that influence hyperactivity also influence academic achievement. Molecular genetics research on the childhood disorders ADHD and RD suggests that this may well be the case. Univariate molecular genetics analyses conducted separately for ADHD and RD have identified a number of quantitative trait loci (QTLs), genes of small and varying effect size that contribute to quantitative traits, which may influence risk of the disorder. Although there are putative susceptibility QTLs that are unique to each disorder, there are also a fair number of QTLs that are common to both disorders (see Gayán et al., 2005 for a summary). More important, bivariate linkage analyses that identify QTLs contributing to the comorbidity between disorders have identified QTLs on chromosomes 6, 13, 14, and possibly, chromosome 20, with pleiotropic effects on ADHD and RD (Gayán et al., 2005; Willcutt et al., 2002). These findings based on diagnostic criteria for ADHD and RD hint that similar pleiotropic effects may influence hyperactive behavioral problems and achievement more generally. However, it remains an empirical question as to whether similar effects will emerge in molecular genetic analyses of unselected populations.

Whatever the mechanism responsible, the finding of a significant genetic correlation between hyperactivity and achievement has important implications for molecular genetic research. Given that approximately half of the genetic influences are common to both behaviors, there is a reasonable chance that some of the genes found for hyperactivity may also influence achievement, either directly (i.e., pleiotropic effects) or indirectly. Consequently, researchers can use molecular genetic findings about one behavior to inform research about the other.

The inclusion of twin pairs in the same and different classrooms in the present study allowed us to explore possible teacher or classroom effects on sources of covariance. As we show in Table 4, our main finding of substantial genetic and modest nonshared environmental overlap between hyperactivity and academic achievement was consistent for both twins with the same teacher and for twins with different teachers. This finding is noteworthy because if teacher or classroom characteristics are important to the covariance between hyperactivity and achievement we would expect to find that shared environmental influences contribute more to the covariance for twins in the same classroom than for twins in different classrooms (i.e., because they do not share teacher or classroom characteristics). This was not the case. As shown in Table 4, the same and different teacher groups could be equated for all sources of covariance. Thus, although it is possible that teacher and classroom characteristics may influence achievement scores, they do not contribute to the covariance between hyperactivity and achievement.

Nonshared environments do, however, contribute to the covariance between the two phenotypes. The finding of a significant, albeit modest, nonshared environmental covariance between hyperactivity and achievement is particularly interesting. Because nonshared environmental influences include measurement error, it might be assumed that this result reflects correlated error—error that is common to measures of both phenotypes. This does not, however, appear to be the case. In the present study, the results held when the two phenotypes were assessed by different raters (i.e., parent-rated hyperactivity and teacher-rated achievement, or when different teachers rated each phenotype). This leaves open more intriguing possibilities as to what nonshared environmental factors covary across the two phenotypes. Parent ratings of hyperactivity and teacher ratings of achievement were obtained in two different contexts, broadly, home, and school; thus, it is clear that there are nonshared environmental factors that influence both phenotypes and that are contextually enduring (i.e., not situationally specific). The search for such nonshared environments remains a goal for future research.

Acknowledgments

The Twins Early Development Study (TEDS) is supported by program Grant G9424799 from the U.K. Medical Research Council. Dr. Saudino is supported in part by Grant MH062375 from the National Institute of Mental Health. The authors gratefully acknowledge the parents and twins in TEDS.

References

Achenbach, TM. Manual for the child behavior checklist/4 – 18 and 1991 profile. Department of Psychiatry, University of Vermont; Burlington: 1991.

Achenbach TM, McConaughy SH, Howell CT. Child/adolescent behavioral and emotional problems: Implications of cross—informant correlations for situational specificity. Psychological Bulletin. 1987; 101:213–232. [PubMed: 3562706]

Adams JW, Snowling MJ, Hennessy SM, Kind P. Problems of behaviour, reading, and arithmetic: Assessments of comorbidity using the Strengths and Difficulties Questionnaire. British Journal of Educational Psychology. 1999; 69:571–585. [PubMed: 10665170]

Barriga AQ, Doran JW, Newell SB, Morrison EM, Barbetti V, Robbins BD. Relationships between problem behaviors and academic achievement in adolescents: The unique role of attention problems. Journal of Emotional and Behavioral Disorders. 2002; 10:233–240.

