A COGNITIVE DIMENSIONAL APPROACH TO UNDERSTANDING COMORBIDITY AMONG READING DISABILITY, MATH DISABILITY, AND ATTENTION-DEFICIT/HYPERACTIVITY DISORDER

A Master's Thesis

Presented to

The Faculty of the Department

of Psychology

University of Houston

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Arts

By

Amanda Child

December, 2015

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Abstract

Reading disability (RD), math disability (MD), and attention-deficit/hyperactivity disorder (ADHD) are common disorders that frequently co-occur in school-aged children. However, it is not yet clear which cognitive factors contribute to the comorbidities between the three disorders and which cognitions are uniquely related to one disorder. Thus, the present study considers how reading, math, and attention outcomes are related to PA, numerosity, WM, and PS. In response to findings that all three disorders exist on a continuum as opposed to representing groups that are fundamentally different from the normative population, this study employed a dimensional approach. Furthermore, in order to elucidate how the cognitive predictors relate to different methods of assessing math and reading ability, both timed and untimed academic outcomes were utilized. Inattention as well as hyperactivity outcomes were also considered. Results from this study support the role of working memory and phonological awareness in the comorbidities between reading, math, and attention outcomes, with a limited role of processing speed. Numerosity was also found to be related to the comorbidity between math and inattention. Results from timed outcomes and hyperactivity were generally similar to those with untimed and inattention outcomes, although hyperactivity was less strongly related to academic and attention outcomes in general. These findings have implications for understanding cognitive deficits that contribute to comorbidities between RD, MD, and ADHD.

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A Cognitive Dimensional Approach to Understanding Comorbidity among Reading Disability, Math Disability, and Attention-Deficit/Hyperactivity Disorder

Disorders of learning and attention are common in childhood. For example, the prevalence of reading disability (RD) is estimated to be between 5 and 12% (Schumacher, Hoffmann, Schmäl, Schulte-Körne, & Nöthen, 2007), the prevalence of mathematics disability (MD) is about 7% (Geary, 2011), and the prevalence of attention-deficit hyperactivity disorder (ADHD) is about 5% (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007). There is substantial phenotypic comorbidity between RD and ADHD (e.g., August & Garfinkel, 1990; Semrud-Clikeman et al., 1992; Willcutt & Pennington, 2000), between RD and MD (e.g., Badian, 1999; Knopik, Alarcón, & DeFries, 1997; Landerl & Moll, 2010), and between MD and ADHD (e.g., Capano, Minden, Chen, Schachar, & Ickowicz, 2008; Gross-Tsur, Manor, & Shalev, 1996), although there is less information regarding this latter comorbidity relative to the others. To date, much of the research focused on the behavioral correlates of these comorbidities has focused on RD and its relationships with MD (e.g. Ashkenazi, Black, Abrams, Hoeft, & Menon, 2013; Branum-Martin, Fletcher, & Stuebing, 2013; De Weerdt, Desoete, & Roeyers, 2013; Fuchs & Fuchs, 2002; Willcutt et al., 2013), or with ADHD (e.g. Shanahan et al., 2006; Willcutt, Betjemann, et al., 2010; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005).

Therefore, the present study aims to fill this gap by expanding our knowledge through identifying correlates of comorbidities between RD, MD, and ADHD from the perspective of the math development and MD literature. Specifically, we aim to delineate the roles of phonological awareness (PA), number sense, and working memory (WM; which have been associated with RD, MD, and ADHD, respectively) as well as processing speed (PS; a domain general ability) within math, reading, and behavioral inattention comorbidities, considering continuous symptomatology rather than categorical diagnoses. Doing so will elucidate shared and unique cognitive factors associated with each of these disorders, better informing our understanding of them, and potentially helping to inform the design and implementation of interventions for children with comorbid conditions. In addition, both timed and untimed outcome measures of math and reading will be used in order to determine if the relation between the cognitive predictor measures and academic outcome measures varies as a function of the timing characteristics of the outcomes.

Timed vs. Untimed Measures of Reading and Math

Within the learning disabilities literature, few studies have differentiated between timed versus untimed reading and math measures when quantifying overall reading or math ability. For example, with regards to reading, some authors use untimed word or passage reading measures or reading comprehension measures to estimate reading ability (Catts, Fey, Tomblin, & Zhang, 2002; Kirby, Parrila, & Pfeiffer, 2003; Pratt & Brady, 1988; Wise et al., 2008) while others use a combination of timed (e.g. fluency-based) and untimed measures (Olson, Wise, Conners, Rack, & Fulker, 1989; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002). However, 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).

