Exploring how symptoms of Attention-Deficit/Hyperactivity Disorder are related to reading and mathematics performance: General genes, general environments

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Exploring how ADHD symptoms are related to reading and mathematics performance: General genes, general environments

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Abstract

Children with Attention Deficit Hyperactivity Disorder (ADHD) tend to perform more poorly on tests of reading and mathematical performance than their typical peers. Quantitative genetic analyses allow for a better understanding of the etiology among ADHD, reading and mathematics outcomes, examining the common and unique genetic and environmental influences. Analyses were based on a sample 271 pairs of 10-year-old monozygotic and dizygotic twins drawn from the Western Reserve Reading and Mathematics Project. In general, the results suggested that the association among ADHD symptoms, reading and math outcomes was influenced by both common genetic and environmental factors. Outside of this common relationship, ADHD symptoms also suggested significant independent genetic effects. The results imply differing etiological factors underlying the relationships among ADHD, reading and mathematics. It appears that both genetic and common family and/or school environments link ADHD and academic performance.
Attention deficit hyperactivity disorder (ADHD) affects 3-7% of all children in the United States (American Psychological Association, 2000). Children with ADHD experience attention and behavior difficulties which can negatively affect academic achievement (Barry, Lyman, & Klinger, 2002). As many as 20-40% of those with ADHD also have comorbid learning disabilities, suggesting that learning and attention problems may be related (Capano, Minden, Chen, Schachar, & Ickowicz, 2008; Willcutt, Pennington, Chabildas, Olson, & Hulslander, 2005). Moreover, ADHD is predictive of lower future academic achievement in both mathematics and reading, even after controlling for intelligence (Rapport, Scanlan, & Denney, 1999).

The educational and cognitive literature has indicated that ADHD may be associated with lower academic achievement due to underlying deficits in executive functions such as working memory (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). If ADHD is associated with both reading and mathematics skills similarly, potentially due to limitations in the general working memory system, then a common etiology should be indicated. On the other hand, some children have ADHD and reading difficulties without math difficulties, and others have ADHD and math difficulties without reading difficulties (Zentall, 2007). This would suggest that the association between ADHD and reading performance may have a different etiology than the association between ADHD and mathematical performance. This could be due to instructional differences or differential task demands between reading and mathematics. Later in the elementary school years, mathematics learning requires more sustained attention in class and independent seat work than reading learning in most classrooms, behaviors which can be difficult for students with ADHD symptoms (DuPaul & Stoner, 2004). This may serve to differentiate the association between ADHD and reading compared to ADHD and math.
Quantitative genetic designs allow for the examination of the genetic and environmental etiology of a specific behavior or among multiple behaviors of interest, such as ADHD, reading and mathematics. Univariate results suggest that ADHD, reading and mathematics each have significant genetic effects, with varying degrees of significant shared environmental influences in children (Plomin & Kovas, 2005; Stevenson, et al., 2005). Bivariate modeling between reading and mathematics alone suggests substantial and significant genetic overlap (Light & DeFries, 1995; Markowitz, Willemsen, Trumbetta, van Beijsterveldt, & Boomsma, 2005). Also, the literature has suggested that attention and behavior difficulties associated with academic problems have a familial component (Doyle, Faraone, DuPre, & Biederman, 2001). Multivariate work has indicated that to the extent to which symptoms of ADHD and some achievement outcomes (e.g., reading) are related, genetic influences are implicated (Saudino & Plomin, 2007). However, the relationship between ADHD and mathematics has not been fully explored (see Monuteaux, Faraone, Herzig, Navsaria, & Biederman, 2005, for initial work).