Bartels MB, Rietveld MJH, Van Baal GCM, Boomsma DI. Heritability of educational achievement in 12-year-olds and the overlap with cognitive ability. Twin Research. 2002; 5:544–553. [PubMed: 12573186]

Becker A, Woerner W, Hasselhorn M, Banaschewski T, Rothenberger A. Validation of the parent and teacher SDQ in a clinical sample. European Child and Adolescent Psychiatry. 2004; 2(Suppl):11–16.

Coplan RJ, Barber AM, Lagacé-Séguin DG. The role of child temperament as a predictor of early literacy and numeracy skills in preschoolers. Early Childhood Research Quarterly. 1999; 14:537–553.

Dale, PS.; Harlaar, N.; Plomin, R. A comparison of two nonconventional procedures for the research assessment of reading skills in 7-year-olds. 2007. Manuscript submitted for publication

DeShazo Barry T, Lyman RD, Klinger LG. Academic underachievement and attention-deficit/hyperactivity disorder: The negative impact of symptom severity on school performance. Journal of School Psychology. 2002; 40:259–283.

DuPaul GJ. Parent and teacher ratings of ADHD symptoms: Psychometric properties in a community-based sample. Journal of Clinical Child Psychology. 1991; 20:245–253.

DuPaul GJ, Volpe RJ, Jitendra AK, Lutz JG, Lorah KS, Gruber R. Elementary school students with AD/HD: Predictors of academic achievement. Journal of School Psychology. 2004; 42:285–301.

Eaves LJ, Silberg JL, Meyer JM, Maes HH, Simonoff E, Pickles A, et al. Genetics and developmental pathology: 2. The main effects of genes and environment on behavioral problems in the Virginia twin study of adolescent behavioral development. Journal of Child Psychology and Psychiatry. 1997; 38:965–980. [PubMed: 9413795]

Fantuzzo J, Bulotsky R, McDermott P, Mosca S, Lutz M. A multivariate analysis of emotional and behavioral adjustment and preschool educational outcomes. School Psychology Review. 2003; 32:185–203.

Fergusson DM, Horwood LJ. Early disruptive behavior, IQ, and later school achievement and delinquent behavior. Journal of Abnormal Child Psychology. 1995; 23:183–199. [PubMed: 7642833]

Fergusson DM, Horwood LJ, Lynskey MT. The effects of conduct disorder and attention deficit in middle childhood on offending and scholastic ability at age 13. Journal of Child Psychology and Psychiatry. 1993; 34:899–916. [PubMed: 8408374]

Fergusson DM, Lynskey MT, Horwood LJ. Attentional difficulties in middle childhood and psychosocial outcomes in young adulthood. Journal of Child Psychology and Psychiatry. 1997; 38:633–644. [PubMed: 9315973]

Frick PJ, Kamphaus RW, Lahey BB, Loeber R, Christ MAG, Hart EL, et al. Academic underachievement and the disruptive behavior disorders. Journal of Consulting and Clinical Psychology. 1991; 59:289–294. [PubMed: 2030190]

Gayán J, Willcutt EG, Fisher SE, Francks C, Cardon LR, Olson RK, et al. Bivariate linkage scan for reading disability and attention-deficit/hyperactivity disorder localizes pleiotropic loci. Journal of Child Psychology and Psychiatry. 2005; 46:1045–1056. [PubMed: 16178928]

Goodman R. The strengths and difficulties questionnaire: A research note. Journal of Child Psychology and Psychiatry. 1997; 38:581–586. [PubMed: 9255702]

Goodman R. Psychometric properties of the Strengths and Difficulties Questionnaire. Journal of the American Academy of Child and Adolescent Psychiatry. 2001; 40:1337–1345. [PubMed: 11699809]

Goodman R, Renfrew D, Mullick M. Predicting type of psychiatric disorder from strengths and difficulties questionnaire (SDQ) scores in child mental health clinics in London and Dhaka. European Child and Adolescent Psychiatry. 2000; 9:129–134. [PubMed: 10926063]

Goodman R, Scott S. Comparing the strengths and difficulties questionnaire and the child behavior checklist: Is small beautiful? Journal of Abnormal Child Psychology. 1999; 27:17–24. [PubMed: 10197403]