With regards to mathematics, math achievement is often measured using untimed measures requiring students to solve calculations (i.e. Compton, Fuchs, Fuchs, Lambert, & Hamlett, 2012; Mazzocco et al., 2011; Mazzocco & Grimm, 2013) and/or word problems (i.e. Branum-Martin et al., 2013; Compton et al., 2012). However, these tasks fail to assess the automaticity of math fact retrieval, and in fact, math fluency deficits have been shown to be a core feature associated with MD (Hanich, Jordan, Kaplan, & Dick, 2001; Jordan, Hanich, & Kaplan, 2003; Jordan & Hanich, 2003; Jordan & Montani, 1997), likely because poor fluency of basic math facts limits the cognitive and executive resources available to perform more difficult mathematics operations (Pellegrino & Goldman, 1987). While some researchers recognize the importance of math fact fluency on mastery of mathematical concepts and, as a result, its likely role in the development of MD, relatively few studies have actually looked at math fact fluency as a primary outcome measure indexing mathematics achievement (Locuniak & Jordan, 2008). Therefore, this study will explore whether timed and untimed measures share similar relations with the cognitive predictors within the reading and math domains.

Comorbidity Models

Numerous models of comorbidity have been proposed in an attempt to explain why certain disorders co-occur. RD/ADHD (e.g., Dykman & Ackerman, 1991; Gilger, Pennington, & DeFries, 1992; Semrud-Clikeman et al., 1992; Shaywitz, Fletcher, & Shaywitz, 1995; Willcutt & Pennington, 2000), MD/RD (e.g., Badian, 1999; Knopik et al., 1997; Kovas et al., 2007; Landerl & Moll, 2010), and MD/ADHD (Capano, Minden, Chen, Schachar, & Ickowicz, 2008) have been shown to co-occur at rates that far exceed what would be expected by chance alone (e.g. between 15 and 40% for RD/ADHD) given that these disorders each occur in between 5 and 12% of the population (Geary, 2011; Polanczyk et al., 2007; Schumacher et al., 2007). Models that explain these high rates of comorbidity between MD/RD/ADHD are 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 unique etiological influences account for the distinction between the disorders. These models are supported by genetics studies (Monuteaux, Faraone, Herzig, Navsaria, & Biederman, 2005; Willcutt, Pennington, et al., 2010) in addition to studies that have found cognitive deficits, including deficits in PS, that are present to varying degrees in all three disorders (Willcutt, Sonuga-Barke, Nigg, & Sergeant, 2008; Willcutt, Pennington, et al., 2010) alongside other deficits are more unique to each disorder, including phonology and rapid naming for reading, numerosity for math, and a number of candidates for ADHD. These are reviewed below.

Phonological Awareness and Reading

Phonological awareness, defined as the detection and manipulation of individual phonemes of spoken language, is theorized to be causally related to reading skill acquisition (Durand, Hulme, Larkin, & Snowling, 2005; Wagner & Torgesen, 1987) and has consistently been identified as a cognitive deficit associated with RD (e.g., Catts, Fey, Tomblin, & Zhang, 2002; Olson, Wise, Conners, Rack, & Fulker, 1989; Stanovich, 1988). PA abilities have been found to be similarly predictive of both timed and untimed reading outcomes (Schatschneider et al., 2002; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004), suggesting that PA is equally important for reading fluency as well as untimed reading abilities.

PA may also have a role in the development of mathematical proficiency (e.g. Cirino, 2011; Fuchs et al., 2005, 2006; Koponen et al., 2007; Krajewski & Schneider, 2009; Simmons & Singleton, 2008), particularly for children with comorbid MD and RD. One hypothesis relating PA to the development of arithmetical skill posits that accurate phonological representations of arithmetic terms and operators in WM are necessary for long-term encoding of math facts (e.g. Brainerd, 1983; Logie, Gilhooly, & Wynn, 1994). This is consistent with studies that found relations between PA and math fact retrieval of small problems (De Smedt, Taylor, Archibald, & Ansari, 2010; Fuchs et al., 2005) as well as findings that individual differences in performance on single-digit arithmetic tasks are mediated by the quality of long-term phonological representations in children (De Smedt et al., 2010).

