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Semantic Language as a Mechanism Explaining the Association between ADHD Symptoms and Reading and Mathematics Underachievement

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Abstract

ADHD is associated with academic underachievement, but it remains unclear what mechanism accounts for this association. Semantic language is an underexplored mechanism that provides a developmental explanation for this association. The present study will examine whether semantic language deficits explain the association between ADHD and reading and mathematics underachievement, taking into account alternative explanations for associations, including verbal working memory (WM) impairments, as well as specificity of effects to inattentive and hyperactive-impulsive ADHD symptom domains. Participants in this cross-sectional study were 546 children (54% male) ages six to twelve ($M=9.77$, $SD=1.49$). ADHD symptoms were measured via maternal and teacher report during structured interviews and on standardized rating forms. Children completed standardized semantic language, verbal WM, and academic testing. Semantic language fully mediated the ADHD-reading achievement association and partially mediated the ADHD-mathematics achievement association. Verbal WM also partially mediated the ADHD-mathematics association but did not mediate the ADHD-reading achievement association. Results generalized across inattentive and hyperactive-impulsive ADHD symptom domains. Semantic language explained the association between ADHD and reading underachievement and partially explained the association between ADHD and mathematics underachievement. Together, language impairment and WM fully explained the association between ADHD and reading underachievement, in line with developmental models suggesting that language and WM conjointly influence the development of attention and subsequent academic achievement. This work has implication for the development of tailored interventions for academic underachievement in children with ADHD.

Keywords

ADHD; academic achievement; semantic language; working memory

Attention-Deficit/Hyperactivity Disorder (ADHD), a childhood behavioral disorder characterized by symptoms of inattention, hyperactivity, and impulsivity (APA, 2000). ADHD affects approximately 6% of children and adults and has a sex-biased prevalence rate favoring boys (Biederman et al., 2002; Faraone & Biederman, 2005; Nigg, 2006), suggesting that the disorder has a chronic course. Further, ADHD is impairing, being associated with executive function deficits, language impairment, problems in interpersonal relationships, and academic underachievement (Loe & Feldman, 2007). Arguably, for children, one of the most important associated problems is academic underachievement, including failing grades and comorbid learning disorders (Frazier, Youngstrom, Glutting, & Watkins, 2007; Loe & Feldman, 2007).

Corroborating the association between ADHD and academic underachievement is etiological research indicating that ADHD and extreme academic underachievement share etiological factors, including common genetic influences (Willcutt et al., 2001; 2007) and shared executive function deficits (Banaschewski et al., 2005; Seidman, Biederman, Monuteaux, Doyle, & Faraone, 2001; Willcutt, Pennington, Olsen, Chhabildas, & Hulslander, 2005; Willcutt et al., 2001; 2010). Though longitudinal associations between ADHD in early childhood and later reading and mathematics underachievement have been established and the two domains appear to share common biological and cognitive etiological factors, other possible shared psychological mechanisms by which ADHD leads to underachievement have received little attention. However, elucidation of the mechanisms by which ADHD is associated with reading and mathematics underachievement is critical for use of early identification strategies and the development of early targeted interventions that might be able to circumvent the later academic underachievement frequently associated with ADHD. ADHD and reading and mathematics underachievement share several common associative features that might explain their co-occurrence at a mechanistic level. One underexplored shared associative feature is semantic language skills (Kim & Kaiser, 2000; Korkman & Pesonen, 1994). Semantic language, more commonly referred to as vocabulary, involves providing definitions of lexical items (Ouellette & Beers, 2010). Corroborating the possibility that semantic language problems might help explain ADHD associations with academic underachievement, Language Impairment (LI) is highly prevalent in children with ADHD and academic underachievement, co-occurring at a rate of approximately 45% (Beitchman, Wilson, Brownlie, Watlter, & Lancee, 1996; Cohen et al., 2000; Tirosh & Cohen, 1998; Tomblin, Zhang, Buckwalter, & Catts, 2000). Further, Purvis and Tannock (1997; 2000) found that ADHD and underachievement are both associated with poor language skills. Research has also suggested that children with early semantic language delays or problems are at risk for later academic underachievement, such that children with poor semantic language skills are less likely to succeed in reading comprehension and mathematics (Aiken, 1971; Ouellette, 2006; Young et al., 2002).

