Shared predictors of academic achievement in children with attention deficit/hyperactivity disorder (ADHD): a multi-sample study

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Running head: Predicting academic achievement in ADHD

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Abstract

Objective: To identify common and shared predictors of academic achievement across samples of children with ADHD. **Method:** Two clinically referred samples from New Zealand (1 n = 88, 82% boys; 2 n = 121, 79% boys) and two community samples from the United States (3 n = 111, 65% boys; 4 n = 114, 69% boys), completed similar diagnostic, cognitive and academic assessments. Hierarchical multiple regression analyses identified significant predictors of word reading, spelling and math computation performance in each sample. **Results:** Entered after IQ, semantic language, age at testing, and verbal working memory emerged as consistent predictors of achievement across academic subjects and samples. Visual-spatial working memory contributed to variance in math performance only. Symptom severity explained limited variance. **Conclusions:** We recommend evaluations of children with ADHD incorporate assessments of working memory and language skills. Classroom/academic interventions should accommodate reduced working memory and address any identified language weaknesses.

Many children with ADHD experience impairment in their academic functioning (American Psychiatric Association, 2013), placing them at increased risk for academic underachievement (Arnold et al., 2020; Breslau et al., 2011; Fleming et al., 2017). These difficulties are often the reason children with ADHD come to clinical attention (Loe & Feldman, 2007).

Symptoms of ADHD are associated with a range of academic problems in clinical and community samples of children with ADHD (Barbaresi et al., 2007; Barry et al., 2002; Daley & Birchwood, 2010; Diamantopoulou et al., 2007; Frazier et al., 2007; Polderman et al., 2010). These associations remain after controlling for IQ, executive functions, psychiatric comorbidity, socioeconomic status, and special education needs (Garner et al., 2013; Polderman et al., 2010). While symptom severity tends to decline with age, academic difficulties persist and may worsen over time (Barbaresi et al., 2007; Murray et al., 2017; Wolraich, 2005), suggesting ADHD symptoms are not the only factors contributing to children's academic functioning.

An association between working memory and academic achievement is well established in typically developing (TD) children (Alloway & Alloway, 2010; Gathercole et al., 2004; Swanson & Alloway, 2012). Research exploring the relationship between working memory, ADHD symptoms and academic achievement indicates working memory predicts significant variance in both teacher rated (Simone et al., 2018; Sjöwall & Thorell, 2014) and objectively measured academic performance in children/adolescents with ADHD (Antonini et al., 2016; Gremillion & Martel, 2012; Rogers et al., 2011; Simone et al., 2018). Verbal working memory scores predict reading, mathematics (Antonini et al., 2016; Gremillion & Martel, 2012; Rogers et al, 2011; Simone et al, 2018) and spelling (Simone et al., 2018) performance. Visual-spatial working memory most consistently predicts math performance (Antonini et al., 2016; Rogers et al., 2011; Simone et al., 2018). Together, verbal and visual-spatial working memory correlate with teacher rated language and mathematics performance (Sjöwall & Thorell, 2014). In many of these studies working memory is reported to partially mediate the relationship between ADHD status/symptoms and academic achievement.

Language skills separately predict academic achievement (reading and literacy) in TD children (Duff et al., 2015; Ouellette & Beers, 2010) raising questions about their contribution to academic functioning in children with ADHD. Children with ADHD and comorbid language

problems have been show to perform less well than those with ADHD only on measures of reading, math computation and spelling (Cohen et al., 2000; Sciberras et al., 2014). Gremillion and Martel (2012) found semantic language fully mediated the relationship between ADHD symptom counts and reading comprehension and partially mediated the relationship with math reasoning skills.

The academic outcomes of children with ADHD appear to worsen over time (Barbaresi et al., 2007; Hinshaw et al., 2006; Massetti et al., 2008; Wolraich, 2005), especially if ADHD is left untreated (Arnold et al., 2020). Murray et al. (2017) reported more than 20% of children in their four-year longitudinal study showed reliable declines in age-standardized reading (23.6%), spelling (27.3%) and arithmetic (21.8%) performance. The widening performance gap between children with ADHD and their TD peers has been attributed to increased cognitive, task, and organizational demands, and reduced adult supervision as children move through school. In addition, the impact of ADHD symptoms on learning opportunities is likely cumulative.