No study could be found which has examined the extent to which the association among symptoms of ADHD, reading and mathematics is influenced by similar or unique genetic and/or environmental effects. We will explore this relationship in a general twin population which represents a range of symptoms along a continuum of behaviors and ability. Although the previous work from the educational literature has typically taken a special education approach, identifying children with diagnosed ADHD and disability, comparisons of this study to that work is possible. This is because it is commonly agreed that disability and behavior problems are the low end of the typical distribution of ability and behavior and not qualitatively different (Polderman, et al., 2007; Shaywitz, Escobar, Shaywitz, Fletcher, & et al., 1992). Therefore, if there is a general underlying etiology among the outcomes of ADHD symptoms, reading and
Exploring how ADHD mathematics performance, then we expect that common genetic and/or shared environmental factors will be important. If there is a unique relationship between ADHD symptoms and reading, and/or ADHD symptoms and mathematics, then differential ADHD/Reading and ADHD/Math genetic and environmental influences would be indicated. Possible classroom level differences in the association of ADHD symptoms with mathematics compared to ADHD and reading could manifest as varying effects due to the shared environment within these relationships. In line with other multivariate work in specific cognitive abilities, we hypothesize that genetic influences will contribute to any common relationship among the outcomes and that environmental influences will contribute to the extent to which they are unique (i.e., Kovas & Plomin, 2007).

Methods

Participants

The Western Reserve Reading and Mathematics Project (WRRMP) is an ongoing longitudinal twin project based in Ohio (Hart, Petrill, Thompson, & Plomin, 2009; Petrill, et al., 2007). Twins are assessed annually across seven home visits focusing on reading, language and mathematics outcomes. The present report is from the fifth home visit, the first of which to simultaneously measure reading and mathematics. Twins are approximately 10-years-old for home visit 5 (M=9.82yrs, SD=.99yrs). Presently, 271 pairs of monozygotic (MZ; N=112) and same-sex dizygotic (DZ; N=159) twins are available for analysis.

Procedure and Measures

Annually, parents are mailed questionnaires to complete. Response rate for the questionnaire is dependent on voluntary return of the questionnaire (N=164). Ratings of ADHD symptoms are derived from maternal responses. Measures of reading and mathematical
Exploring how ADHD performance are collected by two trained testers, one per child, during an annual three-hour home visit. At the end of the home visit, each tester rates one child on his or her behavior. Independent ratings of ADHD symptoms were collected from this survey. Both the maternal ratings and the tester ratings were used for form a rater-free factor of ADHD symptoms.

**ADHD measures.** The Strength and Weaknesses of ADHD-Symptoms and Normal-Behavior (SWAN) scale was used to measure attention and activity levels (Swanson, et al., 2005). This scale is composed of two subscales of 9 items each; Inattention and Hyperactivity/Impulsivity. Mothers rated each child separately for each item on a seven-point Likert scale (1 = far below to 7 = far above). Also, the Bayley Behavior Record (BBR; Bayley, 1993) for each child was completed by a different tester following the home visit. The BBR is a 5-point Likert scale (1=does not attend/constantly hyperactive; 5=constantly attends/consistently not hyperactive), of which we used two items relevant to ADHD symptoms, “Attention to tasks” and “Hyperactivity”. For both scales, raw scores were used for analyses, with lower scores indicating a higher level of ADHD symptoms.

**Reading measures.** Reading performance was measured by two subtests of the Woodcock Reading Mastery Tests (WRMT; Woodcock, 1987). *Word Identification* (Word ID) is a test of whole word decoding, where the child must recognize and correctly pronounce a real word. *Passage Comprehension* is a cloze format test of comprehension.

**Mathematics measures.** Mathematics achievement was measured via four subtests of the Woodcock-Johnson III Achievement test (WJ; Woodcock, McGraw, & Mather, 2001). The *Applied Problems* subtest measures the ability to solve applied math problems. *Quantitative Concepts* is a measure of mathematical concepts, as well as counting ability and understanding
of number series. *Calculation*, is a test of mathematical computations. Finally, *Fluency* is a measure of a participant’s ability to do computations in three minutes.

**Results**

*Descriptive Statistics*

Descriptive statistics of all measures are presented in Table 1. For descriptive purposes alone, all reading and mathematics measures were age- and sex-normed to a population mean of 100, and a standard deviation of 15. All standard scores suggested a slightly higher than average mean, and slightly lower than average standard deviation scores (e.g., $M_{\text{Word ID}}=106.93$, $SD_{\text{Word ID}}=10.54$). Pearson correlation coefficients among the measures can be found in Table 2.