At a theoretical level, one might expect associations between semantic language, ADHD, and reading and mathematics underachievement because developmental theory suggests that general language ability plays a role in shaping attention which is then critical for academic performance (Gartstein, Crawford, & Robertson, 2008). In line with this idea, children with initial semantic language problems are at risk for developing attention problems and have worse school performance (Gartstein et al., 2008; Young et al., 2002). Thus, it appears that

initial language deficits, particularly poor semantic language skills, might be a promising but underexplored mechanism that might at least partially account for the association between ADHD and academic underachievement. There are, of course, other possible alternative explanations for the association between ADHD and reading and mathematics underachievement. Another possible and well-validated mechanism explaining the association between ADHD and academic underachievement is verbal working memory (WM) deficits (Gropper & Tannock, 2009; Thorell, 2007). Approximately 30% of children diagnosed with ADHD exhibit deficits in WM (Wahlstedt, Thorell, & Bohlin, 2009), and effects seem most specific to the inattentive ADHD symptom domain (Wahlstedt et al., 2009; Thorell, 2007). Further, verbal WM abilities predict later mathematical ability and reading comprehension (Bull, Espy & Wiebe, 2008; Cain, Oakhill, & Bryant, 2004; Wilson & Swanson, 2001). Verbal WM deficits appear to be related to both ADHD and underachievement (Martinussen & Tannock, 2006; Passolunghi & Siegel, 2004; Swanson & Sachse-Lee, 2001a; 2001b), possibly explaining comorbidity.

Based on developmental theory, semantic language and verbal WM appear to exhibit a bidirectional relationship with one another (Lui & Tannock, 2007) such that verbal WM appears critical to the development of semantic language, and semantic language also facilitates the further development of verbal WM (Gartstein et al., 2008; Gathercole & Baddeley, 1989; Marchman & Fernald, 2008; Montgomery, 2003). Further, research has indicated that children with ADHD display a “developmental lag” in verbal WM, such that children with ADHD develop verbal WM skills slower than typically developing children (Denckla, 1996; Sowerby, Seal, & Tripp, 2011). Thus, it is entirely possible that both semantic language and verbal WM problems are synergistically related to academic underachievement and ADHD, providing a mechanistic explanation of this association (Bull et al., 2008; Geary, 2004; Jakobson & Kikas, 2007; van Daal, Verhoeven, & van Balkom, 2007).

Further, ADHD symptom domains may be differentially associated with academic underachievement. For example, prior work suggests that children with ADHD who exhibit higher levels of inattentive symptoms are more likely to exhibit academic problems, compared to children with higher levels of hyperactivity-impulsivity (Barriga, Doran, Newal, Morrison, Barbetti, & Robbins, 2002; Breslau et al., 2010; Lahey & Willcutt, 2002; Marshall, Hynd, Handwerk & Hall, 1997). Further, intelligence, or IQ, may be critical to understanding associations between ADHD and underachievement since low IQ has been associated with both ADHD and underachievement (Mayes et al., 2000; Neisser et al., 1996).

The present study will systematically test psychological and cognitive mechanisms that might account for the link between ADHD and academic underachievement with a focus on semantic language skills. The current study additionally adds to the existing literature by testing other possible alternative mechanisms of the association between ADHD and reading and mathematics underachievement. Specifically, verbal WM impairment will be examined as a predictor of the association between ADHD and underachievement over and above the effects of semantic language. It is predicted that semantic language skills will mediate the association between ADHD and reading and mathematics underachievement, over and

above verbal WM deficits. Secondary checks will explore the specificity of these effects to individual ADHD symptom domains (i.e., inattention and hyperactivity-impulsivity) with predictions of increased specificity of effects to inattentive ADHD symptoms.

METHODS

Participants

Overview—Participants were 546 children between the ages of six and twelve ($M=9.69$, $SD=1.44$). Fifty-four percent of the sample was male, and 30% of the sample was ethnic minority (Table 1). Participants were recruited into two groups: those diagnosed with ADHD ($n=266$) and controls ($n=207$). In addition, 73 children classified as having situational or sub-threshold ADHD (i.e., did not meet criteria for either ADHD or control group as explained below) were included to provide more complete coverage of the dimensional trait space of ADHD (Levy, Hay, McStephen, Wood, & Waldman, 1997; Sherman, Iancono, & McGue, 1997). Children came from 539 families; 154 families had two children in the study.

