Published in final edited form as:

J Learn Disabil. 2019 ; 52(1): 15–30. doi:10.1177/0022219418775115.

A Cognitive Dimensional Approach to Understanding Shared and Unique Contributions to Reading, Math, and Attention Skills

Amanda E. Child, MA¹, Paul T. Cirino, PhD¹, Jack M. Fletcher, PhD¹, Erik G. Willcutt, PhD², and Lynn S. Fuchs, PhD³

¹Department of Psychology, University of Houston

²Department of Psychology and Neuroscience, University of Colorado

³Department of Special Education, Vanderbilt University

Abstract

Disorders of reading, math, and attention frequently co-occur in children. However, it is not yet clear which cognitive factors contribute to comorbidities among multiple disorders and which uniquely relate to one, especially because they have rarely been studied as a triad. Thus, the present study considers how reading, math, and attention relate to phonological awareness, numerosity, working memory, and processing speed, all implicated as either unique or shared correlates of these disorders. In response to findings that the attributes of all three disorders exist on a continuum rather than representing qualitatively different groups, this study employed a dimensional approach. Furthermore, we used both timed and untimed academic variables in addition to attention and activity level variables. The results supported the role of working memory and phonological awareness in the overlap among reading, math, and attention, with a limited role of processing speed. Numerosity was related to the comorbidity between math and attention. The results from timed variables and activity level were similar to those from untimed and attention variables, although activity level was less strongly related to cognitive and academic/attention variables. These findings have implications for understanding cognitive deficits that contribute to comorbid reading disability, math disability, and/or attention-deficit/hyperactivity disorder.

Keywords

reading; math; attention; comorbidity; cognitive predictors

Disorders of learning and attention are common in childhood, with prevalence rates between 5 and 12% for reading disability (RD), mathematics disability (MD), and attention-deficit/

Corresponding Author: Amanda E. Child, Department of Psychology, University of Houston, 4849 Calhoun Rd. Mail Rm. 373, Houston, TX 77204. achild@uh.edu.

Paul T. Cirino, Department of Psychology, University of Houston, 4849 Calhoun Rd. Mail Rm. 373, Houston, TX 77204. pcirino@uh.edu

Jack M. Fletcher, Department of Psychology, University of Houston, 126 Heyne, 3695 Cullen Blvd, Houston TX 77204-5022 jack.fletcher@times.uh.edu

Erik G. Willcutt, Department of Psychology and Neuroscience, University of Colorado, UCB 345, Muenzinger Hall, Boulder, CO 80309. erik.willcutt@colorado.edu

Lynn S. Fuchs, Department of Special Education, Vanderbilt University, 288 Peabody, Nashville, TN 37203. lynn.fuchs@vanderbilt.edu

hyperactivity disorder (ADHD; Geary, 2011; Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007; Schumacher, Hoffmann, Schmal, Schulte-Körne, & Nöthen, 2007). There is also substantial phenotypic comorbidity among RD and ADHD, RD and MD, and MD and ADHD (e.g., August & Garfinkel, 1990; Capano, Minden, Chen, Schachar, & Ickowicz, 2008; Landerl & Moll, 2010), although there is little information regarding the last of these comorbidities, and only one (Peterson et al., 2017) addressing all of them. Finally, little emphasis has been given to the role of math-specific contributions. The present study extends such work by delineating shared and unique cognitive correlates among all three comorbidities simultaneously.

Phonological Awareness and Reading

Phonological awareness (PA) is strongly related to reading skill acquisition (Durand, Hulme, Larkin, & Snowling, 2005; Richard K. Wagner & Torgesen, 1987) and deficits in this area are consistently associated with RD (e.g., Catts, Fey, Tomblin, & Zhang, 2002; Olson, Wise, Conners, Rack, & Fulker, 1989; Stanovich, 1988). PA may also have a role in the development of mathematical proficiency (e.g., Cirino, 2011; Fuchs et al., 2005, 2006), particularly for children with comorbid MD and RD (e.g., Brainerd, 1983; Logie, Gilhooly, & Wynn, 1994; Robinson, Menchetti, & Torgesen, 2002). However, empirical support for the hypothesis that PA difficulties underlie MD/RD comorbidity is mixed: Some studies have found that PA is uniquely associated with RD and not MD or MD/RD (Willcutt et al., 2013), although others have found phonological deficits in children with MD and/or MD/RD (Cirino, Fuchs, Elias, Powell, & Schumacher, 2015; De Weerd, Desoete, & Roeyers, 2013; Ostad, 2013) or associations between PA and reading as well as math outcomes (Koponen, Salmi, Eklund, & Aro, 2013). PA does not appear to be related to ADHD alone (Willcutt, Betjemann, et al., 2010).

Numerosity and Mathematics

A key basic numerical skill involves gauging the relative or approximate magnitude, or numerosity, of sets of items (Butterworth, 2010; Piazza & Izard, 2009). The Approximate Number System (ANS) is hypothesized to be activated when estimating or comparing numerosities larger than 4 (Feigenson, Dehaene, & Spelke, 2004), and facilitates later mathematical proficiency (von Aster & Shalev, 2007). ANS acuity is linked to performance on math tasks (Halberda, Mazzocco, & Feigenson, 2008) and is deficient in children with MD (Mazzocco, Feigenson, & Halberda, 2011; Mussolin, Mejias, & Noël, 2010). Although ANS acuity is not always associated with mathematics performance (e.g., Jordan et al., 2013), meta-analytic findings found significant correlations between non-symbolic number acuity and symbolic math performance ($r = 0.20$; Chen & Li, 2014). While symbolic number skills generally more strongly predict math skills relative to non-symbolic skills (De Smedt, Noël, Gilmore, & Ansari, 2013), non-symbolic number skills were assessed here in order to specifically assess relations to math (rather than reading) performance. Very little research has explored the possibility of numerosity deficits in children with RD or ADHD alone, although there is little reason to expect that numerosity per se (when measured with nonsymbolic material) would be an important shared contributor to overlap among reading, math, and attention.

Working Memory and Attention, Reading, and Math

Cognitive correlates of ADHD include executive functions (i.e., inhibition, planning, shifting, working memory; Barkley, 1997; Boonstra, Oosterlaan, Sergeant, & Buitelaar, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), sustained attention (Barkley, 1997; Bellgrove, Hawi, Gill, & Robertson, 2006), and processing speed (Chhabildas, Pennington, & Willcutt, 2001; Rucklidge & Tannock, 2002; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005). Working memory (WM) in particular has empirically been associated with ADHD, including in meta-analytic studies (Kasper, Alderson, & Hudec, 2012; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, et al., 2005). WM also plays a prominent role in many models of ADHD, including Barkley's theory of executive functions and ADHD (Antshel, Hier, & Barkley, 2014). In addition to the strong role of WM in ADHD symptomatology, WM is also associated with reading and math alone (Moll, Göbel, Gooch, Landerl, & Snowling, 2014; Swanson & Jerman, 2006; Willcutt et al., 2013), and verbal WM has been implicated in the comorbidity between reading and math (Moll et al., 2014; Willcutt et al., 2013), albeit not consistently (i.e., Fuchs, Geary, Fuchs, Compton, & Hamlett, 2016).

Processing Speed and Reading, Math, and Attention

Deficits in processing speed (PS) are found in children with RD, MD, or ADHD alone (e.g., Andersson & Lyxell, 2007; Shanahan et al., 2006; Willcutt, Pennington, et al., 2005) as well as comorbid RD/ADHD (Tannock, Martinussen, & Frijters, 2000; Willcutt, Pennington, et al., 2005) and MD/RD (Andersson, 2010). Genetic evidence also suggests that PS difficulties underlie comorbidities among all three disorders (Willcutt, Pennington, et al., 2010). RD as well as MD are associated with deficits in linguistic PS (i.e., naming speed deficits; Mazzocco & Grimm, 2013; Wolf & Bowers, 1999; Wolf et al., 2002) as well as non-linguistic PS (Shanahan et al., 2006; Willcutt et al., 2013). Children with ADHD also exhibit PS deficits (Tannock et al., 2000), and PS has been shown to be one of the best predictors of inattentive symptomatology in this population (Chhabildas et al., 2001). Most PS research has considered these disorders individually, with the exception of a few studies that have found PS deficits in children with RD/ADHD (Tannock et al., 2000; Willcutt, Pennington, et al., 2005) as well as MD/RD comorbidities (Andersson, 2010; Willcutt et al., 2013). Only one study (available only after the completion of the present study) has addressed relations between PS and dimensional measures of math, reading, and attention (Peterson et al., 2017), though this study utilized relatively complex measures of PS.

In general, PS as a construct is not well defined and is measured in many different ways (Shanahan et al., 2006). For example, simple reaction time tasks are sometimes used as an indicator of PS (e.g., Snowling, 2008; Weiler et al., 2000), particularly in very young children. Other studies use more complex speeded tasks that require higher-level cognitive processing in addition to perceptual processing (i.e., naming speed or executive speed tasks; Shanahan et al., 2006). Increasing the complexity of the speeded task may increase the correlation between the task and the targeted cognitive or academic variable (i.e., reading ability), so the theoretical importance of these correlations may be less relevant due to the potential contribution of cognitive as compared to pure PS factors on the relation.

Timed vs. Untimed Measures of Reading and Math

Few studies have differentiated between timed versus untimed reading and math measures when quantifying overall reading or math ability. With regard to reading, some authors use untimed word or passage reading measures or reading comprehension measures to estimate reading ability (Catts, Gillispie, Leonard, Kail, & Miller, 2002; Pratt & Brady, 1988; Wise et al., 2008) while others use a combination of timed (e.g. fluency-based) and untimed measures (Olson et al., 1989; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002). In addition, math achievement is often measured with untimed measures requiring students to solve calculations and/or word problems (Branum-Martin, Fletcher, & Stuebing, 2013; Compton, Fuchs, Fuchs, Lambert, & Hamlett, 2012; Mazzocco et al., 2011), but which do not explicitly assess automaticity of math fact retrieval. There is strong evidence to suggest that untimed word reading, reading fluency, and comprehension measures represent distinct, though related, abilities (Cirino et al., 2013; Hart, Petrill, & Thompson, 2010) in addition to evidence that math fluency deficits are a core feature associated with MD (Hanich, Jordan, Kaplan, & Dick, 2001; Jordan & Hanich, 2003).