With regard to the relation between PA abilities and untimed versus timed math outcomes, studies have found that PA abilities are a unique predictor of performance on math computations, but not math fluency, tasks in elementary school children (Hecht, Torgesen, Wagner, & Rashotte, 2001; Martin, Cirino, Sharp, & Barnes, 2014), suggesting that PA is more strongly related to untimed measures of math performance as compared to timed measures. This somewhat conflicts with the role of PA in MD/RD comorbidity put forth by Robinson, Menchetti, and Torgesen (2002), who hypothesize that children with comorbid MD/RD have weak phonological processing skills (and potentially weak number sense as well) while MD-only children solely possess weak number sense abilities. The authors posit that when number facts are taught orally (i.e. repeating math facts as a group until the fact recitation becomes automatic), children with intact PA abilities learn connections between the string of phonological representations that make up the number fact. This later facilitates recall of the fact's solution (Dehaene & Cohen, 1995, 1997; Robinson et al., 2002). However, children with PA deficits are hypothesized to have more difficulties with learning math facts in this manner because their phonological representations of numbers are weak. Consequently, these children have difficulties in both reading and math (Robinson et al., 2002). However, given the empirical evidence supporting a stronger role of PA in untimed math tasks, this study expects to find stronger relationships between PA and untimed math measures as well as between PA and the comorbidity between untimed measures of math and reading relative to timed measures.

Empirical support for the hypothesis that PA difficulties underlies the comorbidity between MD and RD is somewhat mixed: Some studies have found that PA is uniquely associated with RD, and not MD or MD/RD (Willcutt et al., 2013), while others have found phonological deficits in children with MD and/or MD/RD (Cirino, Fuchs, Elias, Powell, & Schumacher, 2015; De Weerdt et al., 2013; Ostad, 2013). With regard to ADHD, there does not appear to be a relationship between PA deficits and ADHD symptomatology (Willcutt, Betjemann, et al., 2010); thus, PA should be unrelated to any comorbidities involving ADHD symptomatology.

Numerosity and Mathematics

One of the most basic numerical skills that is present in a variety of species (e.g., macaques, Brannon & Terrace, 2000; dolphins, Kilian, Yaman, von Fersen, & Güntürkün, 2003; lions, McComb, Packer, & Pusey, 1994) involves gauging the relative or approximate magnitude, or numerosity (Butterworth, 2010; Piazza & Izard, 2009), of sets of items. Though less widely researched than the link of phonology with RD, there is evidence that this number sense ability is key for the development of mathematical proficiency in children (Butterworth, 2010; Halberda, Mazzocco, & Feigenson, 2008; Robinson et al., 2002). More specifically, the Approximate Number System (ANS) is hypothesized to be activated when estimating or comparing larger (i.e. larger than 4) numerosities (Feigenson, Dehaene, & Spelke, 2004). Later in development, verbal and symbolic representations of exact quantities (i.e. digits) are theorized to map onto preexisting representations of numerosity stored in the

ANS, thus facilitating mathematical proficiency (von Aster & Shalev, 2007). An alternate number system is theorized to be activated when determining the precise magnitudes of small numbers of objects (between 1 and 4 objects in adults), or subitizing (Feigenson et al., 2004).

ANS acuity is often assessed by having children compare numerosities of two sets of objects, like dots (e.g. Cirino, 2011; Mazzocco, Feigenson, & Halberda, 2011) or sticks (Mussolin, Mejias, & Noël, 2010), and judge which set has a greater number of objects. A child's ability to accurately assess which set has more objects is ratio-dependent, with larger ratios being easier to detect as compared to smaller ratios (Mussolin et al., 2010). In addition to studies that have found significant associations between ANS acuity and performance on math tasks (Halberda et al., 2008), studies have also found evidence of ANS deficits (as indicated by relatively poor performance on this type of task) in children with MD (Mazzocco et al., 2011; Mussolin et al., 2010). While there are links between the ANS and mathematical proficiency, it is not clear precisely how ANS deficits contribute to MD. There is evidence that children with MD exhibit deficits in the mapping between number words and the ANS relative to children without MD (Mazzocco et al., 2011; Rousselle & Noël, 2007); however, the origin of these mapping deficits are unknown. For example, it is possible that domain general abilities, like WM, affect the accuracy of the mapping (Mazzocco et al., 2011). Alternatively, it may be the case that children with MD have deficits in either the processing of the symbolic number (Noël & Rousselle, 2011) or in the ANS itself (Butterworth, 2005; Landerl, Bevan, & Butterworth, 2004), either of which would disrupt the process of mapping number words onto the ANS.