Goodman R, Stevenson J. A twin study of hyperactivity I. An examination of hyperactivity scores and categories derived from Rutter teacher and parent questionnaires. Journal of Child Psychology and Psychiatry. 1989a; 30:671–689. [PubMed: 2793956]

Goodman R, Stevenson J. A twin study of hyperactivity II. The aetiological role of genes, family relationships and perinatal adversity. Journal of Child Psychology and Psychiatry. 1989b; 30:691–709. [PubMed: 2793957]

Hawes DJ, Dadds MR. Australian data and psychometric properties of the strengths and difficulties questionnaire. Australian and New Zealand Journal of Psychiatry. 2004; 38:644–651. [PubMed: 15298588]

Hoge RD, Coladarci T. Teacher-based judgments of academic achievement: A review of literature. Review of Educational Research. 1989; 59:297–313.

Johnson W, McGue M, Iacono WG. Disruptive behavior and school grades: Genetic and environmental relations in 11-year-olds. Journal of Educational Psychology. 2005; 97:391–405.

Klasen H, Woerner W, Wolke D, Meyer R, Overmeyer S, Kaschnitz W, et al. Comparing the German versions of the strengths and difficulties questionnaire (SDQ-Deu) and the child behavior checklist. European Child and Adolescent Psychiatry. 2000; 9:271–276. [PubMed: 11202102]

Kovas Y, Harlaar N, Petrill SA, Plomin R. “Generalist genes” and mathematics in 7-year-old twins. Intelligence. 2005; 33:473–489. [PubMed: 19319204]

Kuntsi J, Eley TC, Taylor A, Hughes C, Asherson P, Caspi A, et al. Co-occurrence of ADHD and Low IQ has genetic origins. American Journal of Medical Genetics Part B (Neuropsychiatric Genetics). 2004; 124:41–47.

Light JG, Pennington BF, Gilger JW, DeFries JC. Reading disability and hyperactivity disorder: Evidence for a common genetic etiology. Developmental Neuropsychology. 1995; 11:323–335.

Martin RP, Holbrook J. Relationship of temperament characteristics to the academic achievement of first-grade children. Journal of Psychoeducational Assessment. 1985; 3:131–140.

Masten AS, Roisman G, Long JF, Burt KB, Obradovi J, Riley JR, et al. Developmental cascades: Linking academic achievement and externalizing and internalizing symptoms over 20 years. Developmental Psychology. 2005; 41:733–746. [PubMed: 16173871]

Mathai J, Anderson P, Bourne A. Comparing psychiatric diagnoses generated by the Strengths and Difficulties Questionnaire with diagnoses made by clinicians. Austrialian and New Zealand Journal of Psychiatry. 2004; 38:639–643.

Mathematics, National Curriculum for England, Key Stages 1 – 4. Qualifications and Curriculum Authority; London, U.K.: 1999.

McCarthy, D. McCarthy scales of children’s abilities. The Psychological Corporation; New York: 1972.

McGee R, Partridge R, Williams S, Silva PA. A twelve year follow-up of preschool hyperactive children. Journal of the American Academy of Child and Adolescent Psychiatry. 1991; 30:224–232. [PubMed: 2016226]

McGee R, Prior M, Williams S, Smart D, Sanson A. The long-term significance of teacher-rated hyperactivity and reading ability in childhood: Findings from two longitudinal studies. Journal of Child Psychology and Psychiatry. 2002; 43:1004–1017. [PubMed: 12455922]

McGee R, Share DL. Attention deficit disorder-hyperactivity and academic failure: Which comes first and what should be treated? Journal of the American Academy of Child and Adolescent Psychiatry. 1988; 27:318–325. [PubMed: 3288613]

McGue M, Bouchard TJ. Adjustment of twin data for the effects of age and sex. Behavior Genetics. 1984; 14:325–343. [PubMed: 6542356]

Merrell C, Tymms PB. Inattention, hyperactivity and impulsiveness: Their impact on academic achievement and progress. British Journal of Educational Psychology. 2001; 71:43–56. [PubMed: 11307708]

Nadder TS, Rutter M, Silberg JL, Maes HH, Eaves LJ. Genetic effects on the variation and covariation of attention deficit-hyperactivity disorder (ADHD) and oppositional-defiant disorder/conduct disorder (ODD/CD) symptomalogies across informant and occasion of measurement. Psychological Medicine. 2002; 32:39–53. [PubMed: 11883729]

Neale MC. The use of the Cholesky Decomposition in multivariate models of sex-limited genetic and environmental effects. Behavior Genetics. 2002; 32:479.