*Measurement Modeling*

The main purpose of this study was to examine whether the relationship among ADHD symptoms, reading and mathematics performance is influenced by unitary or multifactorial genetic and environmental effects (see Figure 1). For this multivariate measurement analysis, we employed a latent factor model, to test construct validity and provide random error-free latent factors for further analysis (see Gayan & Olson, 2003). We used this general model to test three specific models of the association between ADHD symptoms, reading, and math. Model 1 tested the association between General ADHD, Reading and Math. Model 2, tested the association between Impulsivity, Reading, and Math. Model 3 tested the association between Hyperactivity, Reading, and Math.

In particular, Model 1 (presented in Figure 1) defined the first factor of the measurement model as a “General ADHD” factor, which was composed of the SWAN Inattentiveness and Hyperactivity/Impulsiveness subscales and the BBR Attention to Tasks and Hyperactivity Scales items (factor loadings=.87, .89, .38 and .30, respectively). The second factor was “Reading”,
which was composed of Word ID and Passage Comprehension (factor loadings=.86 and .85, respectively). Finally, the third factor, “Math” was composed of Applied Problems, Quantitative Concepts, Fluency and Calculation (factor loadings=.85, .90, .70 and .84, respectively). Model 2 defined the ADHD factor as “Inattention” using the SWAN Inattention and BBR Attention to Tasks measures. Model 3 defined the ADHD factor as “Hyperactivity” using SWAN Hyperactivity/Impulsivity and BBR Hyperactivity measures. Models 2 and 3 defined the Reading and Math factors identical to the procedure described in Model 1.

Quantitative Genetic Modeling

An independent pathway model was then simultaneously applied to the measurement models described above (see Figure 1 for Model 1). Briefly, variance is a statistical term commonly used in quantitative genetic designs, which describes the individual differences in a population of a given trait. The term covariance follows from this, and describes how the individual differences of a given trait may be associated with the individual differences on another given trait. In other words, covariance is a measure of the degree to which two traits are related. Covariance is very similar to the more commonly used statistic of correlation, but covariance uses an unstandardized metric whereas correlation uses a standardized metric. Given this, quantitative genetic methodology specifically allows for the variance and covariance among the measurement factors to be decomposed into identified components, defined by biometric factors of genetics (the combined effect of all additive genetic effects; A), shared environment (those environments that make siblings more similar; C) and nonshared environment (those influences that make siblings unique; E; Neale & Cardon, 1992).

The first set of biometric factors estimated in an independent pathway model (A₁, C₁, and E₁) represented general overlapping genetic and environmental influences on the covariance
Exploring how ADHD among ADHD, Reading, and Math. Results from this factor were important to the fundamental question of the extent to which ADHD symptoms, reading and math are affected by general genetic and/or environmental factors. The second set of biometric factors \((A_2, C_2, \text{ and } E_2)\) estimated the genetic and environmental influences on the independent variance associated with ADHD. \(A_3, C_3, \text{ and } E_3\) estimated the genetic and environmental effects on independent Reading specific variance only, and \(A_4, C_4, \text{ and } E_4\) estimated the independent variance associated with Math only. These independent pathways test the extent to which ADHD, Reading, and Math were influenced by specific genetic and environmental factors, above and beyond those general genetic and environmental influences shared across ADHD, Reading, and Math. Genetic models were estimated using Mx with all available raw data, with 95% confidence intervals to test for significance (Neale, Boker, Xie, & Maes, 2006). Age and sex were included as covariates in these analyses, and were modeled concurrently using Mx. Table 3 presents the standardized path estimates and 95% confidence intervals for the three models.

Looking first at Model 1 with “General ADHD” as the first factor, we first present the univariate genetic and environmental estimates of each latent factor \((h^2, c^2 \text{ and } e^2); \text{ see Table 3})\). The ADHD and Reading factors suggested moderate genetic effects \((h^2=.64 \text{ and } .63)\) and low shared environmental effects \((c^2=.30 \text{ and } .35)\). The Math factor indicated low genetic influences \((h^2=.18)\) and high shared environmental effects \((c^2=.81)\). For all factors, the influences for child-specific environmental effects were low.