Although not all studies have found a consistent relation of ANS acuity with mathematics performance (e.g. Jordan et al., 2013), Chen and Li (2014) conducted a meta-analysis using data from a range of articles that assessed non-symbolic number acuity and mathematics ability across development. In addition to finding that number acuity and symbolic math performance were significantly correlated when combining results from cross-sectional studies ($r = 0.20$), they also determined that previous studies that had not found a relationship between the two variables likely did not find significant results due to small sample sizes. In addition, their meta-analysis of longitudinal studies in the literature revealed that ANS acuity is both prospectively and retroactively correlated to mathematics performance, suggesting that number acuity influences the development of mathematics performance while mathematics performance also shapes number acuity (Chen & Li, 2014).

When considering timed and untimed math outcome measures separately, studies have found relations between symbolic (Locuniak & Jordan, 2008) and nonsymbolic (Mazzocco et al., 2011) number sense and performance on math fluency tasks. With regards to nonsymbolic number sense specifically, Mazzocco et al. (2011) found that in ninth grade students, ANS acuity is significantly related to children's accuracy on difficult math fluency items where students were instructed to perform all calculations in their heads, but was not related to a timed math task where students were permitted to utilize other strategies (i.e. counting on their fingers) to solve the problems. This study also found significant, and stronger, relations between ANS acuity and earlier performance on untimed calculations tasks, suggesting that numerosity is more strongly related to untimed versus timed math outcomes. This is likely because timed tasks generally require children to retrieve math fact solutions from memory rather than use skills (such as magnitude assessment) to solve the problem, particularly for older children.

Very little research has explored the possibility of numerosity deficits in children with RD or ADHD. There is some evidence that children with RD also experience deficits in measures of foundational numerical competency, including numerosity, relative to children in the control group, although these deficits were not as strong as those observed in children with MD or MD/RD (Cirino et al., 2015). However, the measures of numerosity used in that study featured Arabic numerals and other linguistic components, and the use of symbolic materials may have impacted the performance of children with RD. Therefore, evaluating the extent to which numerosity is a relevant or overlapping factor for reading is perhaps best considered with less symbolic materials (e.g., nonsymbolic/dot comparison). There is no theoretical reason to expect that numerosity per se would be an important contributor to reading and math comorbidities. Similarly, there are no known studies that examine the role of numerosity in the comorbidity among reading and attentional symptomatology, and therefore none are expected.

Working Memory and Attention

There are numerous cognitive correlates of ADHD; some of the more common include executive functions (i.e. response inhibition, planning, set shifting, WM) (Barkley, 1997; Boonstra, Oosterlaan, Sergeant, & Buitelaar, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), sustained attention (Barkley, 1997; Bellgrove, Hawl, Gill, & Robertson, 2006), and PS (Chhabildas, Pennington, & Willcutt, 2001; Rucklidge & Tannock, 2002; Weiler, Bernstein, Bellinger, & Waber, 2000; Willcutt, Pennington, et al., 2005). Of the executive functions, WM in particular plays a prominent role in many models of ADHD, and there is strong empirical support that a variety of measures of WM are implicated in ADHD. For example, Barkley posits that behavioral inhibition, self-awareness, and WM (particularly nonverbal) all develop together and, as a result, are all primary deficits found in children with ADHD (Antshel, Hier, & Barkley, 2014). Other models posit that WM functions as a primary deficit leading to behavioral inhibition (Rapport, Chung, Shore, & Isaacs, 2001) or as a cognitive endophenotype (Castellanos & Tannock, 2002)

However WM relates to theoretical models of ADHD, it is clear that it plays an important role in ADHD symptomatology. At the empirical level, numerous studies support the role of WM in ADHD (Barnett et al., 2001; Kempton et al., 1999; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, et al., 2005). For example, a meta-analysis by Willcutt, Doyle, Nigg, Faraone, and Pennington (2005) found that WM, particularly spatial WM, had one of the strongest effect sizes between ADHD and non-ADHD children, suggesting that this cognitive ability is an appropriate measure of ADHD. Similarly, meta-analyses conducted by Martinussen et al. (2005) and Kasper, Alderson, and Hudec (2012) also found evidence that children with ADHD exhibit WM deficits relative to children without ADHD. While some studies have found no evidence for WM deficits in children with ADHD, these studies have generally used auditory or verbal WM tasks, which seem to be less strongly related to ADHD as compared to spatial WM (Castellanos & Tannock, 2002; Pennington & Ozonoff, 1996).