Neale, M.; Boker, SM.; Xie, G.; Maes, HH. Mx: Statistical modeling. 6th ed. Department of Psychiatry, Virginia Commonwealth University; Richmond: 2003.

Neale, MC.; Cardon, LR. Methodology for genetic studies of twins and families. Kluwer Academic Publishers; Boston: 1992.

Newman J, Noel A, Chen R, Matsopoulos AS. Temperament, selected moderating variables and early reading achievement. Journal of School Psychology. 1998; 36:215–232.

Petrill SA, Rempell J, Dale PS, Oliver B, Plomin R. Testing cognitive abilities by telephone in a sample of 6-to 8-year olds. Intelligence. 2002; 30:353–360.

Petrill SA, Thompson LA. The phenotypic and genetic relationships among measures of cognitive ability, temperament, and scholastic achievement. Behavior Genetics. 1993; 23:511–518. [PubMed: 8129692]

Plomin, R.; DeFries, JC.; McClearn, GE.; McGuffin, P. Behavioral genetics. 4th ed. Worth Publishing; New York: 2001.

Price TS, Freeman B, Craig I, Ebersole L, Plomin R. Infant zygosity can be assigned by parent questionnaire data. Twin Research. 2000; 3:129–133. [PubMed: 11035484]

Price T, Simonoff E, Waldman I, Asherson P, Plomin R. Hyperactivity in preschool children is highly heritable. Journal of the American Academy of Child and Adolescent Psychiatry. 2001; 40:1362–1364. [PubMed: 11765277]

QCA key stage 1: Assessment and reporting arrangements. The Stationery Office, Department for Education and Employment; U.K.: 2000.

Rabiner DL, Malone PS. The impact of tutoring on early reading achievement for children with and without attention problems. Journal of Abnormal Child Psychology. 2004; 32:273–284. [PubMed: 15228176]

Rapport MD, Scanlan SW, Denney CB. Attention-deficit/hyperactivity disorder and scholastic achievement: A model of dual developmental pathways. Journal of Child Psychology and Psychiatry. 1999; 40:1169–1183. [PubMed: 10604396]

Saudino KJ, Ronald A, Plomin R. Etiology of behavior problems in 7 year-old twins: Substantial genetic influence and negligible shared environmental influence for parent ratings and ratings by same and different teachers. Journal of Abnormal Child Psychology. 2005; 33:113–130. [PubMed: 15759595]

Spinath, F.; Walker, SO.; Saudino, KJ.; Plomin, R. The relationship between teacher-assessed academic achievement and general cognitive ability: A twin study of 7 year-olds. 2005. Manuscript submitted for publication

Spinath FM, Ronald A, Harlaar N, Price TS, Plomin R. Phenotypic “g” early in life: On the etiology of general cognitive ability in a large population sample of twin children aged 2 to 4 years. Intelligence. 2003; 31:195–210.

Stevenson J. Evidence for a genetic aetiology in hyperactivity in children. Behavior Genetics. 1992; 22:337–344. [PubMed: 1616463]

Taylor E. Clinical foundations of hyperactivity research. Behavioral Brain Research. 1998; 94:11–24.

Thapar A, Hervas A, McGuffin P. Childhood hyperactivity scores are highly heritable and show sibling competition effects: Twin study evidence. Behavior Genetics. 1995; 25:537–543. [PubMed: 8540892]

Thorndike, RL.; Hagen, EP.; Sattler, JM. Technical manual for the Stanford – Binet intelligence scale. 4th ed. Riverside; Chicago: 1986.

Torgesen, JK.; Wagner, RK.; Rashotte, CA. Test of word reading efficiency. Pro-Ed; Austin, TX: 1999.

Trouton A, Spinath FM, Plomin R. Twins early development study (TEDS): A multivariate, longitudinal genetic investigation of language, cognition and behaviour problems in childhood. Twin Research. 2002; 5:444–448. [PubMed: 12537874]

Wadsworth SJ, DeFries JC, Fulker DW, Plomin R. Cognitive ability and academic achievement in the Colorado adoption project: A multivariate genetic analysis of parent – offspring and sibling data. Behavior Genetics. 1995; 25:1–5. [PubMed: 7755514]

Walker SO, Petrill SA, Spinath FM, Plomin R. Nature, nurture and academic achievement: A twin study of teacher ratings of 7 year-olds. British Journal of Educational Psychology. 2004; 74:323–342. [PubMed: 15296543]

Wechsler, D. Wechsler intelligence scale for children. 3rd ed. The Psychological Corporation; London: 1992.