Defining MD, RD, and ADHD

Researchers have frequently defined MD and RD using arbitrary cut points (e.g., scoring below the 25th percentile on a mathematics measure). While useful for identifying children in need of intervention, academic skills are inherently normally distributed; consequently, approaching these disorders by looking across the continuum increases statistical power, reliability, and validity (e.g., Branum-Martin et al., 2013). Therefore, in this study, we focus on relationships among dimensional measures of reading, math, and behavioral attention. Attention and hyperactivity are distinct constructs (Willcutt et al., 2012); although prior work has focused on attention, the present study will also consider activity level to better understand cognitive deficits associated with each symptom dimension of ADHD. Of note, although inattention has often been studied as a predictor of academic outcomes (i.e., Fuchs et al., 2016), the current study conceptualizes attention as an outcome in order to further characterize cognitive skills that are related to ADHD symptomatology, and compare/contrast these with the role of those same cognitive skills with regard to reading and math.

Current Study

There is evidence for relations among phonology and both reading and math, numerosity and math, WM and behavioral attention, and PS and all three dimensions. However, what are less clear are the potential roles of PA, numerosity, WM, and PS in the overlap *among* math, reading, and attention/activity level, particularly when timed and untimed math and reading variables are considered separately. Consistent with the correlated liabilities (Neale & Kendler, 1995; Willcutt et al., 2013) or multiple deficits (Pennington, 2006) models, which posit that comorbidity occurs as a result of shared etiological influences between disorders, but with unique etiological influences accounting for the distinction between the disorders, we will assess which cognitive factors are more shared and which are more unique in association with each of these dimensions. In addition, given that much of the existing comorbidities research focuses on children who are in third grade and above (Fuchs &

Fuchs, 2002; Willcutt et al., 2001; Willcutt, Pennington, et al., 2005), exploring these relations in second grade children will provide insight into cognitive variables that play a role earlier in the development of these disorders.

Hypotheses

Our hypotheses focused on two related aims, namely the relative roles of PA, numerosity, WM, and PS in: (a) association *within* reading, math, and attention/activity level; and (b) shared overlap *among* these same variables.

Reading

We hypothesized that PA (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994; Willcutt et al., 2013), WM (Berninger et al., 1994; Willcutt et al., 2013), and PS (Shanahan et al., 2006; Willcutt et al., 2013) would significantly account for untimed reading performance, with a stronger contribution of PA relative to the other two cognitions. PS was expected to most strongly relate to timed reading (Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004), followed by PA (Schatschneider et al., 2004) and WM (Jacobson et al., 2011). Numerosity was not expected to significantly relate to reading.

Math

For untimed math, we expected numerosity to be the strongest significant relation, followed by WM (Willcutt et al., 2013), PS (Bull & Johnston, 1997; Fuchs et al., 2006; Willcutt et al., 2013), and PA (Fuchs et al., 2006; Willcutt et al., 2013). Numerosity was expected to most strongly account for timed math, followed by PS, WM, and PA.

Attention and Activity Level

We hypothesized that WM (Martinussen et al., 2005; Willcutt, Doyle, et al., 2005) and PS (Shanahan et al., 2006; Willcutt, Doyle, et al., 2005; Willcutt, Sonuga-Barke, Nigg, & Sergeant, 2008) would strongly relate to behavioral attention, with no significant contributions of phonological awareness (Fletcher, 2005; Martinussen, Grimbos, & Ferrari, 2014) or numerosity. We did not expect any cognitive variables to be related to activity level, including PS (Chhabildas et al., 2001) and WM (Martinussen & Tannock, 2006).

Overlap

We first considered pairs of academic/behavioral variables. We hypothesized that the correlation between reading and math would be significantly reduced after accounting for variance attributable to PA (De Smedt, Taylor, Archibald, & Ansari, 2010), WM (Moll et al., 2014; Willcutt et al., 2013), and PS (Willcutt et al., 2013). We also expected that correlations between reading and behavioral attention as well as between math and behavioral attention would be significantly reduced after controlling for the effects of PS (McGrath et al., 2011; Shanahan et al., 2006; Willcutt et al., 2008) and WM (Willcutt et al., 2008). We did not expect PA to contribute to any comorbidities involving attention (McGrath et al., 2011; Willcutt et al., 2010), or numerosity to significantly reduce the correlation between any pairs of academic/behavioral variables. Considering all three academic/behavioral variables simultaneously with canonical correlation allowed us to affirm that these three outcomes

strongly interrelate, as well as explore how cognitive skills contribute to this interrelation. We hypothesized that PS and WM would be most strongly related to an academic/behavioral variate that is strongly correlated with reading, math, and attention outcomes (Willcutt et al., 2008). We did not expect PA and numerosity to relate to the academic/behavioral variate, or cognitive variables to relate to overlap among outcomes when considering activity level instead of attention.

Methods

Participants

Two hundred thirty-three second grade children were included in this study. The average age of the participants was 7.58 ($SD = 0.40$), although the ages for three children were missing. Forty eight percent of the children were female, and 85% received reduced or free lunch at school. Forty percent did not speak English as their primary language, but all were instructed in English. With regard to ethnicity, 35% were black, 29% were Hispanic, 29% were Caucasian, and 7% were of another ethnicity. Participants were from the fourth cohort of a larger math intervention study (Author, 2014) in the southeastern US selected from a number of schools and classrooms as only this cohort received all the requisite measures evaluated in this study (prior to any intervention). All participants met a cutoff of $>2^{\text{nd}}$ percentile on the Wechsler Abbreviated Scales of Intelligence (WASI; Weschler, 1999); average IQ was 91.8 ($SD = 12.1$). Raw scores for all measures (and correlations) are presented in Table 1. Given that participants were selected for a math study, they had lower average standard scores on WRAT-3 Arithmetic ($M = 91.92$, $SD = 12.23$) relative to WRAT-3 Reading ($M = 100.17$, $SD = 13.83$).

Cognitive Variables

PA was measured using the *Elision* task from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999). Subjects are given a word and asked to repeat the word without one of its sounds. Coefficient alpha for 7-year-old children is 0.91 (Wagner et al., 1999).

Numerosity was assessed using the *Panamath* task (Halberda et al., 2008). Participants are presented with series of dot arrays that vary in quantity, and participants judge which side of the screen displays more dots as quickly as possible. Different tones indicate a correct or incorrect response immediately after a key press. ANS acuity is typically quantified either with the Weber fraction or percent correct on the task, which are highly correlated with each other ($r = -0.85$ to -0.87 ; Libertus, Feigenson, & Halberda, 2013). Accuracy is a more reliable outcome variable relative to the Weber fraction (Inglis & Gilmore, 2014), however, so percent correct was used for this study. Split-half reliabilities range from 0.65 to 0.72 in preschool age children (Libertus et al., 2013) and 0.73 in 11 to 17-year-old children (Halberda, Ly, Wilmer, Naiman, & Germine, 2012). In our sample, data points for three children were removed for aberrant *Panamath* results (i.e., a reaction time of $< 50\text{ms}$ or $> 7000\text{ms}$ in addition to accuracy below 50%, or chance).

WM was assessed with three central executive tasks from the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001), that each requiring recalling and manipulating information in WM. All subtests contain span levels from 1–6 to 1–9, each with six items, and children progress to the next span level after passing four items at a given level. The subtest ends when three items are failed at a span level. For Listening Recall, children listen to a series of sentences, deciding whether each is true or false. After listening to a series of sentence, participants recall the last word of each sentence in order. Counting Recall presents arrays of 4, 5, 6, or 7 dots and are asked to count the dots in each array. At the end of each trial, children recall the number of dots presented on each card in their original order. For Backward Digit Recall, students listen to a list of numbers, which they then reproduce in reverse order. Total number of correct trials for each task was used in analyses. Test-retest reliability for 5.9- to 6.9-year-old children was 0.83 for listening recall, 0.74 for counting recall, and 0.53 for backward digit recall (Pickering & Gathercole, 2001). Correlations between the subtests ranged from 0.26 and 0.31, similar to previously reported correlations (0.30 to 0.37; De Smedt et al., 2009), and alpha for this composite was 0.56. While these correlations and alpha values are relatively low, zero-order and partial correlation analyses revealed that individual subtests were similarly related to individual outcomes as well as overlap between pairs of outcomes as compared to the composite variable, consistent with studies finding that different domains of WM exhibit similar relations to math and reading (Peng & Fuchs, 2016; Peng, Namkung, Barnes, & Sun, 2016).

PS was assessed using the *Cross Out* task from the Woodcock-Johnson III Tests of Cognitive Abilities (WJ-III; Woodcock, McGrew, & Mather, 2001). This task requires students to find and circle two identical symbols in a row of six symbols. Students are given three minutes to complete as many items as possible. Credit is given when both matching symbols are circled. Total number of correct items was used in the analyses. Reliability is 0.72 for 7-year-olds (Woodcock, McGrew, & Mather, 2001).

Academic/Behavioral Variables

Untimed math abilities were assessed using the Arithmetic subtest from the Wide Range Achievement Test (WRAT3; Wilkinson, 1993). This measure assesses a range of computational processes, and although there is a time limit, it is highly unusual for young children to run out of time, so it is essentially an untimed task. WRAT-3 Reading was used to evaluate untimed reading abilities. This measure assesses a range of reading abilities, from letter identification to reading words of increasing difficulty. Raw scores for both measures were used in analyses, and reliabilities in this age range was 0.94 in a related study using different participants from a similar population of students (Cirino et al., 2015) and 0.90 as reported by the WRAT-3 manual (Wilkinson, 1993).