This study hypothesizes that WM will be most strongly related to measures of attention, though there is also evidence for associations between WM and reading (Jacobson et al., 2011; Moll, Göbel, Gooch, Landerl, & Snowling, 2014; Swanson & Jerman, 2006, 2007; Willcutt et al., 2013) as well as with math (Moll et al., 2014; Swanson & Jerman, 2006; Willcutt et al., 2013). Furthermore, verbal WM has been implicated in the comorbidity between reading and math (Moll et al., 2014; Willcutt et al., 2013). Relations between WM and untimed math (Barnes et al., 2014) and reading (Swanson & Jerman, 2007) outcomes have been found to be stronger than relations with timed outcomes. Thus, it is likely that WM will be implicated in the comorbidities between attention, reading, and math.

Processing Speed and Reading, Math, and Attention

Deficits in processing speed, or the speed with which simple tasks are completed with reasonable accuracy (Case, 1985), have been found in children with a wide range of disorders that are associated with cognitive and academic difficulties. Children with RD (Shanahan et al., 2006; Willcutt, Pennington, et al., 2005; Willcutt et al., 2008), ADHD (Shanahan et al., 2006; Willcutt, Pennington, et al., 2005; Willcutt et al., 2008), comorbid RD/ADHD (Tannock, Martinussen, & Frijters, 2000; Willcutt, Pennington, et al., 2005), MD (Andersson & Lyxell, 2007; Willcutt et al., 2008; Willcutt, Pennington, et al., 2010), and comorbid MD/RD (Andersson, 2010) have also been shown to exhibit PS deficits. This evidence linking PS to cognitive and academic performance is consistent with a conceptualization of PS put forth by Kail and Salthouse (1994), which proposes that PS abilities facilitate or enhance a wide range of cognitive processes.

It is worth noting that PS as a construct is not well defined and, as a result, researchers measure PS in different ways (Shanahan et al., 2006). For example, some authors choose to use simple reaction time tasks as an indicator of speed of processing (e.g. Snowling, 2008; Weiler et al., 2000), particularly in very young children, while others utilize more complex speeded tasks that require higher-level cognitive processing in addition to perceptual processing as an indicator of PS ability (i.e. naming speed or executive speed tasks; Shanahan et al., 2006). While increasing the complexity of the speeded task may increase the correlation between the task and the target cognitive or academic variable (i.e.

reading ability), 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. Thus, the current study will utilize a task that minimizes reliance on cognitive abilities other than PS.

With regard to reading, children are believed to read familiar words by retrieving the pronunciation from long-term memory, and PS appears to affect the speed and accuracy of this retrieval (Christopher et al., 2012). The role of PS in reading is echoed in the Double Deficit Hypothesis of RD, which posits that naming speed deficits strongly contribute to RD symptomatology in conjunction with PA deficits (Wolf & Bowers, 1999; Wolf et al., 2002). This hypothesis is supported by empirical studies (Mazzocco & Grimm, 2013) as well as a meta-analysis (Araújo, Reis, Petersson, & Faísca, 2014) that have found rapid automatized naming (RAN) deficits in children with RD across a range of ages. There is also evidence for non-linguistic PS deficits in children with RD, suggesting that children with RD possess PS deficits that are independent of phonological deficits (Shanahan et al., 2006). Furthermore, there is evidence that RAN correlates most strongly with reading fluency measures and is also related, albeit to a lesser degree, to word recognition outcomes as well (Bowers, 2001).

RAN deficits (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Mazzocco & Grimm, 2013) and non-linguistic PS deficits (Willcutt et al., 2013) are also evident in children with MD. PS is thought to be related to math ability because it can affect a person's ability to match current stimuli to representations stored long term memory as well as to utilize information in WM. For example, when solving familiar arithmetic problems, children often retrieve the answer directly from long-term memory (Bull & Johnston, 1997); however, slowed PS appears to affect the efficiency and accuracy of this retrieval process (Christopher et al., 2012). Similarly, when solving unfamiliar arithmetic problems, PS likely affects how quickly children can count numbers in the problem, thus raising the possibility that information will decay in WM before solving the problem (Fuchs et al., 2008; Geary, 1993).

PS deficits have also been found in children with ADHD (Tannock et al., 2000) and have been shown to be one of the best predictors of inattentive symptomatology in ADHD (Chhabildas et al., 2001). The cognitive-energetic model of ADHD (Sergeant, 2005) proposes that the slower and less consistent reaction times that are evident in children with ADHD are a result of cognitive under-arousal (Sergeant, 2005; Shanahan et al., 2006). This model is supported by meta-analytic results that found slower and more variable reaction times in children with ADHD on Go trials of the stop-signal task (Alderson, Rapport, & Kofler, 2007) as well as EEG studies that have found evidence for cortical under-arousal in children with ADHD (Clarke et al., 2003).