Willcutt EG, Pennington BF, DeFries JC. Twin study of the etiology of comorbidity between reading disability and attention-deficit/hyperactivity disorder. American Journal of Medical Genetics (Neuropsychiatric Genetics). 2000; 96:293–301. [PubMed: 10898903]

Willcutt EG, Pennington BF, Smith SD, Cardon LR, Gayán J, et al. Quantitative trait locus for reading disability on chromosome 6p is pleiotropic for attention-deficit/hyperactivity disorder. American Journal of Medical Genetics (Neuropsychiatric Genetics). 2002; 114:260–268. [PubMed: 11920845]

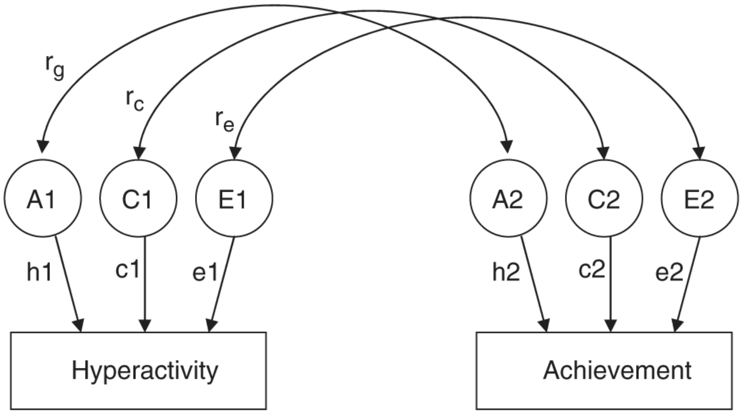

Figure 1.

Correlated factors model. The latent variables A1, C1, and E1 refer to the additive genetic effects, shared environmental effects, and nonshared environmental effects on hyperactivity, and A2, C2, and E2 refer to the additive genetic effects, shared environmental effects, and nonshared environmental effects on academic achievement. h1, c1, and e1 are the path coefficients representing the effect of the latent variables on hyperactivity. h2, c2, and e2 are the path coefficients representing the effect of the latent variables on academic achievement. r_g, r_c, and r_e are the genetic, shared environmental, and nonshared environmental correlations between hyperactivity and academic achievement.

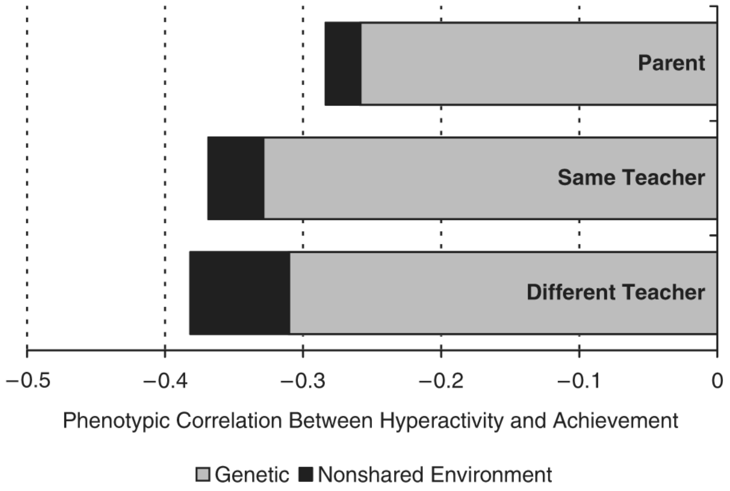

Figure 2.

Genetic and environmental contributions to the phenotypic correlations between hyperactivity, as rated by parents, same teachers, and different teachers; and achievement.