Recruitment and Identification—The present study used a community recruited sample enriched for clinical symptoms. Participants were recruited from Michigan schools, clinics, and the community using public advertisements and announcements, mass mailings, and outreach to schools and clinics. After recruitment, families passed through a multi-gated screening process. An initial telephone screening was conducted to rule out children prescribed long-acting psychotropic medication (e.g., antidepressants), neurological impairments, seizure history, head injury with loss of consciousness, other major medical conditions, or a prior diagnosis of mental retardation or autistic disorder, as reported by the parent. All families screened into the study at this point completed written and verbal consents in accordance with guidelines of the National Institute of Mental Health and of the Michigan State University institutional review board.

During the second stage, youth completed IQ and achievement testing, and parents and teachers of eligible youth completed the ADHD Rating Scale (ADHD-RS; DuPaul, Power, Anastopolous, & Reid, 1998). In addition, parents completed the Kiddie Schedule for Affective Disorders and Schizophrenia (KSADS-E; Puig-Antich & Ryan, 1986), a structured clinical interview to ascertain symptom presence, duration, and impairment. A trained graduate student or advanced undergraduate with at least 10 hours of training administered the KSADS-E. Fidelity to interview procedure was checked by having the interview recorded with 5% reviewed by a certified trainer. For children who met criteria regarding age of onset, duration, impairment, and cross-situational manifestation, an “or” algorithm was used to determine diagnosis and to obtain a final ADHD symptom count. Teacher reported symptoms on the ADHD-RS could be added to parent symptoms from the KSADS-E, with up to three additional symptoms to obtain a total number of symptoms with a maximum of 18 symptoms (Lahey et al., 1994). A clinical diagnostic team consisting of board certified and licensed clinical child psychologists reassessed diagnostic status, using the same “or” algorithm with acceptable agreement rates (all kappas $> .89$). Children failing to meet cut-offs for all parent and teacher ADHD rating scales at the 80th percentile and

having four or fewer symptoms of ADHD with the “or” algorithm were considered controls. However, those with intermediate levels of symptoms or lack of cross-situational symptom expression were retained for analyses in order to allow for examination of the full range of symptoms in view of evidence that ADHD represents an arbitrary cut point on a continuous dimension of behavior which favors the statistically more powerful dimensional approach over the categorical approach (Haslam, Williams, Prior, Haslam, Graetz, & Sawyer, 2006; Levy et al., 1997; Sherman et al. 1997). Families were screened out here only if they failed to attend the laboratory visit or if parent and teacher ratings could not be obtained.

Medication Status—Parents of children taking psycho-stimulant medication were asked to consult with a physician about discontinuing medication for 24 to 48 hours prior to the laboratory visit to ensure a more accurate measure of cognitive performance.

Measures

Symptom Counts—Maternal report on ADHD symptoms was available via report on the ADHD-RS, an ADHD symptom checklist using an ordinal scale ranging from 0 to 3, and via report on the KSADS-E which assesses symptoms using a dichotomous 0 or 1 response. Teacher ratings were obtained via teacher report on the ADHD-RS. Parents and teachers were instructed to rate children’s behavior based on children’s behavior when they were not taking psychostimulant medication, to the extent possible. Primary analyses used symptom counts from the “or” algorithm, integrating parent and teacher report, calculated as discussed above.

Semantic Language—The vocabulary subtest of the Wechsler Intelligence Scale for Children—Fourth Edition (WISC-IV; Wechsler, 2003) was administered to assess semantic language. This particular subtest measures degree of language development, word knowledge, concept formation, and receptive and expressive language (Sattler, 2008) and is similar to the Word Definitions subtest of the Clinical Evaluations of Language Fundamentals—4, which measures semantic language in the expressive domain (Semel, Wiig, & Secord, 2003). The benefit of using the vocabulary subtest as a measure of semantic language in this age range is that it provides an age-sensitive measure of semantic language development and receptive and expressive language competence (White, Campbell, Echeverria, Knox, & Janulewicz, 2009; Wiig, 2008). The vocabulary subtest exhibits high internal consistency and high test-retest reliability (Wechsler, 2003) as well as high content and construct validity for this age group (Sattler, 2008). Raw scores were used in primary analyses with lower scores indicating poor semantic language ability. Scores for the current sample ranged from 9 to 64.