With regard to the underlying causes of MD, RD, and ADHD comorbidity, Willcutt, Pennington, et al. (2010) reviewed results from multivariate twin analyses and found that genetic factors relating to PS may underlie the comorbidity between these three disorders. Although this genetic evidence suggests that PS deficits may contribute to comorbidity between the three disorders, a majority of cognitive research in PS has considered these disorders individually, with the exception of a few studies that have looked at PS deficits in children with comorbidities between RD and ADHD (Peterson et al., in press; Tannock et al., 2000; Willcutt, Pennington, et al., 2005) as well as between MD and RD (Andersson, 2010; Willcutt et al., 2013). However, while these studies all found PS deficits in the children with comorbid conditions, none have addressed relations between PS and dimensional measures of math, reading, as well as attention. In addition, when considering academic outcomes, PS is expected to be more strongly related to timed outcome measures of reading and math as compared to the untimed outcome measures due to the speeded nature of the timed tasks.

Defining MD, RD, and ADHD

In addressing these comorbidities, it is crucial to consider the ways in which the above disabilities are defined. Researchers have frequently defined MD and RD using cut points (i.e. children who score below the 25^{th} percentile on a mathematics measure have MD). More recently, though, LD researchers are approaching MD and RD by looking at mathematics and reading abilities on a continuum as opposed to artificially creating groups. This philosophical change is in part due to evidence that risk for RD (Kovas et al., 2007; Willcutt, Pennington, et al., 2010), MD (Kovas et al., 2007; Willcutt, Pennington, et al., 2010), and ADHD (Levy, Hay, McStephen, Wood, & Waldman, 1997) arise from multiple genetic and environmental risk factors that are generally responsible for normal variation throughout the population (Kovas et al., 2007; Plomin & Kovas, 2005). Thus, children with these disorders appear to represent extremes of a normal distribution as opposed to being qualitatively different than children without these disorders. In addition, from a methodological perspective, when cognitive profiles are compared between LD and no LD groups, any profile differences may be an artifact of cut points and the correlational nature of the data as opposed to reflecting true group differences (Branum-Martin et al., 2013). Thus, the present study takes a dimensional perspective on these disorders. Instead of forming groups based on cutoffs and looking for group differences, we focus on attempting to explain relationships among outcome measures of reading, math, and behavioral attention symptomatology. In addition, given that inattention and hyperactivity have been shown to be distinct constructs (Willcutt et al., 2012), hyperactivity outcomes will be considered as well as inattention outcomes in order to better understand cognitive deficits associated with each symptom dimension of ADHD.

Current Study

In sum, the literature provides evidence for relations between phonology and both reading and math, numerosity and math, WM and ADHD symptomatology, and PS and all three outcome variables. However, what are less clear are the potential roles of PA, numerosity, WM, and PS in the overlap *among* math, reading, and attention abilities. Addressing these gaps will help elucidate why MD, RD, and ADHD are highly comorbid with each other (i.e. shared underlying cognitive deficits) as well as why they also occur in isolation (i.e. distinct cognitive deficits associated with one or two of the disorders). In addition, much of the existing comorbidities research focuses on children who are in third grade and above(Fuchs & Fuchs, 2002; Willcutt, Pennington, et al., 2005; Willcutt et al., 2001). Exploring these relations in second grade children will fill a gap in the literature and provide more insight into cognitions that play a role earlier in the development of these disorders.

In addition, a majority of studies looking at these disorders have utilized a categorical approach to identifying children with MD, RD, and/or ADHD (e.g. Fuchs & Fuchs, 2002; Geary, Bailey, Littlefield, Wood, & Hoard, 2010; Martinussen & Tannock, 2006), although recent evidence suggests that issues can arise from studying these dimensional disorders using a categorical approach (Branum-Martin et al., 2013). By taking a dimensional approach with this study, findings from previous studies exploring the relationships between the aforementioned cognitions and disorders using a categorical approach can be reevaluated and discrepancies and consistencies with previous results can be explored. Furthermore, many studies have not distinguished between timed and untimed measures when assessing reading or math abilities (e.g. Hecht et al., 2001), despite differences between the two. Evaluating both types of outcome measures and their overlaps will allow for the assessment of relations between cognitive deficits and each specific type of outcome measure will be better understood. In addition, the implications for choosing one type of outcome measure over another will be clearer for future research endeavors. Given previous research that has found differences in academic performance based on race/ethnicity, sex, socioeconomic status, primary language, and age (Kao & Thompson, 2003; Ladson-billings & Madison, 1997; Lubienski, 2002; McGraw, Lubienski, & Strutchens, 2006; Tate, 1997), all of these variables will be evaluated as potential covariates.