Interest in the contribution of processing speed to academic performance in children with ADHD is emerging. Processing speed has direct effects on reading and math fluency tasks and math calculation in TD children (Caemmerer et al., 2018), and processing speed weaknesses are thought to affect approximately 25% of children with ADHD (Mayes & Calhoun, 2007). While the number of studies assessing the contribution of processing speed to academic performance is limited, the available evidence suggests it plays a role in timed and untimed reading performance (see meta-analysis by Cook et al., 2018).

Symptoms of ADHD, working memory, language skills, and age emerge as predictors of academic functioning in children with ADHD. However, few studies consider these variables together in the prediction of academic performance in children with ADHD. Typically, sets of predictor variables are evaluated in a single sample (see Lundervold, et al., 2017 as an exception) limiting the generalizability of the findings beyond the specific study sample. In general, more is known about the predictors of reading performance, with less research attention given to math and especially spelling performance. Determining if the identified variables predict academic achievement across academic subjects and samples is key to establishing their general value in assessment and intervention planning for ADHD.

Here we assess the contribution of ADHD symptom severity, IQ, semantic language skills, age at testing, and verbal and visual-spatial working and short-term memory to academic achievement (word reading, spelling and math computation) in two clinically referred and two community samples of children diagnosed with ADHD. As there is limited consensus regarding how processing speed should be defined, and the research base is limited, we *explore* its contribution to academic performance in this study. Across samples children completed similar multi-method multi-informant diagnostic, cognitive and academic assessments. The ability of the predictor variables to explain variance in academic achievement was assessed through correlational analyses and hierarchical multiple regression.

We assume the well-established link between intellectual functioning and academic performance extends to children with ADHD (Miller & Hinshaw, 2010) and expect IQ to contribute to academic achievement across subject areas and samples. Semantic language is hypothesized to explain significant variance in reading and spelling performance. Verbal working memory is expected to contribute broadly to academic achievement, visual-spatial working memory primarily to math performance (Oakhill et al., 2011; Rogers et al., 2011; Simone et al., 2018). If the academic progress of children with ADHD is slower than that of their age mates, then age is expected to correlate negatively with, and explain variance in, age-standardized academic performance. The meta-analysis by Cook and colleagues (2007) suggests processing speed may contribute to reading performance. As all included children meet diagnostic criteria for ADHD, the ability of symptom severity to predict academic performance may be attenuated in the current study. The clinically referred samples are expected to obtain lower cognitive and academic test scores.

Method

Participants

Data from four samples of English speaking children with ADHD, their parents and teachers are included in this study. The children were recruited through ADHD Research Clinics at the University of Otago, New Zealand (NZ, sample 1 n = 88, 1997-2001; sample 2 n = 121, 2003-2010) and the Okinawa Institute of Science and Technology (OIST) Graduate University, Japan (sample 3 n = 111,

2010-2015; sample 4 n = 114, 2015-2018) during the time periods indicated. University of Otago participants were primarily referred by pediatric and child psychiatry outpatient services. Families participating at OIST received study information from American (US) school personnel, health care professionals, and community support organizations and volunteered directly.

Child inclusion criteria were: DSM-IV or DSM-V diagnosis of ADHD; WISC Full Scale IQ (FSIQ) $\geq$ 70; normal or corrected vision; no significant past or current head trauma, neurological disorder or psychoses; English as the child's primary language; gestational age $\geq$ 35 weeks; and aged between 6 years and 12 years 11 months. Children with comorbid disorders were not excluded. See Table 1 for demographic and diagnostic information.

Ethical approval was obtained from the Otago Ethics Committee/Southern Regional Ethics Committee (NZ) and the OIST Human Subjects Research Review Committee (Japan). Parents and teachers provided written consent, children verbal consent (sample 1) or written assent (samples 2, 3, 4) to take part. All participating children, parents and teachers were volunteers.

Table 1 about here

Procedure

Assessments were conducted, or supervised, by doctoral level licensed (US)/registered (NZ/Australia) clinical/school psychologists.