Reading and Mathematics Achievement—The Reading Comprehension and Math Reasoning subtests of the Wechsler Individual Achievement Test—Second Edition (WIAT-II; Wechsler, 2001), an achievement test normed for ages 4 through 19, were administered to test reading and mathematics achievement. The Reading Comprehension subtest measures literal and inferential reading comprehension skills. The passages are grade specific, with questions covering a range of difficulty. The major benefit of the WIAT-II reading comprehension subtest over other measures of reading comprehension is that this specific

subtest maps onto reading achievement in school and is not overly dependent on language ability (Lichtenberger & Smith, 2005; Wechsler, 2001). Because of the expected high association between language and reading ability, the Math Reasoning subtest of the WIAT-II was also administered to test generalizability across academic domains. The Math Reasoning subtest measures ability to identify mathematical patterns as well as math problem solving skills such as addition, subtraction, and multiplication (Wechsler, 2001). Raw scores were calculated by summing correct responses with lower scores indicating lower academic achievement. Scores for the current sample ranged from 27 to 129 for the Reading Comprehension subtest and from 12 to 64 for the Math Reasoning subtest.

Working Memory—The Digit Span Backward (DSB) subtest of the WISC-IV (Wechsler, 2003) was administered to assess verbal WM, the type of WM theoretically believed to be most related to the development of early academic skills which are highly dependent on verbal reasoning and memory (Sattler, 2008). DSB tests verbal WM and auditory sequential processing, or the recall and manipulation of auditory information (Sattler, 2008). Raw scores were used with lower scores denoting worse verbal WM. Scores for the current sample ranged from 0 to 13.

IQ—Estimated full scale IQ was assessed using an abbreviated three subtest version (i.e., Block Design, Information, and Vocabulary) of the WISC-IV that is both reliable and valid for this age range (Wechsler, 2003; Sattler, 2008). The Block Design subtest, a core subtest of perceptual reasoning, measures spatial visualization and nonverbal reasoning (Sattler, 2008). The Information subtest measures generalized knowledge and ability to recall information from long-term memory (Wechsler, 2003). The Vocabulary subtest assesses degree of language development, word knowledge, concept formation, and receptive and expressive language (Sattler, 2008). The age-adjusted scaled scores were used to estimate full scale IQ for each child. Scores for the current sample ranged from 75 to 140. This full scale IQ was used to exclude children with mental retardation from the study; children were excluded if they scored below 75. Secondary checks evaluating the effect of IQ on analyses involving language utilized a nonverbal IQ measure that consisted only of raw scores on the Block Design subtest, the only available measure of nonverbal IQ.

Data Analysis—Missingness was minimal in the current study, affecting less than 8% of the sample for all measures except verbal WM. The WM measure was available for 65% of the sample by design ($n=355$; i.e., data was collected during the second visit after additional families had been screened out). This missingness and nonnormality of data was addressed using robust full information maximum likelihood estimation (FIML; i.e., direct fitting) in Mplus, a method of directly fitting models to raw data without imputing data (McCartney, Burchinal, & Bub, 2006). The presence of siblings and the resulting non-independence of data points were addressed using the clustering feature of Mplus (Muthén & Muthén, 1998–2008). Data analysis was systematic. Independent samples t-tests and chi-square tests were conducted in SPSS to test for mean differences between the ADHD and non-ADHD groups. Then, a series of multiple linear regressions using ADHD symptom counts were conducted using Mplus (Muthén & Muthén, 1998–2008) in order to assess Baron and Kenny's (1986) mediation criteria, followed by Sobel tests, as suggested by Holmbeck (2002). Multiple

mediation analyses were conducted in SPSS using macros as suggested by Preacher and Hayes (2004).

Results

Preliminary evaluation of group differences on demographic variables indicate that the ADHD and control groups did not differ on age, $t(471)=.51$, $p=.609$ (Table 1) or ethnicity, $X^2(4)=3.11$, $p=.540$. However, children with ADHD were more likely to be male than non-ADHD comparison children, $X^2(1)=29.16$, $p<.001$. In order to control for this group difference and because current literature suggests sex differences for both ADHD and language impairment (Biederman et al., 2002; Hawke, Olson, Willcutt, Wadsworth, & DeFries, 2009), sex was covaried in all subsequent correlation and regression analyses. In line with study hypotheses, independent samples t-tests indicated that children with ADHD had significantly lower semantic language, $t(471)=2.74$, $p=.006$, $d=.25$, significantly lower mathematics achievement, $t(471)=3.43$, $p<.001$, $d=.32$, significantly poorer verbal WM, $t(353)=3.73$, $p<.001$, $d=.35$, and significantly lower estimated FSIQ, $t(469)=2.81$, $p=.005$, $d=.26$, than non-ADHD comparison children. Contrary to study hypotheses, children with ADHD did not have significantly lower reading achievement compared to non-ADHD comparison children, $t(471)=1.16$, $p=.246$.