Timed math abilities were assessed with a composite consisting of four speeded measures of addition and subtraction from the *Math Facts Fluency Assessment* (Fuchs, Hamlett, & Powell, 2003). Each allows students 1 minute to solve as many items as possible, and 25 items are included on each subtest. Total correct was used for analyses. Subtest intercorrelations ranged from $r = 0.38$ to 0.80. Alpha values range from 0.86 to 0.91 from a prior study (authors, 2009), and coefficient alpha for this cohort was 0.83.

Timed reading abilities were assessed using *Word Identification Fluency* (Fuchs, Fuchs, & Compton, 2004), where children are presented with a list of 50 high-frequency words and are asked to read as many words as possible in one minute. In this sample, the two *Word Identification Fluency* subtests correlated $r = 0.88$ with a coefficient alpha of 0.94 for the composite. Total number of words read correctly for each subtest was standardized, and the subtest z-scores were averaged in order to generate the variable used in analyses. In a sample of first graders, alternate form reliability for this measure was 0.88 from two consecutive weeks (Fuchs et al., 2004).

The Strengths and Weaknesses of ADHD symptoms and Normal behavior scale (SWAN) was used as the measure of behavioral attention (Swanson et al., 2012), corresponding to DSM IV criteria of inattentive and hyperactive/impulsive behaviors associated with ADHD. Each item is ranked on a seven-point scale ranging from far below average to far above average, thus providing a dimensional assessment of these behaviors and ensuring a normal distribution of scores in the population (Polderman et al., 2007; Swanson et al., 2012). Inattention and hyperactivity/impulsivity items were considered separately (Willcutt et al., 2012). Higher scores indicate lower levels of attention and higher activity levels. Cronbach's alpha of the SWAN in this sample was 0.97 for inattention and 0.98 for hyperactivity.

Procedure

Students were assessed within their schools for measures administered in groups and individually. Students were assessed on all measures in September and October. Examiners were experienced with testing in schools and were trained to criterion on all of the measures. The individual test sessions were audiotaped, and a random sample of sessions was rescored using the tapes by a second research assistant (agreement was at 0.98). Once testing was finished, all protocols were double entered/verified before the database was finalized. Standard scores, where available, were computed for all measures after testing was completed.

Analyses

We used multiple regression analyses, partial correlations, and canonical regression to assess the relationships between the cognitive and academic/behavioral variables. Variable distribution examination did not reveal anomalies, and Q-Q plots revealed normal distribution of residuals. Analyses were conducted with and without outliers with high leverage, and because the pattern of results did not change, outliers were included in all analyses.

In order to determine appropriate covariates to consider, race/ethnicity, sex, socioeconomic status, primary language, and age (Kao & Thompson, 2003; Ladson-Billings & Madison, 1997; Lubienski, 2002; McGraw, Lubienski, & Strutchens, 2006; Tate, 1997) were correlated with cognitive and academic/behavioral variables. Reduced/free lunch status, race, language, and sex significantly correlated with at least three cognitive or academic/behavioral variables; thus, these variables were considered in all subsequent analyses.

The analyses utilized three composites for WM, timed math, and timed reading. Composites were created by standardizing the raw score of each subtest relative to the sample mean and

averaging the subtest z-scores. For all analyses, academic/behavioral variables were the sample-standardized composites noted above or raw scores (though the results were not different when standard scores were used where available).

Results

Multiple Regression Analyses

Multiple regression results appear in Table 2, with all cognitive variables included in the models for each academic/behavioral variable. The overall models for untimed reading, $F(4, 228) = 36.82, p < 0.001, R^2 = 0.39$, untimed math, $F(4, 226) = 21.03, p < 0.001, R^2 = 0.27$, and attention, $F(4, 228) = 25.24, p < 0.001, R^2 = 0.31$, were all significant. PA ($p < 0.001$ and $p = 0.002$, respectively) and WM ($p = 0.001$ and $p = 0.002$) were significantly related to untimed reading and untimed math, while numerosity also significantly accounted for variance in untimed math, $p < 0.001$. All of the cognitive variables were related to attention, $p = 0.001$ to $p = 0.003$.

The pattern of cognitive variables uniquely related to academic/behavioral variables was consistent for timed vs. untimed reading, although overall R^2 values were smaller for timed outcomes, $F(4, 228) = 21.77, p < 0.001, R^2 = 0.28$. For timed math, some differences in pattern were noted. Specifically, PS was a unique relation, $p = 0.007$, whereas WM was not a unique relation, $p = 0.608$; however, the overall model significance was similar for timed math, $F(4, 228) = 21.00, p < 0.001, R^2 = 0.27$, and untimed math. Of note, even when correcting for multiple comparisons (significance cutoff = 0.05/6, or 0.008), all relations for untimed and timed variables remained significant.

The results for activity level showed that instead of all cognitive variables showing a unique contribution (as was the case for attention), now only PA, $p = 0.037$, and numerosity, $p = 0.007$, remained significant. Of note, PA was no longer significant when correcting for multiple comparisons. The overall model, $F(4, 228) = 8.75, p < 0.001, R^2 = 0.13$, was weaker relative to the model for attention ($R^2 = 0.31$). Including covariates did not significantly change the results of any multiple regression analyses, although R^2 values for the full models did increase an average of $R^2 = 0.07$ (range from 0.02 to 0.12).

Correlation Analyses

Table 1 shows zero-order correlations among all variables. Correlations between outcome variables (timed and untimed) were all significant and ranged from $r(231) = 0.22, p = 0.001$, to $r(231) = 0.76, p < 0.001$. Table 3 shows zero-order correlations (r) for untimed academics and attention with each other, as well as the strength of these same correlations when variance of each of the four cognitive variables was partialled (pr). Also presented is the proportion of variance shared among each pair of outcomes (with nothing partialled; r^2), followed by variance shared with a given cognitive variable partialled (pr^2), and the difference between those values (change in r^2). Previous studies have used percent decrease in shared variance (i.e., Shanahan et al., 2006); however, because zero-order correlations between outcomes vary widely here, absolute differences are presented to facilitate the comparison of a cognitive variable's contribution across different pairs of outcomes.

As predicted, PA contributed to the overlap between untimed reading and math. For example, untimed reading and math correlated 0.41 (17% overlap), and this correlation was reduced to 0.27 (7% overlap) when PA was partialled, resulting in an absolute change in shared variance of 10%. Partialling for WM also decreased the correlation, $pr = 0.28$ (8% overlap), and variance shared between the outcomes (9% decrease). Controlling for PS, $pr = 0.38$ (3% decrease in shared variance), and numerosity, $pr = 0.37$ (2% decrease in shared variance), minimally reduced the correlation.

Untimed reading and attention correlated 0.45 (21% overlap), which was reduced after controlling for WM, $pr = 0.31$ (11% decrease in shared variance) and PA, $pr = 0.31$ (11% decrease in shared variance). Only minor reductions resulted from controlling for PS, $pr = 0.40$ (5% decrease in shared variance). Minimal decreases resulted from controlling for numerosity (2% decrease in shared variance).

Untimed math and attention correlated 0.44 (20% overlap), which, as expected, is reduced after controlling for WM, $pr = 0.33$ (9% decrease). Although decreases were found after controlling for PS, $pr = 0.40$ (4% decrease), a more significant role of this cognitive variable was expected. More substantial reductions than anticipated were found after controlling for PA, $pr = 0.35$ (7% decrease) as well as numerosity, $pr = 0.39$ (4% decrease).

Table 3 also presents results for timed academics. We hypothesized similar results for timed and untimed outcomes, and decreases in shared variance after controlling PA, numerosity, and PS for timed academics were similar to those found for untimed academics. However, with timed outcomes, decreases in r^2 due to WM were smaller for all outcome pairs, now accounting for 5% to 10% of the shared variance (as compared to 9 to 11% for untimed outcomes).

The timed and untimed results with the hyperactivity/impulsivity (rather than inattention) scale of the SWAN are presented in Supplementary Table 1. As expected, zero-order correlations tended to be lower between activity level and academic skill, relative to those with attention. Reductions in shared variance were also lower for outcome pairs involving activity level (ranging from 2% to 5%) relative to attention (ranging from 0% to 11%). Inclusion of covariates did not substantively change the pattern or general level of results.

Canonical Correlation Analyses

Canonical correlation analyses evaluate relations between two sets of variables (i.e., academic and cognitive) and decompose individual variable contributions within and across set; this approach is ideal for determining which predictors likely underlie the overlap between all three outcomes. Since our smallest set of variables (in this case, outcome variables) consisted of three variables, three canonical functions were produced (Grimm & Yarnold, 2000). Each canonical function consisted of two canonical variates, one academic and one cognitive, generated such that correlations between variates in a function (i.e., canonical correlations) are maximized. Of primary interest to this study were the magnitude of the overall relationship and correlations between cognitive variables and the academic variate, as these reveal which cognitive variables more strongly contribute to overlap

between outcomes. Results considering how the individual outcome variables related to the cognitive variate are presented in the tables.

First, the significance of the three canonical variates was assessed. With all 3 canonical functions included, Wilks' Lambda = 0.48, $p < 0.0001$. In order to determine the significance of each canonical function, the functions were removed in sequential order (Hanks et al., 1999). With the first (and largest) canonical function removed, Wilks' Lambda = 0.91, $p = 0.001$. After removing the second canonical function, the test is no longer significant, Wilks' Lambda = 0.99, $p = 0.235$. Thus, the first two pairs of canonical variates account for significant relations between the sets of variables. Specifically, the correlation between the first set of canonical variates is 0.70. The first canonical function thus accounts for 49% of variance shared between the cognitive and academic/attention variates (i.e., canonical R^2). The second canonical correlation is 0.28 (8% of shared variance). The findings from these two variates are the focus of the results presented below.