Diagnostic assessment

Participating children were diagnosed with ADHD following multi-method multi-informant assessments (see Table 2). Parents completed semi-structured clinical and diagnostic interviews; symptom severity ratings for ADHD, oppositional defiant disorder (ODD), and conduct disorder (CD); broadband rating scales to assess co-occurring difficulties; and developmental and medical history questionnaires. Teachers answered questions about children's behavioral, academic and social functioning; rated ADHD, ODD and CD symptom severity; and completed teacher versions of the broadband rating scales. Children were interviewed about their behavior, academic performance and peer relationships. For children taking medication for ADHD symptom management, parents and teachers were asked to rate the child's behavior when medication free.

Data from all sources was used in diagnostic decision-making. A diagnosis of ADHD[1] was made when: the child exhibited six or more symptoms of inattention and/or hyperactivity/impulsivity in at least one setting (reported by the same informant); there was evidence of symptoms in a second setting; symptoms caused clinically significant impairment, were not better accounted for by another mental disorder or medical factors, and were inconsistent with the child's developmental level. Preliminary diagnoses were made by the interviewing clinician and reviewed by PhD senior clinical psychologists.

Cognitive and academic assessment

Assessments (see Table 2) were scheduled in the morning and took 3-4 hours to complete, carried out over 1-2 days[2]. Children prescribed stimulant medication for ADHD were required to be medication free for at least 24 hours prior to testing.

Table 2 about here

Measures

ADHD and ODD symptom severity

Inattention, hyperactivity/impulsivity, and ODD symptom severity scores were calculated by summing ratings (0 = not at all/seldom, 1 = just a little/occasionally, 2 = pretty much/quite a bit/often, and 3 = very much/very often) for each of the DSM-IV/DSM-5 inattention, hyperactivity/impulsivity and ODD items from the rating scales administered[3]. Mothers data were typically used, fathers/other caregivers when mothers data was not available.

Intellectual functioning

The Wechsler Intelligence Scales for Children (WISC)[4] are standardized measures of general intellectual functioning for children aged 6 to 16 years. Children were administered the edition in use

[1] DSM-IV and DSM-5 diagnostic criteria for ADHD include the same symptom lists (Criteria A), they differ for Criteria B: age of symptom onset (before 7 vs 12 years) and Criteria C (some vs several cross setting symptoms). As Criteria C was applied conservatively across the samples, all children meet criteria for DSM-5 ADHD.

[2] This time included child interviews and other cognitive or experimental tasks depending on the study. Details available from the senior author.

[3] If fewer than 3 items of either inattention or hyperactivity/impulsivity were missing scores were prorated.

[4] For the NZ samples the Australasian adaptations of the WISC-III and WISC-IV were used.

at the time they participated. Core subtests were administered and used to calculate FSIQ scores. For the regression analyses, two subtest estimated IQ scores were calculated (sample 1, Similarities and Block Design; samples 2-4, Similarities and Matrix Reasoning, Sattler, 2001; 2008).

Processing speed

The Processing Speed Index (PSI) scores from the WISC were used as a measure of processing speed.

Working and short-term memory

Verbal memory. The Digit Span subtest from the WISC was used to measure verbal short term (digits forward) and working (digits backward) memory. The WISC-III Process Instrument (PI), WISC-IV Integrated, and the WISC-V manuals provide age standardized scaled scores for digits forwards and backwards.

Visual spatial memory. The Spatial Span subtest from the WISC-III PI and WISC-IV Integrated was used to assess visual-spatial short-term (forward span) and working (backwards span) memory in samples 1 and 2. Scaled scores were obtained from the accompanying manuals. Children in samples 3 and 4 completed the forwards and reverse versions of the CANTAB® Spatial Span task. As norms for the CANTAB® are limited, we calculated age corrected z-scores for the longest forwards and backwards spans using the age-based means and standard deviations from the the WISC-IV and WISC-V integrated manuals. The WISC and CANTAB spatial span tasks are very similar, both derived from the original Corsi block tapping test.

Semantic language

Vocabulary subtest scaled scores from the WISC were used as a measure of semantic language.