For the multivariate results from the Model 1, a general genetic factor underlying ADHD, Reading and Math factors was suggested, represented by significant path estimates from \(A_1 (.44, .63 \text{ and } .33)\). This would indicate that there were shared genetic effects that underlie the covariance among ADHD, Reading and Math. Beyond the variance associated with the general
genetic factor ($A_1$), there were independent genetic influences on the ADHD factor represented by the pathway of $A_2=.67$. This path estimate suggests that 45% ($0.67^2$) of the variance in the ADHD factor is associated with independent genetic effects. Furthermore, the general shared environmental factor, $C_1$ suggested significant environmental overlap among all three factors (pathways .24, .59 and .90). This implies that there are also general environmental influences underlying the covariance among the factors, in addition to the general genetic effects. No other pathways were statistically significant, as evidenced by confidence intervals bounded by zero.

Results were similar for Model 2, where “Inattention” was the first factor. Again, we found moderate to high univariate estimates of heritability for the factor of Inattention and Reading ($h^2=.66$ and .62), and low estimates for Math ($h^2=.18$). Similarly, the univariate shared environment estimates were low for Inattention and Reading ($c^2=.31$ and .35), and high for Math ($c^2=.81$). All univariate estimates of the nonshared environment were nonsignificant. As for the multivariate independent pathway results, the general genetic factor ($A_1$) again suggested significant genetic covariance among all the factors (.71, .55 and .36). The $C_1$ factor in this model indicated significant shared environmental overlap between Reading and Math only (.59 and .90). There were no latent factor specific (i.e., independent pathway) significant influences in this model.

Finally, when examining Model 3 (Hyperactivity as the first factor), univariate genetic and environmental estimates for Hyperactivity, Reading, and Math factors were similar to Models 1 and 2. As with the other models, multivariate results suggested the general genetic factor ($A_1=.32$, .73 and .31) was significant. Furthermore, the independent genetic pathways on the Hyperactivity factor and the Math factor, outside of the general genetic overlap ($A_1$), were significant ($A_2=.80$, $A_4=.29$). This indicated that beyond the general genetic influences
underlying the covariance among the factors, 64% (.80²) of the unique variance associated with
the Hyperactivity factor and 8% (.29²) of the unique variance of Math was affected by
independent genetic influences. The general shared environmental factor suggested that the
covariance among the factors of Reading and Math was driven by family specific environmental
effects (C₁= .56 and .90)

Discussion

This study was the first to examine ADHD symptoms, reading, and math simultaneously
using a genetically sensitive design. Findings from the cognition literature suggesting that
working memory deficits may underpin ADHD, as well as reading and mathematical difficulties
(e.g., Rapport, et al., 2008; Siegler, 1988), is consistent with our finding of overlapping genetic
effects among all three constructs. Indeed, it has been predicted that the association between
ADHD and learning disabilities would be explained by general genetic influences (duPaul &
Volpe, 2009). Furthermore, general genetic effects are also consistent with the “generalist genes
hypothesis”, suggesting a general genetic etiology across different learning disorders (e.g.,
Plomin & Kovas, 2005). That said, this report also measured further significant independent
genetic influences for ADHD symptoms outside of the general genetic effects, and a trend
towards independent genetic influences on the reading and math outcomes. This would suggest
that there are unique genetic influences on ADHD symptoms which are not associated with
reading or math performance, in keeping with the idea that ADHD does not co-occur
consistently with learning disabilities (duPaul & Volpe, 2009).

It is noteworthy that in addition to the common genetic etiology between ADHD
symptoms, Reading and Math, there was evidence for common shared environmental influences
among them when General ADHD was modeled. From the ADHD literature, it has been
hypothesized that one of the ways ADHD may affect achievement outcomes is through a behavioral pathway (Rapport, et al., 1999). More specifically, this works suggests that the behavioral pathway mediates the relationship of ADHD on academic performance through disruptive classroom behaviors. It may be the case that certain attentional and behavioral actions are required for a child to successfully learn during formal instruction. For example, sitting in a chair quietly during direct mathematics tutoring is a difficult attentional task, but typically required for success. Indeed, research has suggested that environmental factors, such as study skills and academic engagement are important mediators of the relationship of ADHD on achievement (Volpe, et al., 2006).