Table 4 presents correlations between the cognitive and untimed academic/attention variables and the cognitive and academic/attention canonical variates. First, contributions of the academic/attention variables to the outcome variate are considered. The first academic variate was strongly and positively correlated to a similar extent with untimed reading, $r = 0.88$, untimed math, $r = 0.71$, and attention, $r = 0.76$, indirectly supporting the hypothesis that all three outcomes were related to one another. Also consistent with hypotheses, this variate was related to WM, $r = 0.56$, and PS, $r = 0.35$, although the correlation appears smaller with PS relative to WM when similarly strong relations were expected. PA, $r = 0.58$, was also strongly correlated with the first outcome variate; although this relation was not hypothesized, it is consistent with other analyses. Numerosity, $r = 0.29$, also weakly correlated with the first variate.

Further exploratory results from the second canonical variate provided an interesting contrast to the results from the first variate. The second outcome variate is primarily defined by a contrast between math and reading skills, as evidenced by positive correlations with untimed math, $r = 0.55$, and attention, $r = 0.31$, but with a negative correlation with untimed reading, $r = -0.47$. Consistent with this interpretation of the second outcome variate, it was correspondingly associated with a positive correlation with numerosity, $r = 0.22$, and a negative correlation with PA, $r = -0.13$; relations WM and PS were minimal. However, this canonical function only accounted for 8% of the shared variance.

Timed as opposed to untimed outcomes are presented in Table 5, and Supplementary Tables 2 and 3 portray the results for activity level instead of attention. The pattern of results generally did not change when considering timed as opposed to untimed math and reading outcomes, although WM was negatively correlated with the second cognitive variate, $r = -0.31$. No notable changes were observed when considering activity level instead of attention or when covariates were included in the model.

Discussion

The aim of this study was to determine shared cognitive factors underlying comorbid associations among reading, math, and attention/activity level as well as to elucidate cognitive variables that are unique to each dimensional outcome. Although previous studies have considered these outcomes in isolation or in pairs, only one known very recent published study has looked at all three together (Peterson et al., 2017). Also, previous studies have not considered reading, math, and attentional abilities on a dimensional scale, and compared academic timed and untimed outcomes as well as attention and activity level outcomes.

Relations for Individual Untimed Outcomes

We hypothesized that PA would most strongly relate to reading, numerosity would most strongly relate math, and WM would be most strongly relate to attention. As expected, PA most strongly related to untimed reading outcomes, affirming the importance of PA in reading skill development (e.g., Catts, Fey, et al., 2002; Olson et al., 1989; Stanovich, 1988). However, our predictions regarding the degree to which numerosity and WM relate to math and attention were only partially supported. Although numerosity accounted for untimed math (and not reading) outcomes, supporting its role in the development of math proficiency (Chen & Li, 2014), the strength of the relation between numerosity and untimed math was similar to that of PA and WM. Thus, it was not the primary predictor of math outcomes (analogous to PA for reading). However, significant, but not large, relations between number sense and math performance is consistent with meta-analytic findings (Chen & Li, 2014), and it is likely that symbolic number skills would have yielded stronger relations with math outcomes in 2nd grade children (De Smedt et al., 2013). Similarly, although WM was significantly related to attention outcomes along with PS, as expected (Martinussen et al., 2005; Shanahan et al., 2006; Willcutt et al., 2008), PA and numerosity were also related to attention to similar degrees.

Variables Related to Overlapping Outcomes

We expected that PS and WM would relate to all outcomes and thus overlaps between all outcomes, with PA contributing to the overlap between reading and math. Numerosity was not expected to contribute to any overlap. Consistent with these hypotheses, WM contributed to each outcome (except for activity level), each pairwise overlap, and the linear combination of all three outcomes. Overall, although Peterson et al. (2017) only found relations between WM and math, this supports the role of WM as a domain-general cognitive domain associated with reading, math, and attention as well as their overlap (Moll et al., 2014; Willcutt et al., 2013). In contrast, PS was only modestly related to overlap between timed and untimed reading/math/attention and uniquely related to only timed math and attention, despite evidence implicating that PS plays an equivalent (Willcutt et al., 2013), or more prominent (Peterson et al., 2017), role than WM in overlap between these skills.

The limited role of PS in overlap between outcomes, as well as the lack of unique relation between PS and untimed academic and timed reading outcomes, was likely in part due to the

simple, nonlinguistic measure used in this study. PS is conceptualized in many ways, with some studies finding a distinction between simple and complex PS skills (Chiaravalloti, Christodoulou, Demaree, & DeLuca, 2003) or, alternatively, linguistic and nonlinguistic PS skills (Shanahan et al., 2006). Linguistic PS relates to RD, MD, and ADHD (Moll et al., 2014; Shanahan et al., 2006), but non-linguistic PS deficits have not been found in children with RD (Bonifacci & Snowling, 2008; Moll et al., 2014) or MD (Moll et al., 2014) when using relatively simple PS tasks, such as symbol scanning and cancellation. The measure of the current study (WJ Cross-Out) did not have linguistic elements that may inflate the relation between PS and reading or math outcomes. Thus, it is possible that variance shared among academic/attention outcomes are more strongly related to PS measures with verbal elements or additional complexity, while relations to simple PS measures are limited. Of note, most studies that have associated PS with comorbidity also have learning components, implying that basic learning of symbolic relations and their automaticity is more critical than simple processing speed. Future studies should systematically explore the relation of PS in LD and ADHD according to such parameters as complexity, stimulus material, and output modality.

PA accounted for overlap between reading and math, as expected, supporting the role of PA in the development of adequate reading and math abilities. This is also consistent with Peterson et al. (2017), who also found a role for verbal skills in reading and math overlap. Our results also affirmed that numerosity is a domain-specific skill that contributes to math, but not reading outcomes. Given that the relative strengths of the relations of cognitive variables differ across outcomes, however (i.e., PA was more important for reading than numerosity was for math), these strengths across outcomes should be considered in addition to the pattern of cognitions within an outcome. Contrary to predictions, both PA and numerosity exhibited relations with attention. Specifically, PA was related to overlap between outcome pairs involving attention in addition to being implicated in the overlap between all three outcomes, and significant relations were found between numerosity and attention/math overlap (Cirino, Fletcher, Ewing-Cobbs, Barnes, & Fuchs, 2007). Although unexpected, these relations among PA, numerosity, and attention are consistent with studies that have explored bidirectional relations between academic achievement and attention. In one study, improvements in attention predicted later reading and math skills, and improvements in math (but not reading) also predicted later attentional abilities (Claessens & Dowsett, 2014). Other studies have also found that attention in kindergarten significantly predicts later reading decoding skills (Dally, 2006; Rabiner & Coie, 2000), even when controlling for previous reading ability (Rabiner & Coie, 2000). Attention may limit the development of PA and numerosity skills in general, thus contributing to impaired reading and math skills, while improvements in number sense and subsequent math skills may contribute to improvements in attention. However, is also possible that Panamath task performance actually reflects visual-spatial WM or inhibitory control ability (Bugden & Ansari, 2016; Fuhs & Mcneil, 2013), both of which would be expected to relate to math and attention outcomes (St Clair-Thompson & Gathercole, 2006).

Timed Outcomes and Additional Findings

For timed outcomes PS was expected to strongly relate to both timed reading and math due to the speeded nature of these tasks, although PS did not uniquely relate to timed reading. Although it did significantly relate to timed math, it was less strongly related relative to PA and had similar strength relations as numerosity. As noted, the surprisingly weak relation of PS to timed outcomes parallels the results for untimed academic outcomes and may also be attributable to the relatively weaker predictive value of simple, nonlinguistic PS tasks for academic outcomes in general (Chiaravalloti et al., 2003; Moll et al., 2014; Shanahan et al., 2006). In addition, timed math was expected to be most strongly related to numerosity when, instead, numerosity was similarly related to PS and less strongly related relative to PA. This also echoes earlier untimed findings suggesting a significant, although not larger than other cognitive variables, relation of numerosity to math outcomes.

A majority of other timed academic results are consistent with findings already addressed, suggesting that similar cognitive abilities are required for both timed and untimed reading and math tasks. In addition, overlap did not significantly differ between untimed and timed outcomes, as expected. This may be because timed reading and math tasks are composed of simple words or math facts, while untimed reading and math tasks generally include items with a range of difficulty in order to assess the age or grade level of the child. Since the difficulty levels of these two tasks are very similar in second grade children, these findings may primarily be applicable to basic math and reading skills, regardless of the timed or untimed nature of the task, while studies in older children may find a larger discrepancy in the concomitants of the two types of task (i.e., Barnes et al., 2014; Swanson & Jerman, 2007).

A few discrepancies between the timed and untimed outcomes were evident. Although PA and numerosity related to both sets of math outcomes, WM, and not PS, were associated with untimed outcomes while timed math significantly related to PS, not WM. This may be attributable to task demands; the untimed math task involved slightly more difficult calculations as compared to the simple math problems in the timed math task, thus placing greater demands on WM abilities. In contrast, PS is more critical for the timely completion of a timed math task, although this ability is not as necessary for an untimed math task.

In general, the results with regard to activity level versus attention were also largely consistent with original predictions. Cognitive variables explained less variance overall in models with activity level as an outcome relative to models with attention and each cognitive variable individually accounted for less variance (i.e., smaller β values), suggesting that attention is more strongly associated with academic and cognitive abilities relative to activity level (McGrath et al., 2011). Consistent with the attention results (but contrary to hypotheses), PA and numerosity were significantly related to activity level. Given similar results with attention, the results from this study generally suggest a link between behavioral factors, including attention and activity level, and early cognitive skills that are foundational for later academic proficiency.

Finally, a novel finding with the second canonical variate suggests that when assessing relations between linear combinations of cognitive and academic/attention variables, a small

portion of the variance is related to a pattern of relative strengths and weaknesses. More specifically, the second academic variate, which is defined by positive correlations with math and attention skills and negative correlations with reading skills, is positively correlated with numerosity and negatively correlated with PA. Overall, this suggests that the specificity of numerosity as a predictor may increase in children with relatively strong math skills in the context of weaker reading skills, consistent with the two-factor theory of MD (Robinson et al., 2002). Given the small effect size of this finding, however, this should be further explored.