Academic achievement

Academic achievement in the areas of word reading, spelling and math computation were measured using the appropriate versions of the Wide Range Achievement Test (WRAT) in samples 1 (WRAT-3) and 3 (WRAT-4) and the Wechsler Individual Achievement Test (WIAT) in samples 2 (WIAT-II) and 4 (WIAT-III). Raw scores were converted to age standardized scores for all samples.

Statistical Analyses

Demographic and diagnostic characteristics and cognitive and academic test scores were compared across samples. Continuous variables with one-way analysis of variance (ANOVA) or the Welch

test[5], followed by post hoc Tukey's or Tamhane tests. Categorical variables were compared using chi square, the adjusted standard residuals used to identify lack of statistical independence between variables.

For each sample, bivariate correlations assessed associations between the academic outcome and predictor variables and guided variable inclusion in subsequent hierarchical multiple linear regression analyses, i.e., predictor variables were not included in regression analyses if they did not correlate with the outcome variable. Regression analyses were performed using IBM SPSS REGRESSION, with EXPLORE used to evaluate the assumptions of multiple regression. Separate models were tested for each academic subject for each sample. Predictor variables were entered into the models as separate steps in the following order, as appropriate: ADHD symptoms, estimated IQ, sematic language, age at testing, verbal working and short-term memory, spatial working and short-term memory. Symptom severity and IQ were entered first/early as control variables. Language was entered next as it is known to predict academic achievement in TD children and is increasingly recognized as an area of impairment for many children with ADHD. Age at testing was considered next in response to questions regarding whether or not children which ADHD show a decline in performance over time. Memory performance was entered later in the models given its known association with academic performance in those with ADHD. We were interested in its ability to predict performance once these other variables were controlled/considered. Exploratory analyses assessed the contribution of processing speed to the final models, entered before and after memory measures. When significant predictors were identified, their entry into the model, with the exception of symptom severity and estimated IQ, were varied to assess for suppressor variables and possible mediation.

Data from all four samples met the assumptions for multiple regression without transformation. All samples were sufficiently large to test the overall multiple correlation. Samples 1 and 2 were slightly smaller than recommended for testing individual predictors.

[5] When the assumption of homogeneity of variance was not met.

Results

Sample Characteristics/Performance

Descriptive statistics and sample comparisons for demographic and diagnostic characteristics are presented in Table 1, and for neuropsychological and academic performance in Table 3. Gender, ADHD subtype, presence of externalizing behavior disorders (ODD and CD), and use of stimulant medication were not independent of sample. The proportion of boys was higher in sample 1 and lower in sample 3. Samples 1 and 2 included a larger proportion of children with combined type ADHD and a smaller proportion with inattentive type ADHD. The opposite pattern was observed in sample 3. Sample 2 included a higher proportion of children with comorbid ODD, samples 3 and 4 a smaller proportion. Levels of CD were low across all four samples, arguably higher in sample 1 and lower in samples 3 and 4. Medication use was lower in sample 1 and higher in samples 3 and 4. Children in sample 1 were significantly younger than those in samples 3 and 4. Symptom severity for hyperactivity/impulsivity and ODD was higher in samples 1 and 2 than in samples 3 and 4.

Mean FSIQ, processing speed index, and semantic language scores were lower in samples 1 and 2 than in samples 3 and 4. Estimated IQ was lower in sample 1 than samples 3 and 4, in sample 2 than sample 3, and in sample 4 than sample 3. Verbal short-term memory scores were lower in sample 1 than sample 4, with verbal working memory scores were lower in sample 2 than 3. Visual-spatial memory was compared separately for the NZ and US samples. Mean Spatial Span forwards and backwards scores were higher in sample 1 than sample 2. Sample 3 obtained a longer mean forwards spatial span than sample 4.

For word reading and spelling, standard scores were lower for sample 1 than for samples 3 and 4, while children in sample 2 performed less well than those in sample 3. For math computation children in samples 1 and 2 performed less well than those in samples 3 and 4, with those in sample 4 performing less well than those in sample 3.

Table 3 about here

Correlational Analyses

Table 4 presents the pairwise intercorrelations for the predictor and academic outcome variables for each of the four samples. These data informed variable inclusion in the subsequent hierarchical regression analyses. Correlations for the NZ samples appear in panel A, those for the US samples in Japan in panel B. Correlations between ODD symptom severity and the outcome variables were nonsignificant and are not presented.