Table 1

Phenotypic Correlations Achievement and General Cognitive Ability

	Hyperactivity rating, *r*		
Correlate	**Parent**	**Same teacher**	**Different teacher**
Unadjusted achievement[a]			
Males	$-.33^{**}$	$-.42^{**}$	$-.39^{**}$
Females	$-.29^{**}$	$-.44^{**}$	$-.47^{**}$
General cognitive ability			
Males	$-.16^{**}$	$-.19^{**}$	$-.17^{**}$
Females	$-.15^{**}$	$-.20^{**}$	$-.21^{**}$
Achievement			
Males	$-.29^{**}$	$-.38^{**}$	$-.35^{**}$
Females	$-.24^{**}$	$-.38^{**}$	$-.41^{**}$

Note. Parent ratings: *N* males = 1,572, *N* females = 1,804; same teacher ratings: *N* males = 1,104, *N* females = 1,290; different teacher ratings: *N* males = 632, *N* females = 646. To correct for the lack of independence arising from the fact that we have two members from a family, the significance levels for all correlations are based on the number of twin pairs rather than individuals.

[a] Scores were not residualized for general cognitive ability.

** $p<.01$.

Table 2

Twin Intraclass and Cross-Correlations for Hyperactivity and Achievement

	Males		Females	
Intraclass correlations	**MZ, *r***	**DZ, *r***	**MZ, *r***	**DZ, *r***
Unadjusted achievement[a]	.85**	.47**	.80**	.52**
Achievement	.77**	.47**	.72**	.51**
Hyperactivity				
Parent ratings	.57**	−.04	.55**	−.08
Same teacher rating	.76**	.38**	.72**	.28**
Different teacher rating	.64**	.20 *	.49**	.20 *
Twin cross-correlations				
Hyperactivity × Unadjusted Achievement				
Parent ratings	−.28**	−.07	−.21**	−.08
Same teacher rating	−.35**	−.25**	−.37**	−.22**
Different teacher rating	−.34**	−.17*	−.40**	−.18*
Hyperactivity × Achievement				
Parent ratings	−.24**	−.07	−.18**	−.06
Same teacher rating	−.34**	−.22**	−.33**	−.19**
Different teacher rating	−.28**	−.16*	−.33**	−.20*

Note. Number of twin pairs, parent ratings: MZ males = 405, DZ males = 381, MZ females = 475, DZ females = 427; same teacher ratings: MZ males = 281, DZ males = 271, MZ females = 334, DZ females = 311; different teacher ratings: MZ males = 164, DZ males = 152, MZ females = 177, DZ females = 146.

[a] Scores were not residualized for general cognitive ability.

* *p*<.05;

** *p*<.01.

Table 3

Model-fitting Results for Bivariate Analyses of Parent-Rated Hyperactivity and Academic Achievement

Full model Parameter estimates	**Hyperactivity**				**Achievement**					
	***h* ²**	***c* ²**	***e* ²**	***i***	***h* ²**	***c* ²**	***e* ²**	r_g	r_c	r_e
Males (95% CI)	.78 (.46, .83)	.00 (.00, .41)	.21 (.12, .27)	−.22 (−.42, −.16)	.60 (.45, .76)	.16 (.01, .30)	.23 (.20, .27)	−.42 (−.57, −.20)	1.0 (−1.0, 1.0)	−.13 (−.22, −.03)
Females (95% CI)	.77 (.56, .82)	.00 (.00, .28)	.22 (.16, .28)	−.23 (−.35, −.17)	.41 (.27, .56)	.30 (.16, .43)	.29 (.23, .33)	−.46 (−.64, −.28)	1.0 (−1.0, 1.0)	−.08 (−.17, .01)

Model comparisons	χ^2	***df***	***p***	**AIC**	**RMSEA**	$\Delta\chi^2$	**Δ *df***	***p***
1. Full model	19.347	20	.499	−20.653	.009			
2. Equate r_g, r_c, r_e	19.936	23	.646	−26.064	.003	0.589	3	.899
3. Equate r_g, r_c, r_e, h^2, c^2, e^2	28.573	29	.487	−29.427	.012	9.226	9	.417
4. Equate all parameters (Model 3 + equate *i*)	29.462	30	.493	−30.538	.008	10.114	10	.431
5. Model 4 + no C on Hyperactivity	29.780	32	.579	−34.220	.007	10.433	12	.578