Limitations

First, each construct was defined using one variable or a composite of similar tasks from one battery. In order to improve the robustness of the results as well as verify the constructs being studied, similar future studies should use multiple measures for each construct. It would be of particular interest to consider how processing speed relates to outcomes across levels of complexity as well as in different modalities (i.e., visual vs. auditory). In addition, we used WM as a primary predictor of attention outcomes. Although using other cognitive predictors, such as inhibition, would have been informative, it is likely that attention is relatively equally predicted by multiple predictors as opposed to having one very strong predictor. Working memory measures are also more strongly related to math than inhibition (Bull & Lee, 2014), affirming that the WMTB-C tasks used here were a particularly appropriate choice for exploring overlap with math. Furthermore, the measures selected for each cognitive and academic/behavioral variable were less cognitively complex than other available measures, which may limit the generalizability of the findings and the magnitude of the individual relations found. However, this was a deliberate choice in order to provide a strong test of our hypotheses, and selecting an untimed word reading task to parallel untimed math computations as opposed to utilizing an untimed reading comprehension task rendered the reading variables more comparable to the math variables, where there is no analog to a reading comprehension measure.

Our measure of attention and activity level was a teacher-report measure, as opposed to a parent-report measure, behavioral observation, or experimental task. Since teachers interact with children in the academic setting, however, their report of a child's behavior is likely more relevant to academic performance outcomes relative to a parent report measure. In addition, teacher report measures of attention are significantly related to math and reading skills, suggesting that behavioral ratings may also be indicative of academic performance. Nonetheless, there is some evidence that teacher behavioral ratings are influenced by their perception of the child's academic functioning (Fuchs et al., 2006), so the present study may have benefited from cross-informant measures of attention (Power, Costigan, Leff, Eiraldi, & Landau, 2001). Finally, it would also be beneficial to explore relations among these cognitive and academic/behavioral variables in children who were not oversampled for math difficulties, as well as utilizing a time delay to determine if these cognitions truly predict later academic performance. Studying older children, whose timed skills are more automatized and untimed skills are more advanced, as compared to second grade children, where the difficulty levels of these measures are similar would also be valuable.

Conclusions

This study found evidence for the contribution of WM and PA to overlap between reading, math, and attention outcomes, with a surprisingly weak role of PS. We also found relations between numerosity and math/attention outcomes. In addition to empirically supporting theories that some cognitions facilitate proficiency in multiple outcomes while others are specific to one outcome (i.e., correlated liabilities model; Neale & Kendler, 1995), these results may also inform the design of future interventions (i.e., the importance of limiting WM load). Future studies will continue to explore how these findings manifest in children of different ages as well as how different conceptualizations of these constructs, such as more complex or verbal PS, affect the observed pattern of the results.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was supported by Award Number R01 HD059179, Calculations, Word Problems, and Algebraic Cognition; and Award Number P20 HD075443, Word Problems, Language, & Comorbid Learning Disabilities, from the Eunice Kennedy Shriver National Institute of Child Health & Human Development to Vanderbilt University. The content is the sole responsibility of the authors and does not necessarily represent the official views of the Eunice Kennedy Shriver National Institute of Child Health & Human Development or the National Institutes of Health.

References

- Andersson U. 2010; Skill development in different components of arithmetic and basic cognitive functions: Findings from a 3-year longitudinal study of children with different types of learning difficulties. *Journal of Educational Psychology*. 102(1):115–134. DOI: 10.1037/a0016838
- Andersson U, Lyxell B. 2007; Working memory deficit in children with mathematical difficulties: A general or specific deficit? *Journal of Experimental Child Psychology*. 96(3):197–228. DOI: 10.1016/j.jecp.2006.10.001 [PubMed: 17118398]
- Antshel, KM, Hier, BO, Barkley, RA. Executive functioning theory and ADHD. In: Goldstein, S, Naglieri, JA, editors. *Handbook of Executive Functioning*. New York, NY: Springer New York; 2014. 107–120.
- August GJ, Garfinkel BD. 1990; Comorbidity of ADHD and reading disability among clinic-referred children. *Journal of Abnormal Child Psychology*. 18(1):29–45. DOI: 10.1007/BF00919454 [PubMed: 2324400]
- Barkley RA. 1997; Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*. 121(1):65–94. [PubMed: 9000892]
- Barnes MA, Raghubar KP, English L, Williams JM, Taylor H, Landry S. 2014; Longitudinal mediators of achievement in mathematics and reading in typical and atypical development. *Journal of Experimental Child Psychology*. 119:1–16. DOI: 10.1016/j.jecp.2013.09.006 [PubMed: 24269579]
- Bellgrove MA, Hawi Z, Gill M, Robertson IH. 2006; The cognitive genetics of attention deficit hyperactivity disorder (ADHD): Sustained attention as a candidate phenotype. *Cortex*. 42(6):838–845. DOI: 10.1016/S0010-9452(08)70426-X [PubMed: 17131588]
- Berninger VW, Cartwright AC, Yates CM, Swanson HL, Abbott RD. 1994; Developmental skills related to writing and reading acquisition in the intermediate grades: Shared and unique functional systems. *Reading and Writing*. 6(1991):161–196. DOI: 10.1007/BF01026911
- Bonifacci P, Snowling MJ. 2008; Speed of processing and reading disability: A cross-linguistic investigation of dyslexia and borderline intellectual functioning. *Cognition*. 107(3):999–1017. DOI: 10.1016/j.cognition.2007.12.006 [PubMed: 18272144]

- Boonstra AM, Oosterlaan J, Sergeant JA, Buitelaar JK. 2005; Executive functioning in adult ADHD: A meta-analytic review. *Psychological Medicine*. 35(8):1097–1108. DOI: 10.1017/S003329170500499X [PubMed: 16116936]
- Brainerd CJ. 1983; Young children's mental arithmetic errors: A working-memory analysis. *Child Development*. 54:812–830.
- Branum-Martin L, Fletcher JM, Stuebing KK. 2013; Classification and identification of reading and math disabilities: The special case of comorbidity. *Journal of Learning Disabilities*. 46(6):490–9. DOI: 10.1177/0022219412468767 [PubMed: 23232442]
- Bugden S, Ansari D. 2016; Probing the nature of deficits in the “Approximate Number System” in children with persistent Developmental Dyscalculia. *Developmental Science*. 19(5):817–833. DOI: 10.1111/desc.12324 [PubMed: 26227387]
- Bull R, Johnston RS. 1997; Children's arithmetical difficulties: Contributions from processing speed, item identification, and short-term memory. *Journal of Experimental Child Psychology*. 24:1–24.
- Butterworth B. 2010; Foundational numerical capacities and the origins of dyscalculia. *Trends in Cognitive Sciences*. 14(12):534–41. DOI: 10.1016/j.tics.2010.09.007 [PubMed: 20971676]
- Capano L, Minden D, Chen SX, Schachar RJ, Ickowicz A. 2008; Mathematical learning disorder in children with attention-deficit hyperactivity disorder. *La Revue Canadienne de Psychiatrie*. 53(6)
- Catts HW, Fey ME, Tomblin JB, Zhang X. 2002 A longitudinal investigation of reading outcomes in children with language impairments. *Journal of Speech, Language, and Hearing Research*. 45Dec.: 1142–1157.
- Catts HW, Gillispie M, Leonard LB, Kail RV, Miller CA. 2002; The role of speed of processing, rapid naming, and phonological awareness in reading achievement. *Journal of Learning Disabilities*. 35(6):509–524. DOI: 10.1177/00222194020350060301 [PubMed: 15493249]
- Chen Q, Li J. 2014; Association between individual differences in non-symbolic number acuity and math performance: A meta-analysis. *Acta Psychologica*. 148:163–72. DOI: 10.1016/j.actpsy.2014.01.016 [PubMed: 24583622]
- Chhabildas NA, Pennington BF, Willcutt EG. 2001; A comparison of the neuropsychological profiles of the DSM-IV subtypes of ADHD. *Journal of Abnormal Child Psychology*. 29(6):529–40. [PubMed: 11761286]
- Chiaravalloti, ND; Christodoulou, C; Demaree, Ha; DeLuca, J. Differentiating simple versus complex processing speed: Influence on new learning and memory performance. *Journal of Clinical and Experimental Neuropsychology*. 2003.
- Cirino PT. 2011; The interrelationships of mathematical precursors in kindergarten. *Journal of Experimental Child Psychology*. 108:713–733. DOI: 10.1016/j.jecp.2010.11.004 [PubMed: 21194711]
- Cirino PT, Fletcher JM, Ewing-Cobbs L, Barnes MA, Fuchs LS. 2007; Cognitive arithmetic differences in learning difficulty groups and the role of behavioral inattention. *Learning Disabilities Research & Practice*. 22(1):25–35. DOI: 10.1111/j.1540-5826.2007.00228.x
- Cirino, PT; Fuchs, LS; Elias, JT; Powell, SR; Schumacher, RF. Cognitive and mathematical profiles for different forms of learning difficulties. *Journal of Learning Disabilities*. 2015.
- Cirino PT, Romain MA, Barth AE, Tolar TD, Fletcher JM, Vaughn S. 2013; Reading skill components and impairments in middle school struggling readers. *Reading and Writing*. 26(7):1059–1086. DOI: 10.1007/s11145-012-9406-3 [PubMed: 24000271]
- Claessens A, Dowsett C. 2014; Growth and change in attention problems, disruptive behavior, and achievement from kindergarten to fifth grade. *Psychological Science*. 25(12):2241–2251. DOI: 10.1177/0956797614554265 [PubMed: 25376191]
- Compton DL, Fuchs LS, Fuchs D, Lambert W, Hamlett C. 2012; The cognitive and academic profiles of reading and mathematics learning disabilities. *Journal of Learning Disabilities*. 45(1):79–95. DOI: 10.1177/0022219410393012 [PubMed: 21444929]
- Dally K. 2006; The influence of phonological processing and inattentive behavior on reading acquisition. *Journal of Educational Psychology*. 98(2):420–437. DOI: 10.1037/0022-0663.98.2.420
- De Smedt B, Janssen R, Bouwens K, Verschaffel L, Boets B, Ghesquière P. 2009; Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to

second grade. *Journal of Experimental Child Psychology*. 103(2):186–201. DOI: 10.1016/j.jecp.2009.01.004 [PubMed: 19281998]