Ultimately, the goal of this research is to further understand the pattern of deficits of children with comorbid disorders and determine clearer targets for direct intervention, or ameliorating the adverse effects of the deficits in the context of content-based intervention design. Clarifying the cognitive characteristics of comorbid disorders and how they relate to timed and untimed methods of assessing academic ability may also aid in diagnoses, even if indirectly. Children are often referred for difficulties in one particular area, but it is also important to recognize when they may be at risk for deficits in other areas as well. The outcome of this study also has theoretical implications, such as exploring if PA is associated with the overlap between reading and math, but not math specifically, as is specified by the two-factor theory of MD (Robinson et al., 2002).

Hypotheses

We utilized four approaches to evaluate the differential contribution of predictors across outcomes, and the extent to which outcome overlap is due to their associated relations with predictors. These types of analysis have previously been used to explore comorbidities: partial correlations (Shanahan et al., 2006), multivariate regression analyses, multiple regression analyses (Willcutt et al., 2013), and canonical regression analyses (Swanson, 2012); however, each analysis provides a unique perspective on the relationship between the predictor (cognitive) and outcome (academic and behavioral) variable sets. Partial correlation analyses are the most direct approach to assessing cognitions related to comorbidities between math, reading, and attention. These analyses determine the degree to which the relationship between two outcome variables decreases after controlling for variance attributable to a given predictor variable. However, additional information can be obtained by assessing different combination of predictor and outcome variables. Multiple regression analyses evaluate the influence of predictor variables on a given outcome, in the context of all predictors; in contrast, multivariate regression analyses evaluate the relative roles of predictor(s) on one outcome versus another outcome. Finally, canonical analyses address relationships among variable sets, and decompose individual variable contributions within and across set; this approach is ideal for determining which predictors likely underlie the comorbidity between all three outcomes.

Hypothesis 1: Partial Correlations. Predictors reduce correlations among outcomes. The first analytic approach will utilize partial correlation analyses. If the partial correlation between two outcome variables is significantly reduced relative to the first order correlation when controlling for a predictor variable, this suggests that the predictor variable helps account for the overlap between the outcome variables (i.e. comorbidity). With these analyses, other predictors are not controlled for (i.e., partialled) when exploring the effects of a particular predictor variable, nor will the effects of each predictor variable be directly compared to other predictors. Hypotheses are the same for timed and untimed academic outcomes. Greater decreases are expected for inattention relative to hyperactivity, where significant relations are predicted (Chhabildas et al., 2001; Martinussen & Tannock, 2006).

1. We hypothesize that the correlation between reading and math will be significantly reduced after accounting for variance attributable to PA (De Smedt et al., 2010), WM (Moll et al., 2014; Willcutt et al., 2013), and PS (Willcutt et al., 2013). In contrast, numerosity will not significantly reduce the correlation between these two outcome variables.
2. We predict that the correlation between reading and behavioral inattention will be significantly reduced after controlling for the effects of PS (McGrath et al., 2011; Shanahan et al., 2006; Willcutt et al., 2008; Willcutt, Betjemann, et al., 2010) and WM (Willcutt et al., 2008). PA (McGrath et al., 2011; Willcutt, Betjemann, et al., 2010) and numerosity are not expected to significantly affect the correlation.
3. We hypothesize that the correlation between math and attention will be significantly reduced after controlling for WM and PS. PA and numerosity are not expected to significantly affect the correlation.

Hypothesis 2: Multiple Regression. Outcomes have different patterns of significant predictors. The second analytic approach selected is multiple regression analyses. This type of analysis determines the relative importance of cognitive predictor variables in the context of one another, for each outcome separately.

1. For untimed reading outcomes, we hypothesize that PA will be the strongest significant predictor (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994; Willcutt et al., 2013), followed by WM (Berninger et al., 1994; Willcutt et al., 2013)

and PS (Shanahan et al., 2006; Willcutt et al., 2013). For timed reading, PS is expected to be the strongest predictor of timed reading outcomes (Schatschneider et al., 2004), followed by PA (Schatschneider et al., 2004) and WM (Jacobson et al., 2011). Numerosity is not expected to be a significant predictor of (untimed or timed) reading.