Table 4 about here

Regression Analyses

Table 5 summarizes the variance explained by the predictor variables, and final regression models, for word reading, spelling and math computation for each of the four samples of children. The detailed hierarchical linear multiple regression results (final models only), for each academic domain, are available in Supplementary Tables 1 (word reading), 2 (spelling) and 3 (math computation). In all models a single predictor was entered at each step. For all models R was significantly different from zero at each step. All models explained significant variance in academic performance.

ADHD symptom severity predicted very little variance in academic performance. Severity of inattention accounted for significant variance in math computation scores in sample 2 while hyperactivity/impulsivity symptom severity predicted word reading in sample 3. Estimated IQ explained significant variance in academic performance across academic subjects and samples, with the exception of spelling in sample 1. Semantic language predicted word reading across the four samples and was significantly related to spelling in samples 1, 2 and 3. It predicted math computation scores in sample 4 only. Age at testing accounted for significant variance in word reading in samples 2 and 3, spelling scores in samples 1 and 2 and math computation in sample 2. Verbal working memory explained significant variance in word reading in samples 1, 2 and 3, and spelling and math computation in samples 1 and 2. The contribution of verbal short term memory was limited to spelling in samples 1 and 3. Spatial working memory accounted for small, but significant, amounts of variance

in word reading in sample 3 and math computation in samples 3 and 4. Spatial short term memory was significantly related to math computation in samples 2 and 4. Overall the variance explained across academic domains and study samples ranged from 2.4% to 17.4% for individual predictors and from 8.3% to 47.4% for the final models.

Table 5 about here

Exploratory Analyses

A series of exploratory hierarchical regression analyses assessed the contribution of processing speed to academic performance, entered before and after memory measures. Processing speed explained significant additional variance in spelling scores in samples 3 (4.9-5.2% depending on order of entry) and 4 (6.5%) and math computation in sample 3 (8.4-8.8%, depending on order of entry). It did not explain significant additional variance in word reading.

Discussion

Academic difficulties are common in children with ADHD. Improved management requires that we better understand the factors that contribute to academic performance in this population. Here we assessed the contribution of ADHD symptom severity, IQ, semantic language, age, and memory (short-term and working memory) to variance in academic achievement in two clinically referred and two community samples of children with ADHD. After controlling for estimated IQ, semantic language skills and working memory emerged as the most consistent predictors of academic performance. Severity of ADHD symptoms explained limited variance in academic test scores.

Semantic language skills emerged as significant and at times strong predictors of reading and spelling performance across samples. These findings are consistent with earlier reports linking language skills and reading and spelling performance in children with ADHD (Cohen et al., 2000; Gremillion & Martel, 2012; Sciberras et al., 2014). Conversely, semantic language contributed little to explaining math scores, possibly reflecting our testing of computational skills only. Supporting this hypothesis, Gremillion and Martel (2012) found semantic language partially mediated the relationship between ADHD symptoms and math reasoning performance, which emphasizes verbal problem-solving skills.

Entered after IQ and vocabulary, working memory explained significant variance in academic achievement across samples. Verbal working memory contributed to variance in performance across the academic areas assessed, visual-spatial working memory to math computation only. The amount of variance explained by working memory was typically moderate, and smaller than that reported by Simone et al. (2018). Their analyses did not control for IQ or sematic language which likely explains their larger reported effects. Short-term memory made small, less consistent, contributions across academic subjects and samples. As memory scores were entered after estimated IQ, our findings suggest working memory, and to a lesser extent short-term memory, make unique contributions to academic performance in children with ADHD, i.e., they are not serving as a proxy for intellectual ability (Alloway & Alloway, 2010).