Are ADHD symptoms associated with semantic language deficits and underachievement?

Partial correlations controlling for sex were conducted to examine descriptive associations between reading and mathematics achievement, semantic language, verbal WM, and ADHD symptoms. In line with study hypotheses, increased inattentive, hyperactive-impulsive, and total number of ADHD symptoms were associated with lower semantic language ability, worse verbal WM, and poorer reading and mathematics achievement (all $p<.001$; Table 2). Poor semantic language was associated with lower academic achievement and worse WM (all $p<.01$).

Does semantic language mediate the association between ADHD symptoms and underachievement?

To test the hypothesis that semantic language mediated the association between continuous ADHD symptoms and academic underachievement, a series of multiple regression analyses were performed. For analyses predicting reading achievement, all pathways were significant in the expected direction (Figure 1). More ADHD symptoms were associated with lower reading achievement and lower semantic language. Lower semantic language ability was associated with lower reading achievement. Once semantic language was entered into the model, the association between ADHD symptoms and reading underachievement became non-significant, suggesting that semantic language mediated the association between ADHD symptoms and reading underachievement, $r^2=.20$, $p<.001$; indirect effects: $z=-.01$, $p=.02$.

Using the same procedure described above predicting mathematics underachievement, multivariate regressions indicated that more ADHD symptoms were significantly associated

with poorer mathematics achievement (Figure 2), and lower semantic language scores were significantly associated with poorer mathematics achievement. Once semantic language was entered into the model, the association between ADHD symptoms and mathematics achievement dropped substantially, although it remained significant. As indicated by follow-up Sobel tests, semantic language significantly partially mediated the association between ADHD symptoms and mathematics underachievement, $r^2 = .58, p < .001$; indirect effects: $z = -.027, p < .001$.

Do verbal WM deficits independently mediate the ADHD-underachievement association?

Multivariate regressions were conducted to test the mediating effects of verbal WM on the association between ADHD symptoms and academic underachievement. More ADHD symptoms were significantly associated with poorer verbal WM, estimate = $-.22, p = .002$, and lower reading achievement, estimate = $-.37, p = .028$, and mathematics achievement, estimate = $-.28, p < .001$. Poorer verbal WM was also significantly associated with lower reading and mathematics achievement, estimate = $.60, p = .028$ for reading; estimate = $.45, p < .001$ for mathematics. Verbal WM independently partially mediated the association between ADHD symptoms and mathematics underachievement, $r^2 = .23, p < .001$; indirect effects: $z = -.015, p < .001$. However, verbal WM did not significantly partially mediate the association between ADHD symptoms and reading underachievement $r^2 = .40, p < .001$; indirect effects: $z = -.023, p = .141$.

Do combined semantic language and verbal WM deficits additively mediate the ADHD-underachievement association?

The relative contribution of semantic language and verbal WM as mediators of the ADHD-underachievement association was tested using a multiple mediator model (Preacher & Hayes, 2004). The overall model predicting reading achievement was significant, $r^2 = .54, p = .007$ (Figure 3). With both semantic language and verbal WM in the model, the association between ADHD symptoms and reading underachievement became non-significant, suggesting that semantic language and verbal WM together fully mediated this association. Bootstrap results for indirect effects were significant, estimate = $-.44, 95\% \text{ CI} = -.69 \text{ to } -.20$. The indirect effects of semantic language, estimate = $-.35, 95\% \text{ CI} = -.57 \text{ to } -.13$, appeared to be somewhat stronger than the indirect effects of verbal WM, estimate = $-.09, 95\% \text{ CI} = -.18 \text{ to } -.03$. Differences in indirect effects of semantic language and verbal WM were significant, $z = -4.02, p < .001$.

The multiple mediator model was also conducted for mathematics achievement. Overall, the model was significant, $r^2 = .63, p < .001$ (Figure 3). With both semantic language and verbal WM in the model, the association between ADHD symptoms and mathematics underachievement dropped substantially but remained significant. However, bootstrap results for indirect effects were significant, estimate = $-.28, 95\% \text{ CI} = -.47 \text{ to } -.11$, suggesting partial mediation of the ADHD-mathematics achievement association by semantic language and verbal WM. Again, the indirect effects of semantic language, estimate = $-.23, 95\% \text{ CI} =$

–40 to –.07, appeared to be somewhat stronger than the indirect effects of verbal WM, estimate=–.05, 95% CI=–.12 to –.02. Differences in indirect effects of semantic language and verbal WM were significant, $z=-2.69$, $p=.007$.