- De Smedt B, Noël MP, Gilmore C, Ansari D. 2013; How do symbolic and non-symbolic numerical magnitude processing skills relate to individual differences in children's mathematical skills? A review of evidence from brain and behavior. *Trends in Neuroscience and Education*. 2(2):48–55. DOI: 10.1016/j.tine.2013.06.001
- De Smedt B, Taylor J, Archibald L, Ansari D. 2010; How is phonological processing related to individual differences in children's arithmetic skills? *Developmental Science*. 13(3):508–20. DOI: 10.1111/j.1467-7687.2009.00897.x [PubMed: 20443971]
- De Weerd F, Desoete A, Roeyers H. 2013; Working memory in children with reading disabilities and/or mathematical disabilities. *Journal of Learning Disabilities*. 46(5):461–72. DOI: 10.1177/0022219412455238 [PubMed: 22941463]
- Durand M, Hulme C, Larkin R, Snowling M. 2005; The cognitive foundations of reading and arithmetic skills in 7- to 10-year-olds. *Journal of Experimental Child Psychology*. 91(2):113–136. DOI: 10.1016/j.jecp.2005.01.003 [PubMed: 15890173]
- Feigenson L, Dehaene S, Spelke E. 2004; Core systems of number. *Trends in Cognitive Sciences*. 8(7):307–314. DOI: 10.1016/j.tics.2004.05.002 [PubMed: 15242690]
- Fletcher JM. 2005; Predicting math outcomes: Reading predictors and comorbidity. *Journal of Learning Disabilities*. 38(4):308–312. [PubMed: 16122061]
- Fuchs LS, Compton DL, Fuchs D, Paulsen K, Bryant JD, Hamlett CL. 2005; The prevention, identification, and cognitive determinants of math difficulty. *Journal of Educational Psychology*. 97(3):493–513. DOI: 10.1037/0022-0663.97.3.493
- Fuchs LS, Fuchs D. 2002; Mathematical problem-solving profiles of students with mathematics disabilities with and without comorbid reading disabilities. *Journal of Learning Disabilities*. 35(6):563–573. [PubMed: 15493253]
- Fuchs LS, Fuchs D, Compton D. 2004; Monitoring early reading development in first grade: Word identification fluency versus nonsense word fluency. *Exceptional Children*. 71(1):7–21.
- Fuchs LS, Fuchs D, Compton DL, Powell SR, Seethaler PM, Capizzi AM, ... Fletcher JM. 2006; The cognitive correlates of third-grade skill in arithmetic, algorithmic computation, and arithmetic word problems. *Journal of Educational Psychology*. 98(1):29–43. DOI: 10.1037/0022-0663.98.1.29
- Fuchs LS, Geary DC, Fuchs D, Compton DL, Hamlett CL. 2016; Pathways to third-grade calculation versus word-reading competence: Are they more alike or different? *Child Development*. 87(2):558–567. DOI: 10.1111/cdev.12474.Pathways [PubMed: 26700885]
- Fuchs, LS, Hamlett, CL, Powell, SR. Grade 3 Math Battery. 2003. Available from L. S. Fuchs, 328 Peabody, Vanderbilt University, Nashville, TN 37203
- Fuchs MW, Mcneil NM. 2013; ANS acuity and mathematics ability in preschoolers from low-income homes: Contributions of inhibitory control. *Developmental Science*. 16(1):136–148. DOI: 10.1111/desc.12013 [PubMed: 23278935]
- Geary DC. 2011; Consequences, characteristics, and causes of mathematical learning disabilities and persistent low achievement in mathematics. *Journal of Developmental and Behavioral Pediatrics: JDBP*. 32(3):250–63. DOI: 10.1097/DBP.0b013e318209edef [PubMed: 21285895]
- Grimm, LG, Yarnold, PR. Reading and understanding more multivariate statistics. Washington, DC: American Psychological Association; 2000.
- Halberda J, Ly R, Wilmer JB, Naiman DQ, Germine L. 2012; Number sense across the lifespan as revealed by a massive Internet-based sample. *Proceedings of the National Academy of Sciences of the United States of America*. 109(28):11116–20. DOI: 10.1073/pnas.1200196109 [PubMed: 22733748]
- Halberda J, Mazzocco MMM, Feigenson L. 2008 Individual differences in non-verbal number acuity correlate with maths achievement. *Nature*. 455Oct.:665–669. DOI: 10.1038/nature07246 [PubMed: 18776888]
- Hanich LB, Jordan NC, Kaplan D, Dick J. 2001; Performance across different areas of mathematical cognition in children with learning difficulties. *Journal of Educational Psychology*. 93(3):615–626. DOI: 10.1037//0022-0663.93.3.615

- Hart SA, Petrill SA, Thompson LA. 2010; A factorial analysis of timed and untimed measures of mathematics and reading abilities in school aged twins. *Learning and Individual Differences*. 20(2):63.doi: 10.1016/j.lindif.2009.10.004 [PubMed: 20161680]
- Inglis M, Gilmore C. 2014; Indexing the approximate number system. *Acta Psychologica*. 145(1):147–155. DOI: 10.1016/j.actpsy.2013.11.009 [PubMed: 24361686]
- Jacobson LA, Ryan M, Martin RB, Ewen J, Mostofsky SH, Denckla MB, Mahone EM. 2011; Working memory influences processing speed and reading fluency in ADHD. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence*. 17(3):209–224. DOI: 10.1080/09297049.2010.532204 [PubMed: 21287422]
- Jordan NC, Hanich LB. 2003; Characteristics of children with moderate mathematics deficiencies: A longitudinal perspective. *Learning Disabilities Research and Practice*. 18(4):213–221. DOI: 10.1111/1540-5826.00076
- Jordan NC, Hansen N, Fuchs LS, Siegler RS, Gersten R, Micklos D. 2013; Developmental predictors of fraction concepts and procedures. *Journal of Experimental Child Psychology*. 116(1):45–58. DOI: 10.1016/j.jecp.2013.02.001 [PubMed: 23506808]
- Kao G, Thompson JS. 2003; Racial and ethnic stratification in educational achievement and attainment. *Annual Review of Sociology*. 29(2003):417–442. DOI: 10.1146/annurev.soc.29.010202.100019
- Kasper LJ, Alderson RM, Hudec KL. 2012; Moderators of working memory deficits in children with attention-deficit/hyperactivity disorder (ADHD): A meta-analytic review. *Clinical Psychology Review*. 32(7):605–17. DOI: 10.1016/j.cpr.2012.07.001 [PubMed: 22917740]
- Koponen T, Salmi P, Eklund K, Aro T. 2013; Counting and RAN: Predictors of arithmetic calculation and reading fluency. *Journal of Educational Psychology*. 105(1):162–175. DOI: 10.1037/a0029285
- Ladson-Billings G, Madison W. 1997; It doesn't add up: African American students' mathematics achievement. *Journal for Research in Mathematics Education*. 28(6):697–708.
- Landerl K, Moll K. 2010; Comorbidity of learning disorders: Prevalence and familial transmission. *Journal of Child Psychology and Psychiatry and Allied Disciplines*. 51(3):287–294. DOI: 10.1111/j.1469-7610.2009.02164.x
- Libertus ME, Feigenson L, Halberda J. 2013; Is approximate number precision a stable predictor of math ability? *Learning and Individual Differences*. 25:126–133. DOI: 10.1016/j.lindif.2013.02.001.Is [PubMed: 23814453]
- Logie RH, Gilhooly KJ, Wynn V. 1994; Counting on working memory in arithmetic problem solving. *Memory & Cognition*. 22(4):395–410. DOI: 10.3758/BF03200866 [PubMed: 7934946]
- Lubienski ST. 2002; A closer look at black-white mathematics gaps: Intersections of race and SES in NAEP achievement and instructional practices data. *The Journal of Negro Education*. 71(4):269–287.
- Martinussen R, Grimbos T, Ferrari JLS. 2014; Word-level reading achievement and behavioral inattention: Exploring their overlap and relations with naming speed and phonemic awareness in a community sample of children. *Archives of Clinical Neuropsychology*. 29(7):680–690. DOI: 10.1093/arclin/acu040 [PubMed: 25178628]
- Martinussen R, Hayden J, Hogg-Johnson S, Tannock R. 2005; A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*. 44(4):377–84. DOI: 10.1097/01.chi.0000153228.72591.73 [PubMed: 15782085]
- Martinussen R, Tannock R. 2006; Working memory impairments in children with attention-deficit hyperactivity disorder with and without comorbid language learning disorders. *Journal of Clinical and Experimental Neuropsychology*. 28(7):1073–94. DOI: 10.1080/13803390500205700 [PubMed: 16840237]
- Mazzocco MMM, Feigenson L, Halberda J. 2011; Impaired acuity of the approximate number system underlies mathematical learning disability (dyscalculia). *Child Development*. 82(4):1224–37. DOI: 10.1111/j.1467-8624.2011.01608.x [PubMed: 21679173]
- Mazzocco MMM, Grimm KJ. 2013; Growth in rapid automatized naming from grades K to 8 in children with math or reading disabilities. *Journal of Learning Disabilities*. 46(6):517–33. DOI: 10.1177/0022219413477475 [PubMed: 23449728]