Best model (Model 5) Parameter estimates	**Hyperactivity**				**Achievement**					
	***h* ²**	***c* ²**	***e* ²**	***i***	***h* ²**	***c* ²**	***e* ²**	r_g	r_c	r_e
Both sexes (95% CI)	.78 (.74, .81)	—	.22 (.19, .26)	−.22 (−.26, −.18)	.49 (.39, .60)	.24 (.15, .33)	.26 (.24, .29)	−.41 (−.49, −.34)	—	−.11 (−.17, −.04)

Note. h^2 = genetic variance, c^2 = shared environmental variance, e^2 = nonshared environmental variance, i5sibling interaction parameter. r_g, r_c, and r_e denote the genetic, shared environmental, and nonshared environmental correlations, respectively, between hyperactivity and achievement. $\Delta\chi^2$ = chi-square difference between reduced model and full model. Δ*df* = degrees of freedom difference between reduced model and full model. AIC = Akaike’s Information Criterion. RMSEA = root mean square error of approximation.

Table 4

Model-fitting Results for Bivariate Analyses of Teacher-rated Hyperactivity and Academic Achievement

Full model Parameter estimates	Hyperactivity			Achievement					
	h^2	c^2	e^2	h^2	c^2	e^2	r_g	r_c	r_e
Same teacher									
Males (95% CI)	.73 (.55, .79)	.03 (.00, .19)	.24 (.19, .29)	.41 (.30, .56)	.40 (.25, .53)	.19 (.16, .23)	−.41 (−.56, −.20)	1.0 (−1.0, 1.0)	−.21 (−.32, −.10)
Females (95% CI)	.72 (.64, .77)	.01 (.00, .08)	.27 (.22, .32)	.58 (.44, .75)	.24 (.08, .38)	.18 (.15, .21)	−.44 (−.57, −.31)	1.0 (−1.0, 1.0)	−.19 (−.29, −.08)
Different teacher									
Males (95% CI)	.61 (.43, .69)	.00 (.00, .16)	.39 (.31, .48)	.69 (.55, .76)	.00 (.00, .13)	.31 (.24, .39)	−.47 (−.61, −.34)	.43 (−1.0, 1.0)	−.13 (−.27, .01)
Females (95% CI)	.45 (.22, .57)	.04 (.00, .22)	.51 (.41, .63)	.19 (.00, .52)	.34 (.06, .54)	.47 (.38, .57)	−.68 (−1.0, 1.0)	1.0 (−1.0, 1.0)	−.20 (−.33, −.06)

Model comparisons	χ^2	*df*	*p*	AIC	RMSEA	$\Delta\chi^2$	Δ *df*	*p*
1. Full model	50.387	44	.236	−37.622	.023			
Tests of sex differences								
2. Equate r_g, r_c, r_e	52.169	50	.390	−47.831	.015	1.791	6	.938
3. Equate r_g, r_c, r_e, h^2, c^2, e^2	72.920	62	.162	−51.080	.028	22.542	18	.209
Tests of teacher differences								
4. Equate r_g, r_c, r_e	52.106	50	.392	−47.849	.015	1.729	6	.943
5. Equate r_g, r_c, r_e, h^2, c^2, e^2	187.913	62	.000	63.913	.084	137.536	18	.000
Reduced model								
6. Model 3 + no C on Hyperactivity	77.928	66	.149	−54.072	.030	27.551	22	.191

Best model (Model 6) Parameter estimates	Hyperactivity			Achievement					
	h^2	c^2	e^2	h^2	c^2	e^2	r_g	r_c	r_e
Same teacher (95% CI)	.74 (.71, .78)	—	.26 (.22, .29)	.56 (.46. ,67)	.26 (.16, .35)	.18 (.16, .21)	−.51 (−.59, −.44)	—	−.18 (−.26, −.11)
Different teacher (95% CI)	.55 (.48, .62)	—	.45 (.38.52)	.62 (.42, .67)	.00 (.00, .17)	.38 (.33, .45)	−.53 (−.68, −.43)	—	−.17 (−.27, −.07)

Note. h^2 = genetic variance, c^2 = shared environmental variance, e^2 = nonshared environmental variance. r_g, r_c, and r_e denote the genetic, shared environmental, and nonshared environmental correlations, respectively, between hyperactivity and achievement. $\Delta\chi^2$ = chi-square difference between reduced model and full model. Δdf = degrees of freedom difference between reduced model and full model. AIC = Akaike's Information Criterion. RMSEA = root mean square error of approximation.