As hypothesized, age at testing explained significant variance in academic performance, especially in Cohort 2. As the academic performance measures were age standardized, negative correlations between age and academic achievement suggest the performance gains of children with ADHD are not keeping pace with those of their age mates. This finding is consistent with reports that adolescents and adults with ADHD have poorer educational outcomes than their peers (Owens et al., 2017). Murray et al. (2017) noted half the children (51%) in their follow-up study showed a reliable decline in at least one academic subject over time. While some caution in interpretation is warranted, given our use of population norms rather than control samples, without early and appropriate academic support, children with ADHD risk falling behind their classmates academically. The reason(s) for the increased importance of age to performance in sample 2 is not obvious. Rates of ODD were significantly higher in this group, but ODD symptom severity did not correlate with academic performance. Other variables, e.g., age distribution, range of academic scores, amount of variance already explained, do not account for this finding.

ADHD symptom severity explained very little of the variance in the children's academic performance. This might be explained by the nature of the samples, i.e., all of the children were diagnosed with ADHD, however it does not seem to be an issue of restricted range. The nature of the testing environment may offer a better explanation for this finding. The children were assessed under "ideal" conditions, i.e., a distraction free room with one-to-one attention from an experienced

examiner, circumstances known to reduce the effect of ADHD symptoms on performance (Draeger et al., 1986; Tripp & Luk, 1997). In the classroom, ADHD symptoms are more likely to negatively impact children's performance. Consistent with this suggestion, Simone et al. (2018) reported symptom severity predicted teacher reports, but not objective measures, of academic performance. Similarly, Arnold et al. (2020) reported children treated for ADHD demonstrated greater improvement on formally administered achievement tests than in their classroom performance. ADHD symptom severity should continue to be considered in the classroom management of ADHD. The current findings would seem to offer suggestions for how the impact of ADHD symptoms on academic performance might be mitigated through environmental accommodations.

This study demonstrates consistency in the factors contributing to variability in academic performance across subject domains and samples. For word reading, semantic language, verbal working memory and age emerged as a consistent set of predictors (samples 1, 2 and 3). Beyond IQ, only semantic language explained significant variance in reading in sample 4. For spelling, semantic language again predicted significant variance in samples 1-3, with age and verbal working memory both contributing significantly to variance in samples 1 and 2. Spelling was the only academic subject to which short-term verbal memory made a significant contribution (samples 1 and 3), possibly through influencing recall of target words. Common predictors for math computation were verbal (samples 1, 2 and 3) and visual-spatial (samples 3 and 4) working memory. Visual-spatial memory contributed somewhat specifically to math computation.

We explored the contribution of processing speed to the children's academic performance. Contrary to the meta-analytic findings of Cook et al. (2018), processing speed did not add to the prediction of word reading. It did explain additional variance in spelling in samples 3 and 4 and math computation in sample 3. The limited associations between processing speed and academic performance may reflect the untimed nature of the academic performance tests used. Prior control of IQ and semantic language, especially for reading performance, may also help to explain the limited role played by processing speed in our regression models. Processing speed may be more important to the children's classroom performance where time for task completion is limited.

The question arises whether differences in the regression models and the variance they explain, are a reflection of sample differences. Comparisons of demographic and diagnostic characteristics together with neuropsychological and academic test performance highlight these differences. Samples 1 and 2 are clearly more impaired (IQ, semantic language, academic performance, ADHD symptom severity, behavioral comorbidity) and more similar to one another than to samples 3 and 4, which are more similar to one another, consistent with study entry route. New Zealand children were referred from specialty pediatric and child psychiatry clinics. Access to such clinics is referral based and typically available to children presenting with more severe and persistent difficulties. In contrast, children in samples 3 and 4 were parent referred, albeit recommended by the child's teacher or health care professional. Compared with the NZ participants, these children would be assessed as lower priority referrals. A possible exception to this explanation are the low math scores of samples 1 and 2. International comparisons indicate the math performance of NZ primary (elementary) school children falls below that of many countries including the US (for details see https://www.educationcounts.govt.nz/indicators/main/education-and-learning-outcomes/Mathematics-Pangarau-Primary-Schooling). For math we may be observing an additive effect of country and level of impairment.