- McGrath LM, Pennington BF, Shanahan Ma, Santerre-Lemmon LE, Barnard HD, Willcutt EG, ... Olson RK. 2011; A multiple deficit model of reading disability and attention-deficit/hyperactivity disorder: Searching for shared cognitive deficits. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*. 52(5):547–57. DOI: 10.1111/j.1469-7610.2010.02346.x
- McGraw R, Lubienski S, Strutchens M. 2006; A closer look at gender in NAEP mathematics achievement and affect data: Intersections with achievement, race/ethnicity, and socioeconomic status. *National Council of Teachers of Mathematics*. 37(2):129–150. DOI: 10.2307/30034845
- Moll, K; Göbel, SM; Gooch, D; Landerl, K; Snowling, MJ. Cognitive risk factors for specific learning disorder: Processing speed, temporal processing, and working memory. *Journal of Learning Disabilities*. 2014.
- Mussolin C, Mejias S, Noël MP. 2010; Symbolic and nonsymbolic number comparison in children with and without dyscalculia. *Cognition*. 115(1):10–25. DOI: 10.1016/j.cognition.2009.10.006 [PubMed: 20149355]
- Neale MC, Kendler KS. 1995; Models of comorbidity for multifactorial disorders. *American Journal of Human Genetics*. 57(4):935–53. [PubMed: 7573055]
- Olson R, Wise B, Conners F, Rack J, Fulker D. 1989; Specific deficits in component reading and language skills: Genetic and environmental influences. *Journal of Learning Disabilities*. 22(6): 339–348. [PubMed: 2738467]
- Ostad SA. 2013; Private speech use in arithmetical calculation: Contributory role of phonological awareness in children with and without mathematical difficulties. *Journal of Learning Disabilities*. 46(4):291–303. DOI: 10.1177/0022219411419013 [PubMed: 22134964]
- Peng P, Fuchs D. 2016; A meta-analysis of working memory deficits in children with learning difficulties: Is there a difference between verbal domain and numerical domain? *Journal of Learning Disabilities*. 49(1):3–20. DOI: 10.1177/0022219414521667 [PubMed: 24548914]
- Peng P, Namkung J, Barnes M, Sun C. 2016; A meta-analysis of mathematics and working memory: Moderating effects of working memory domain, type of mathematics skill, and sample characteristics. *Journal of Educational Psychology*. 108(4):455–473. DOI: 10.1037/edu0000079
- Pennington BF. 2006; From single to multiple deficit models of developmental disorders. *Cognition*. 101(2):385–413. DOI: 10.1016/j.cognition.2006.04.008 [PubMed: 16844106]
- Peterson RL, Boada R, McGrath LM, Willcutt EG, Olson RK, Pennington BF. 2017; Cognitive prediction of reading, math, and attention: Shared and unique influences. *Journal of Learning Disabilities*. 50(4):408–421. DOI: 10.1017/CBO9781107415324.004 [PubMed: 26825667]
- Piazza M, Izard V. 2009; How humans count: Numerosity and the parietal cortex. *The Neuroscientist*. 15(3):261–273. DOI: 10.1177/1073858409333073 [PubMed: 19436075]
- Pickering, S, Gathercole, S. *Working Memory Test Battery for Children*. London: Psychological Corporation; 2001.
- Polanczyk G, de Lima MS, Horta BL, Biederman J, Rohde LA. 2007; The worldwide prevalence of ADHD: A systematic review and metaregression analysis. *The American Journal of Psychiatry*. 164(6):942–8. DOI: 10.1176/appi.ajp.164.6.942 [PubMed: 17541055]
- Polderman TJC, Derks EM, Hudziak JJ, Verhulst FC, Posthuma D, Boomsma DI. 2007; Across the continuum of attention skills: A twin study of the SWAN ADHD rating scale. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*. 48(11):1080–7. DOI: 10.1111/j.1469-7610.2007.01783.x
- Power TJ, Costigan TE, Leff SS, Eiraldi RB, Landau S. 2001; Assessing ADHD across settings: Contributions of behavioral assessment to categorical decision making. *Journal of Clinical Child Psychology*. 30(3):399–412. DOI: 10.1207/S15374424JCCP3003_11 [PubMed: 11501256]
- Pratt AC, Brady S. 1988; Relation of phonological awareness to reading disability in children and adults. *Journal of Educational Psychology*. 80(3):319–323. DOI: 10.1037//0022-0663.80.3.319
- Rabiner D, Coie JD. 2000; Early attention problems and children's reading achievement: A longitudinal investigation. *Journal of the American Academy of Child and Adolescent Psychiatry*. 39(7):859–67. [PubMed: 10892227]
- Robinson CS, Menchetti BM, Torgesen JK. 2002; Toward a two-factor theory of one type of mathematics disabilities. *Learning Disabilities Research and Practice*. 17(2):81–89. DOI: 10.1111/1540-5826.00035

- Rucklidge JJ, Tannock R. 2002; Neuropsychological profiles of adolescents with ADHD: effects of reading difficulties and gender. *J Child Psychol Psychiatry*. 43(8):988–1003. DOI: 10.1111/1469-7610.00227 [PubMed: 12455921]
- Schatschneider C, Carlson CD, Francis DJ, Foorman BR, Fletcher JM. 2002; Relationship of rapid automatized naming and phonological awareness in early reading development: Implications for the double-deficit hypothesis. *Journal of Learning Disabilities*. 35(3):245–256. [PubMed: 15493321]
- Schatschneider C, Fletcher JM, Francis DJ, Carlson CD, Foorman BR. 2004; Kindergarten prediction of reading skills: A longitudinal comparative analysis. *Journal of Educational Psychology*. 96(2): 265–282. DOI: 10.1037/0022-0663.96.2.265
- Schumacher J, Hoffmann P, Schmal C, Schulte-Körne G, Nöthen MM. 2007; Genetics of dyslexia: The evolving landscape. *Journal of Medical Genetics*. 44(5):289–97. DOI: 10.1136/jmg.2006.046516 [PubMed: 17307837]
- Shanahan MA, Pennington BF, Yerys BE, Scott A, Boada R, Willcutt EG, ... DeFries JC. 2006; Processing speed deficits in attention deficit/hyperactivity disorder and reading disability. *Journal of Abnormal Child Psychology*. 34(5):585–602. DOI: 10.1007/s10802-006-9037-8 [PubMed: 16850284]
- Snowling MJ. 2008; Specific disorders and broader phenotypes: The case of dyslexia. *Quarterly Journal of Experimental Psychology*. 61(1):142–56. DOI: 10.1080/17470210701508830
- St Clair-Thompson HL, Gathercole SE. 2006; Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *The Quarterly Journal of Experimental Psychology*. 59(4):745–759. DOI: 10.1080/17470210500162854 [PubMed: 16707360]
- Stanovich KE. 1988; Explaining the differences between the dyslexic and garden-variety poor reader: The phonological-core variable-difference model. *Journal of Learning Disabilities*. 21(10):590–604. [PubMed: 2465364]
- Swanson HL, Jerman O. 2006; Math disabilities: A selective meta-analysis of the literature. *Review of Educational Research*. 76(2):249–274. DOI: 10.3102/00346543076002249
- Swanson HL, Jerman O. 2007; The influence of working memory on reading growth in subgroups of children with reading disabilities. *Journal of Experimental Child Psychology*. 96(4):249–83. DOI: 10.1016/j.jecp.2006.12.004 [PubMed: 17437762]
- Swanson JM, Schuck S, Porter MM, Hartman CA, Sergeant JA, Clevenger W, ... Wigal T. 2012; Categorical and dimensional definitions and evaluations of symptoms of ADHD: History of the SNAP and the SWAN rating scales. *International Journal of Educational and Psychological Assessment*. 10(1):51–70. [PubMed: 26504617]
- Tannock R, Martinussen R, Frijters J. 2000; Naming speed performance and stimulant effects indicate effortful, semantic processing deficits in Attention-Deficit/Hyperactivity Disorder. *Journal of Abnormal Child Psychology*. 28(3):237–252. [PubMed: 10885682]
- Tate WF. 1997; Race-ethnicity, SES, Gender, and language proficiency trends in mathematics achievement: An update. *Journal of Research in Mathematics Education*. 28(6):652–679. DOI: 10.2307/749636
- von Aster MG, Shalev RS. 2007; Number sense and developmental dyscalculia. *Developmental Medicine and Child Neurology*. 49:868–873. [PubMed: 17979867]
- Wagner RK, Torgesen JK. 1987; The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin*. 101(2):192–212. DOI: 10.1037//0033-2909.101.2.192
- Wagner, RK, Torgesen, JK, Rashotte, CA. *Comprehensive Test of Phonological Processing*. Austin, TX: Pro-Ed; 1999.
- Weiler MD, Harris NS, Marcus DJ, Bellinger D, Kosslyn SM, Waber DP. 2000; Speed of information processing in children referred for learning problems: Performance on a visual filtering test. *Journal of Learning Disabilities*. 33(6):538–550. DOI: 10.1177/002221940003300603 [PubMed: 15495396]
- Weschler, D. *Wechsler abbreviated scale of intelligence*. San Antonio, TX: Psychological Corporation; 1999.