Are effects specific to ADHD symptom domains?

All primary analyses were conducted using ADHD symptom domains (i.e., inattentive symptoms vs. hyperactive-impulsive ADHD symptoms) in place of the total number of ADHD symptoms. As shown, inattentive and hyperactive-impulsive ADHD symptoms were significantly associated with both reading (Figure 1) and mathematics achievement (Figure 2; all $p<.05$). Lower semantic language scores fully mediated the association between reading achievement and both inattention and hyperactivity-impulsivity, but only partially mediated the association between mathematics achievement and both ADHD symptom domains. Verbal WM also partially mediated the association between mathematics and both ADHD symptom domains, estimate=–.13, indirect effects: $z=-.027$, $p<.01$ for inattention; estimate=–.21, indirect effects: $z=-.023$, $p<.001$ for hyperactivity-impulsivity. Verbal WM did not appear to mediate the association between either ADHD symptom domain and reading underachievement, estimate=–.13, $p=.031$, indirect effects: $z=-.047$, $p=.138$ for inattention; estimate=–.22, $p=.003$, indirect effects: $z=-.049$, $p=.156$ for hyperactivity-impulsivity, suggesting no differential effects based on ADHD symptom domain compared to the total ADHD symptom count.

Using multiple mediator models, effects of semantic language and verbal WM fully mediated the association between inattentive and hyperactive-impulsive symptoms and reading achievement, estimate=–.23, $p=.162$, indirect effects: $z=-.57$ for inattention; estimate=–.17, $p=.346$; indirect effects: $z=-.91$ for hyperactivity-impulsivity. The association between inattention and hyperactivity-impulsivity and mathematics achievement was significantly partially mediated by the combined effects of semantic language and verbal WM, estimate=–.19, $p=.032$, indirect effects: $z=-.36$ for inattention; estimate=–.26, $p=.007$, indirect effects: $z=-.57$ for hyperactivity-impulsivity, suggesting no differential effects based on ADHD symptom domain.

Secondary checks

All results were checked with ethnicity as a covariate with no significant changes in findings. Effects of age were also tested by dividing the sample into younger (ages 6 to 9, $n=239$) and older children (ages 10 to 12, $n=307$). Results for primary mediation analyses remained the same with one exception. For the younger participants, verbal WM fully mediated the association between ADHD symptoms and reading achievement, estimate=–.12, $p=.087$, suggesting that, at younger ages, verbal WM may be more crucial for reading achievement. Because the Vocabulary subtest is highly correlated with general intelligence (IQ) and because the measure of estimated FSIQ was determined using two WISC-IV subtests highly dependent on language (i.e., Vocabulary and Information), regression analyses using semantic language as the mediator between ADHD symptoms and achievement were conducted again, controlling for nonverbal IQ. Results remained the same for the ADHD-mathematics achievement models. With nonverbal IQ entered as a covariate,

semantic language partially mediated, instead of fully mediating, the association between ADHD and reading achievement, indirect effects $z = -.03$, $p = .005$.

DISCUSSION

The present study examined semantic language skills as an underexplored mechanism of the association between ADHD and reading and mathematics underachievement and systematically investigated alternative mechanisms including verbal WM. As hypothesized, semantic language skills appeared to be a primary mechanism, or mediator, of the association between ADHD and reading and mathematics underachievement. Further, verbal WM emerged as another promising mechanism of ADHD-underachievement associations. Together, semantic language primarily and WM secondarily independently and almost fully explained the association between ADHD symptoms and academic achievement. Further, the effects of semantic language and verbal WM on the association between ADHD and underachievement generalized across ADHD symptom domains.