Although all three models suggested very similar general genetic and environmental trends, the literature suggests that the Inattention and Hyperactivity factors would have influenced the academic outcomes differentially (Rabiner, Coie, & The Conduct Problems Prevention Research Group, 2000). For example, it has been indicated that the inattentive symptoms only of ADHD are attributable to lower academic achievement (Massetti, et al., 2008). Despite this, the present results suggest that the extent to which various ADHD symptoms are associated with academic outcomes, there are similar influences due to common genetic and environmental influences. Importantly, these may not be the same genetic and environmental influences, but the magnitude of the effects are similar. Future work can serve to more directly test this.

In conclusion, the power of the present study is that it is the first of its kind to report on the relationship among ADHD symptoms, reading, and math. Future research may begin to better understand not only the genetic processes but importantly the specific aspects of the shared environment are associated with both academic outcomes and ADHD symptoms, especially
focusing on causal explanations. This work can serve to inform future educationally-based interventions, in that identification of these influences may be a key focus in changing outcomes for these commonly co-morbid disabilities.
Acknowledgements

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References


Figure Caption

*Figure 1.* The full latent factor model measurement model with an independent pathway model, with variances and covariances among the factors decomposed into general and independent genetic (A), shared environment (C) and nonshared environmental (E) influences, as well as standardized factor loading scores and residuals.

*\*p<.05*
Table 1

*Descriptive Statistics for all ADHD, reading and mathematics performance measures.*

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<th>SD</th>
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<th>Maximum</th>
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<sup>a</sup> The Strength and Weaknesses of ADHD-Symptoms and Normal-Behavior (SWAN)

<sup>b</sup> Bayley Behavior Report Form (BBR).

<sup>c</sup> Woodcock Reading Mastery Tests (WRMT).

<sup>d</sup> Woodcock-Johnson III (WJ).
Table 2

*Pearson correlation coefficients between all ADHD, reading and mathematics performance measures.*

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<th>BBR Inattention&lt;sup&gt;b&lt;/sup&gt;</th>
<th>SWAN Hyperactivity/Impulsivity&lt;sup&gt;a&lt;/sup&gt;</th>
<th>BBR Hyperactivity&lt;sup&gt;b&lt;/sup&gt;</th>
<th>WRMT Word Identification&lt;sup&gt;c&lt;/sup&gt;</th>
<th>WRMT Passage Comprehension&lt;sup&gt;c&lt;/sup&gt;</th>
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<th>WJ Quantitative Concepts&lt;sup&gt;d&lt;/sup&gt;</th>
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<sup>a</sup> The Strength and Weaknesses of ADHD-Symptoms and Normal-Behavior (SWAN)
<sup>b</sup> Bayley Behavior Report Form (BBR).
<sup>c</sup> Woodcock Reading Mastery Tests (WRMT).
<sup>d</sup> Woodcock-Johnson III (WJ).
Table 3

Independent Pathway Model Result from all Three Latent Factor Measurement Models: General ADHD, Reading and Math; Inattention, Reading and Math; and Hyperactivity, Reading and Math. Univariate Genetic \( (h^2) \) and Shared Environment \( (c^2) \) and Nonshared Environment \( (e^2) \) Estimates on each Latent Factor, as well as the Genetic \( (A) \) and Shared Environment \( (C) \) and Nonshared Environment \( (E) \) Standardized Pathways Representing the Covariance Among the Latent factors [with 95% confidence intervals].

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a General ADHD: SWAN Inattention, SWAN Hyperactivity/Impulsivity, Bayley Behavior Report Form Inattention, Bayley Behavior Report Form Hyperactivity.
b Reading: WMRT Word Identification and WRMT Passage Comprehension.
d Inattention: SWAN Inattention and Bayley Behavior Report Form Inattention.
e Hyperactivity: SWAN Hyperactivity/Impulsivity and Bayley Behavior Report Form Hyperactivity.
General ADHD

Reading

Math

SWAN In
SWAN H/Im
BBR Att
BBR Hyp
Word ID
PC
AP
QC
Fluency
Calc

A_1
A_2
A_3
A_4

C_1
C_2
C_3
C_4

E_1
E_2
E_3
E_4

.23*
.20*
.87*
.92*
.27*
.28*
.27*
.18*
.50*
.27*

.87*
.89*
.38*
.30*
.86*
.85*
.85*
.90*
.70*
.84*

* indicates statistical significance.