- Wilkinson, GS. Wide Range Achievement Test-Third Edition (WRAT-3). Wilmington, DE: Wide Range; 1993.
- Willcutt EG, Betjemann RS, McGrath LM, Chhabildas NA, Olson RK, DeFries JC, Pennington BF. 2010; Etiology and neuropsychology of comorbidity between RD and ADHD: The case for multiple-deficit models. *Cortex*. 46(10):1345–61. DOI: 10.1016/j.cortex.2010.06.009 [PubMed: 20828676]
- Willcutt EG, Doyle AE, Nigg JT, Faraone SV, Pennington BF. 2005; Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry*. 57(11):1336–46. DOI: 10.1016/j.biopsych.2005.02.006 [PubMed: 15950006]
- Willcutt EG, Nigg JT, Pennington BF, Solanto MV, Rohde La, Tannock R, ... Lahey BB. 2012; Validity of DSM-IV attention deficit/hyperactivity disorder symptom dimensions and subtypes. *Journal of Abnormal Psychology*. 121(4):991–1010. DOI: 10.1037/a0027347 [PubMed: 22612200]
- Willcutt EG, Pennington BF, Boada R, Ogline JS, Tunick RA, Chhabildas NA, Olson RK. 2001; A comparison of the cognitive deficits in reading disability and attention-deficit/hyperactivity disorder. *Journal of Abnormal Psychology*. 110(1):157–172. DOI: 10.1037//0021-843X.110.1.157 [PubMed: 11261391]
- Willcutt EG, Pennington BF, Duncan L, Smith SD, Keenan JM, Wadsworth S, ... Olson RK. 2010; Understanding the complex etiologies of developmental disorders: Behavioral and molecular genetic approaches. *Journal of Developmental and Behavioral Pediatrics*. 31(7):533–44. DOI: 10.1097/DBP.0b013e3181ef42a1 [PubMed: 20814254]
- Willcutt EG, Pennington BF, Olson RK, Chhabildas N, Hulslander J. 2005; Neuropsychological analyses of comorbidity between reading disability and attention deficit hyperactivity disorder: In search of the common deficit. *Developmental Neuropsychology*. 27(1):35–78. DOI: 10.1207/s15326942dn2701_3 [PubMed: 15737942]
- Willcutt EG, Petrill SA, Wu S, Boada R, Defries JC, Olson RK, Pennington BF. 2013; Comorbidity between reading disability and math disability: Concurrent psychopathology, functional impairment, and neuropsychological functioning. *Journal of Learning Disabilities*. 46(6):500–16. DOI: 10.1177/0022219413477476 [PubMed: 23449727]
- Willcutt EG, Sonuga-Barke EJ, Nigg JT, Sergeant JA. 2008; Recent developments in neuropsychological models of childhood psychiatric disorders. *Biological Child Psychiatry*. 24:195–226.
- Wise JC, Pae HK, Wolfe CB, Sevcik RA, Morris RD, Lovett M, Wolf M. 2008; Phonological awareness and rapid naming skills of children with reading disabilities and children with reading disabilities who are at risk for mathematics difficulties. *Learning Disabilities Research & Practice*. 23(3):125–136. DOI: 10.1111/j.1540-5826.2008.00270.x
- Wolf M, Bowers PG. 1999; The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology*. 91(3):415–438.
- Wolf M, O'Rourke AG, Gidney C, Lovett M, Cirino P, Morris R. 2002; The second deficit: An investigation of the independence of phonological and naming-speed deficits in developmental dyslexia. *Reading and Writing*. 15:43–72.
- Woodcock, R, McGrew, K, Mather, N. Woodcock-Johnson – III. Itasca, IL: Riverside Publishing; 2001.

Table 1

Correlation Matrix and Means and Standard Deviations for All Variables

	1	2	3	4	5	6	7	8	9	10
1. Untimed Reading										
2. Untimed Math	0.41 ***									
3. Timed Reading	0.76 ***	0.38 ***								
4. Timed Math	0.27 ***	0.62 ***	0.29 ***							
5. Inattention	0.45 ***	0.44 ***	0.44 ***	0.40 ***						
6. Hyperactivity	0.32 ***	0.22 ***	0.24 ***	0.22 ***	0.73 ***					
7. Phonological Awareness	0.57 ***	0.36 ***	0.46 ***	0.43 ***	0.39 ***	0.26 ***				
8. Numerosity	0.17 *	0.35 ***	0.08	0.29 ***	0.28 ***	0.23 ***	0.15 *			
9. Working Memory	0.49 ***	0.39 ***	0.44 ***	0.32 ***	0.44 ***	0.27 ***	0.51 ***	0.18 **		
10. Processing Speed	0.27 ***	0.23 ***	0.26 ***	0.27 ***	0.36 ***	0.20 **	0.16 *	0.17 **	0.39 ***	
Mean	26.19	18.79	89.73	20.40	38.13	40.18	8.13	85.93	29.37	11.03
SD	4.48	2.61	42.20	9.97	11.96	12.39	3.85	11.65	8.32	2.56

Note.

* $p < 0.05$,** $p < 0.01$,*** $p < 0.001$.

Values reflect raw data after data trimming, but prior to standardization. Untimed reading = WRAT Reading; Untimed math = WRAT Arithmetic; Timed reading = *Word Identification Fluency*; Timed math = *Math Facts Fluency Assessment*; Inattention = Inattention subscale of the Strengths and Weaknesses of ADHD symptoms and Normal behavior scale (SWAN); Hyperactivity = Hyperactivity subscale of the SWAN; Phonological awareness = *Elision* subtest of the Comprehensive Test of Phonological Processing; Numerosity = *Panamath*; Working memory = Central executive tasks from the Working Memory Test Battery for Children (WMTB-C); Processing speed = *Cross Out* task from the Woodcock-Johnson III Tests of Cognitive Abilities

Table 2**Multiple Regression Results**

		b	SE(B)	β	p	η^2
<i>Untimed Reading</i>	PA	0.51	0.07	0.44	<.001	0.19
	Numerosity	0.02	0.02	0.04	0.400	0.00
	WM	1.35	0.40	0.22	0.001	0.05
<i>Untimed Math</i>	PS	0.18	0.10	0.10	0.067	0.01
	PA	0.14	0.04	0.20	0.002	0.04
	Numerosity	0.06	0.01	0.29	<.001	0.10
<i>Inattention</i>	WM	0.81	0.25	0.22	0.002	0.04
	PS	0.06	0.06	0.06	0.330	0.00
	PA	0.05	0.02	0.22	0.001	0.05
<i>Timed Reading</i>	Numerosity	0.01	0.00	0.17	0.003	0.04
	WM	0.27	0.09	0.22	0.002	0.04
	PS	0.07	0.02	0.21	0.001	0.05
<i>Timed Math</i>	PA	0.08	0.02	0.32	<.001	0.10
	Numerosity	0.00	0.00	-0.03	0.629	0.00
	WM	0.31	0.09	0.23	0.001	0.05
<i>Hyperactivity</i>	PS	0.05	0.02	0.12	0.053	0.02
	PA	0.08	0.01	0.36	<.001	0.11
	Numerosity	0.01	0.00	0.20	0.001	0.05
<i>Hyperactivity</i>	WM	0.04	0.08	0.04	0.608	0.00
	PS	0.05	0.02	0.17	0.007	0.03
	PA	0.04	0.02	0.15	0.037	0.02
<i>Hyperactivity</i>	Numerosity	0.01	0.01	0.17	0.007	0.03
	WM	0.16	0.10	0.12	0.107	0.01
	PS	0.04	0.02	0.10	0.139	0.01

Note. PA = phonological awareness; WM = working memory; PS = processing speed; b = unstandardized regression coefficient; β = standardized regression coefficient; η^2 = eta-squared, a measure of effect size

Table 3

Zero-Order, Partial Correlations, and Changes in r^2 between Untimed and Timed Outcome Variables after Controlling for Cognitive Predictor Variables

	PA				Numerosity				WM				PS			
	r	r^2	pr	pr^2	Change in r^2	pr	pr^2	Change in r^2	pr	pr^2	Change in r^2	pr	pr^2	Change in r^2		
<i>Untimed</i>																
Reading & Math	0.41***	0.17	0.27***	0.07	-0.10	0.39***	0.15	-0.02	0.28***	0.08	-0.09	0.38***	0.14	-0.03		
Reading & Inattention	0.45***	0.21	0.31***	0.09	-0.11	0.43***	0.19	-0.02	0.31***	0.09	-0.11	0.40***	0.16	-0.05		
Math & Inattention	0.44***	0.20	0.35***	0.13	-0.07	0.39***	0.15	-0.04	0.33***	0.11	-0.09	0.40***	0.16	-0.04		
<i>Timed</i>																
Reading & Math	0.29***	0.08	0.12	0.01	-0.07	0.28***	0.08	-0.01	0.18**	0.03	-0.05	0.24***	0.06	-0.03		
Reading & Inattention	0.44***	0.19	0.32***	0.10	-0.09	0.43***	0.19	0.00	0.30***	0.09	-0.10	0.38***	0.15	-0.04		
Math & Inattention	0.40***	0.16	0.28***	0.08	-0.08	0.35***	0.12	-0.04	0.30***	0.09	-0.07	0.34***	0.11	-0.05		

Note.

* $p < 0.05$,** $p < 0.01$,*** $p < 0.001$.

r = correlation; r^2 = squared correlation, or proportion of variance shared; pr = partial correlation; pr^2 = squared partial correlation, or proportion of variance shared after controlling for cognitive predictor variable; Change in r^2 = difference between r^2 and pr^2 ($pr^2 - r^2$), or proportion of shared variance accounted for by cognitive predictor variable

Table 4

Canonical Correlation Results for Untimed Outcomes and Inattention

Cognitive Variables	Cognitive Variate 1	Cognitive Variate 2	Outcome Variate 1	Outcome Variate 2
PA	0.83	−0.45	0.58	−0.13
Numerosity	0.42	0.80	0.29	0.22
WM	0.80	0.01	0.56	0.00
PS	0.50	0.24	0.35	0.07
Outcome Variables				
Untimed reading	0.61	−0.13	0.88	−0.47
Untimed math	0.49	0.15	0.71	0.55
Inattention	0.53	0.09	0.76	0.31

Note. PA = phonological awareness; WM = working memory; PS = processing speed. See note for Table 2 for measures used to assess academic/attention variables (i.e., untimed reading)

Table 5

Canonical Correlation Results for Timed Outcomes and Inattention

Cognitive Variables	Cognitive Variate 1	Cognitive Variate 2	Outcome Variate 1	Outcome Variate 2
PA	0.82	−0.27	0.56	−0.06
Numerosity	0.42	0.83	0.29	0.19
WM	0.77	−0.31	0.52	−0.07
PS	0.58	0.21	0.39	0.05
Outcome Variables				
Timed reading	0.50	−0.16	0.74	−0.67
Timed math	0.50	0.09	0.75	0.38
Inattention	0.54	0.06	0.81	0.25

Note. PA = phonological awareness; WM = working memory; PS = processing speed. See note for Table 2 for measures used to assess academic/attention variables (i.e., untimed reading)