Based on results of the present study, there was support for the idea that poor semantic language skills in school-age children can help explain the association of ADHD with academic underachievement. Consistent with prior research (Kim & Kaiser, 2000) children with ADHD exhibited worse semantic language skills than children without ADHD. Children with ADHD also exhibited lower levels of mathematics achievement, compared to children without ADHD. Importantly, semantic language explained the association of ADHD symptoms with reading and mathematics underachievement, which is in line with developmental theory suggesting that language and verbal WM exert bidirectional influences on the development of attention with later-emerging effects on academic achievement (Gartstein et al., 2008). Further, poor semantic language seemed to fully account for the ADHD-mathematics achievement association and partially account for the association with reading achievement even over and above deficits in nonverbal IQ. Due to the fact that language comes on-line earlier than ADHD and reading (Kieling et al., 2010; Kuhl & Rivera-Gaxiola, 2008) and in line with research suggesting that language deficits are a predictor of teacher-rated inattention (Jonsdottir, Bouma, Sergeant, & Scherder, 2006), assessment of semantic language in young children might allow for earlier identification of children at high risk for developing ADHD and learning problems so that targeted early intervention can be implemented. The use of semantic language measures as part of a comprehensive assessment battery for children with ADHD is suggested. Further, early language interventions may prove effective for promoting academic success in some children with ADHD (Ward, 1999).

Results of the current study suggested that verbal WM partially explained the relationship between ADHD symptoms and mathematics underachievement, in line with current research that suggests that verbal WM is a better predictor of mathematics achievement than reading achievement (Wilson & Swanson, 2001). In line with this idea, verbal WM did not appear to explain the relationship between ADHD symptoms and reading achievement. However, poor verbal WM fully mediated the association between ADHD symptoms and reading achievement in younger children, in line with previous research suggesting that slower development of verbal WM in children with ADHD may be important for the development

of reading achievement (Denckla, 1996; Sowerby et al., 2011). Interestingly, poor semantic language skills and verbal WM deficits together fully explained the ADHD-reading achievement association, but only partially explained the association between ADHD and mathematics achievement, suggesting that poor semantic language skills in conjunction with poor verbal WM are critical for reading achievement, whereas semantic language skills and poor verbal WM independently partially explain the association between ADHD symptoms and mathematics achievement. However, in both models, poor verbal WM did not appear to exert as strong of an effect as semantic language on either achievement domain, suggesting that semantic language is an important mechanism that needs consideration in future work on ADHD symptoms and achievement.

Contrary to study hypotheses, the mediating effects of both semantic language and verbal WM were not specific to ADHD symptom domains. Although prior research has established that inattentive ADHD symptoms typically are more highly associated with academic underachievement than hyperactive-impulsive ADHD symptoms (Breslau et al., 2010), results of the current study suggested that problems in semantic language and verbal working memory were significantly associated with both ADHD symptom domains. Thus, problems with semantic language and verbal WM may increase risk for academic underachievement in children with ADHD regardless of their symptom profile. There may be other psychological mechanisms of academic underachievement that are specific to the inattentive ADHD symptom domain; that idea needs further evaluation. Regardless, these findings suggest that children with ADHD may benefit from both early language interventions, as well as exercises that enhance WM (Klingberg et al., 2005; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005).

The present study provides a good starting point for investigating the role of language and its association with ADHD; however, it is not without limitations. Namely, demographic variables such as maternal education and family socioeconomic status are important contextual factors that influence achievement and were not investigated in the present study. Language is a broad construct that develops over time. Only one aspect of language, semantic language, was evaluated in the current study. Other work should examine other aspects of language. Further, language in general and the measure of language used in the current study in particular (i.e., the Vocabulary subtest from the WISC), is highly correlated with IQ and academic achievement. Thus, effects of language on academic achievement apart from IQ are difficult to assess, although this was explored in secondary analyses. IQ may in fact represent a general factor influencing both language development and working memory which, in turn, influence academic achievement. Further, language develops over time. Although, in the current study, the Vocabulary section of the WISC-IV was utilized because it is sensitive to semantic language in school-age children, future work should examine the development of language in relation to ADHD and early academics in younger populations (e.g., preschool). Further, the current study is cross-sectional so no conclusions can be drawn regarding the longitudinal progression or trajectory of the associations between language, ADHD, and academic achievement. However, the illustrative pattern of associations seen in this cross-sectional sample, suggest the utility of examination of this question using a longitudinal sample. Finally, the study utilized a community-recruited

sample enriched for ADHD; replication with general population samples and clinic-recruited samples would be beneficial.