Despite greater symptom severity and impairment, children in samples 1 and 2 were less likely to be prescribed medication for ADHD. This likely reflects the availability of specialist assessments for ADHD at the time of data collection together with prescribing practices in NZ. Most children in samples 1 and 2 were first diagnosed with ADHD as research participants, many subsequently prescribed pharmacotherapy for symptom management (see Murray et al., 2017 for follow-up data). Initiation of medication for ADHD in NZ is specialist only (specialist pediatrician or child psychiatrist), with prescription rates lower than in the US, although this is trending upwards (D'Souza et al, 2020). Nearly 40% of children in samples 3 and 4 were prescribed medication by the time they participated, hinting at earlier intervention.

These sample distinctions may explain some, but not all, of the differences in the obtained regression models. For word reading and spelling there is substantial overlap in the final regression

models and their performance in samples 1 through 3, which differ markedly from those of sample 4. For math computation there was substantial overlap in the models for samples 2 through 4.

Importantly what emerges from this study is evidence of shared predictors of academic performance across diverse samples of children meeting diagnostic criteria for ADHD. The current findings offer important information regarding potential targets for intervention with, and accommodation of, academic difficulties in children with ADHD. We believe this study is unique including, as it does, samples of children from different referral sources (clinical referrals and community volunteers), countries (NZ and the US) and time periods (1997-2001, 2003-2010, 2010-2015, 2015-2018). The emergence of common predictors within academic subjects and across samples argues for the reliability and importance of these predictors. The robustness of the findings is further supported by the use of different measures of the same constructs across samples.

The same thorough methodology was applied in the diagnosis and assessment of all children. This is a notable strength as differences in assessment and diagnostic practices have hindered cross study comparisons of the extant literature. We also include a broader range of predictor variables than many studies, allowing us to assess their performance in relation to one another. Data from children less than 35-weeks gestation was excluded to remove possible effects of early prematurity. We included children with IQ's as low as 70 to ensure inclusion of the range of children meeting criteria for ADHD.

The total number of children in the study is substantial, however each sample is moderate in size. The predictor and outcome variables were necessarily restricted to those available fin all samples. Consequently, we do not know if the variables predicting word reading and math computation generalize to reading comprehension and math problem solving, for example. We expect semantic language and verbal working memory to contribute to reading comprehension (Gremillion & Martel, 2012; Simone et al., 2018) and probably math reasoning. Our results also predict a role for visual-spatial memory in math reasoning. We limited our outcome variables to objective measures of academic performance. While this increases measurement reliability, the use of teacher performance ratings would increase the generalizability of the findings to the child's daily academic environment.

As the data was not specifically collected for the current study, measurement of the children's language skills was limited to their WISC vocabulary scores, i.e., semantic language only. The strength of association between these vocabulary scores, reading, and spelling performance raises questions about the contribution of other aspects of language to academic performance. Assessment protocols for future research, and clinical evaluations of children with ADHD, should include more comprehensive measures of language, addressing the child ability to use, comprehend, analyze and recall language, all critical skills for successful academic engagement. Beyond expanding the assessment of language, there is a need for sufficiently powered longitudinal studies that incorporate ecologically valid academic assessments and relevant neuropsychological variables, including measures of processing speed.

Clinical implications

The current study identifies potential targets for academic intervention in children with ADHD. Working memory emerged as a consistent, if modest, predictor of academic performance. To date interventions for working memory have shown limited success beyond the specific treatment targets, and effects are short lived (Melby-Lervåg & Hulme, 2013; Rapport et al., 2013). This argues for establishing a learning environment that reduces the burden on working memory and ensuring parents and teachers understand the challenge of reduced working memory for the child (see Gathercole & Alloway, 2008; Martinussen & Major, 2011; Swanson & Alloway, 2012). Semantic language skills explain variance in academic performance, especially in reading and spelling. Language skills should routinely be screened in children with ADHD, with speech and language referrals/interventions initiated as needed. Childrens' understanding of task instructions should be monitored and supported. Age at testing also emerged as a predictor of academic test performance. This argues strongly for early assessment and intervention in children demonstrating symptoms of ADHD to prevent them falling behind their classmates over time. Although symptom severity was not strongly associated with academic achievement in this study, others have shown it predicts teacher ratings of performance at school. In classroom settings, environmental accommodations for inattention and hyperactivity/impulsivity should be incorporated.

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Conflicts of Interest

The authors report no conflicts of interest.