This study makes an important contribution to existing literature by examining semantic language as a possible mechanism that may explain associations between ADHD and reading and mathematics underachievement. Study results indicated that semantic language explained the association between ADHD and reading underachievement and partially explained the association between ADHD and mathematics underachievement. Further, effects of semantic language generalized across ADHD symptom domains. Together, semantic language and verbal WM explained the association between ADHD symptoms and reading achievement and partially explained the association between ADHD symptoms and mathematics achievement. This work has implication for the development of tailored interventions for academic underachievement in children with ADHD.

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Figure 1.

Does Semantic Language Mediate the Association Between ADHD Symptoms and Reading Achievement?

NOTE: $^{**}=p<.01$; ns =non-significant. Semantic language measured by WISC-IV Vocabulary Raw Score. Reading achievement measured by WIAT-II Reading Comprehension Raw Score.

Figure 2.

Does Semantic Language Mediate the Association Between ADHD Symptoms and Mathematics Achievement?

NOTE: $^{**}=p<.01$; ns =non-significant. Semantic language measured by WISC-IV Vocabulary Raw Score. Mathematics achievement measured by WIAT-II Math Reasoning Raw Score.

Figure 3.

Do Language and Working Memory Additively Mediate the ADHD-Achievement Association?

NOTE: $*$ = $p<.05$; $**$ = $p<.01$; ns =non-significant. Estimates are unstandardized. Indirect effects= $-.44$, Lower CI= $-.69$, Upper CI= $-.20$ for ADHD-reading achievement association. Indirect effects= $-.28$, Lower CI= $-.47$, Upper CI= $-.11$ for ADHD-mathematics achievement association.

Table 1

Descriptive Statistics for the Sample

	ADHD <i>n</i> =266		Control <i>n</i> =207		Total <i>n</i> =546 ¹	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Boys <i>n</i> (%)	173	(65%)	83	(40%)	297	(54%)**
Ethnic Minority <i>n</i> (%)	76	(29%)	54	(26%)	163	(30%)
Age	9.72	(1.50)	9.79	(1.48)	9.77	(1.49)
Total ADHD Symptoms	14.82	(3.09)	4.34	(4.38)	10.33	(6.13)**
Inattentive	8.47	(1.18)	2.52	(2.70)	5.94	(3.42)**
Hyperactive-Impulsive	6.35	(2.73)	1.82	(2.17)	4.39	(3.30)**
Estimated Full-Scale IQ	100.84	14.84	104.65	14.30	102.27	14.68**
WISC Vocabulary	32.96	(9.16)	35.32	(9.42)	34.03	(9.29)**
Academic Achievement						
WIAT Reading	97.47	(33.66)	100.39	(15.20)	98.84	(25.94)
WIAT Math	40.12	(9.39)	43.09	(9.22)	41.46	(9.46)**
Working Memory <i>n</i> (%) ²	201	(76%)	154	(74%)	355	(65%)
Digit Span Backward	6.42	(1.63)	7.10	(1.83)	6.74	(1.73)**

Note.

** $p < .01$, via t-tests or chi-squares. Unless otherwise specified, means and standard deviations are reported.

¹ = Seventy-three children were identified as having situational ADHD or were screened out of the study at a later point in time. The subthreshold cases were included in study analyses to examine the full range of ADHD symptoms but were not included in group comparisons.

² Verbal working memory scores were only available for 65% of the sample by design (i.e., data on verbal working memory was collected at the second lab visit). The number and percentage of the total sample and ADHD and controls groups for which verbal working memory data were available are included above means and standard deviations.

ADHD=Attention-Deficit/Hyperactivity Disorder; WISC=Wechsler Intelligence Scale for Children; WIAT=Wechsler Individual Achievement Test. Raw scores were used for language, achievement, and working memory measures. Standard scores were used for estimated FSQ.

Table 2

Bivariate Correlations

	1	2	3	4	5	6	7
1 ADHD Sx							
2 Inattentive Sx	.92						
3 Hyperactive Impulsive Sx	.91	.66					
4 WISC Vocabulary	-.21	-.15*	-.23				
5 WIAT Reading	-.22	-.20	-.27	.37			
6 WIAT Math	-.27	-.22	-.28	.76	.33		
7 DSB	-.22	-.24	-.23	.37	.42	.44	
8 Estimated Full-Scale IQ	-.23	-.24	-.18	.72	.46	.54	.32

Note.

* $p<.05$.

All unflagged correlations are significant at $p<.001$.

ADHD=Attention-Deficit/Hyperactivity Disorder. Sx=Symptom counts. WISC=Wechsler Intelligence Scale for Children. WIAT=Wechsler Individual Achievement Test.