2. For untimed math, numerosity is expected to be the strongest significant predictor, 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). For timed math outcomes, numerosity is expected to be the strongest predictor, followed by PS, WM, and PA.
3. For behavioral attention, WM (Martinussen et al., 2005; Willcutt, Doyle, et al., 2005) and PS (Shanahan et al., 2006; Willcutt, Doyle, et al., 2005; Willcutt et al., 2008) are hypothesized to be a strong predictor. Neither phonological awareness (Fletcher, 2005; Martinussen, Grimbos, & Ferrari, 2014) nor numerosity are expected to be significant. For hyperactivity as an outcome, no predictors are expected to be significant, including PS (Chhabildas et al., 2001) and WM (Martinussen & Tannock, 2006).

Hypothesis 3: Multivariate Regression. Predictive strength varies across outcomes. The third analytic approach utilized in this study is multivariate regression analyses, which can examine the relative strength of a given predictor for one outcome relative to another while controlling for the effects of other predictors. All predictors and all outcomes are in the models. While including all predictors versus solely the predictor of interest does affect multivariate results since this controls for the other predictors, multivariate effects are not affected by having all outcomes in the model as opposed to just the outcome of interest.

1. PA is hypothesized to significantly predict reading (e.g., Catts, Fey, Tomblin, & Zhang, 2002; Olson, Wise, Conners, Rack, & Fulker, 1989; Stanovich, 1988) and math (De Smedt et al., 2010; Fuchs et al., 2005), with significantly stronger predictions for reading versus math. No relation is expected between PA and inattention/hyperactivity (McGrath et al., 2011; Willcutt, Betjemann, et al., 2010), and both academic outcomes are expected to be more strongly predicted versus inattention and hyperactivity. This same pattern is expected for both timed and untimed reading and math outcomes, although the relation between PA and academic outcomes is expected to be similar for untimed relative to timed reading (Schatschneider et al., 2002, 2004) and stronger for untimed relative to timed math outcomes (Fuchs et al., 2005).
2. We hypothesize that numerosity will significantly predict untimed math outcomes (Cirino, 2011; Mazzocco et al., 2011; Mussolin et al., 2010) as well as timed outcomes (Locuniak & Jordan, 2008). Numerosity is expected to be significantly more predictive of untimed relative to timed math outcomes (Mazzocco et al., 2011). No relation is expected between numerosity and reading or inattention/hyperactivity outcomes; thus, direct comparisons are expected to find stronger relations with math versus timed/untimed reading, inattention, and hyperactivity.
3. WM is expected to similarly predict attention outcomes (Willcutt, Doyle, et al., 2005), math (Moll et al., 2014; Swanson & Jerman, 2006; Willcutt et al., 2013) and reading (Jacobson et al., 2011; Moll et al., 2014; Swanson & Jerman, 2006, 2007;

Willcutt et al., 2013) outcomes and be a significantly less strong predictor of hyperactivity (Martinussen & Tannock, 2006). In addition, the relation is expected to be stronger between WM and untimed math (Barnes et al., 2014) and reading (Swanson & Jerman, 2007) outcomes as compared to timed outcomes.

4. We expect to find that PS is significantly related to reading (Moll et al., 2014; Shanahan et al., 2006; Willcutt et al., 2008), math (Willcutt et al., 2008), and attention (Shanahan et al., 2006; Willcutt et al., 2008) outcomes. No significant relations are expected with hyperactivity (Chhabildas et al., 2001). In addition, relations are expected to be stronger between PS and timed math and reading outcomes relative to untimed outcomes.

Hypothesis 4: Canonical Relations. The set of predictors relates to the set of outcomes, with some predictors more relevant than others. The final analyses selected are canonical analyses. This type of analysis assesses relationships between linear combinations of predictor and outcome variable sets such that correlations between predictor and outcome variates are maximized. Results will elucidate which cognitive variables are predictive of the comorbidity between reading, math, and attention.

1. We hypothesize that PS and WM will be most strongly related to an outcome variate that is strongly correlated with reading, math, and inattention outcomes (Willcutt et al., 2008). PA and numerosity are not expected to be related to the outcome variate.

Methods

Participants

233 second grade children were included in this study. The average age of the participants is 7.58 (*SD* = 0.40), although the ages for three children were missing. Forty eight percent of the children are female, and 85% received reduced or free lunch at school.

Forty percent do not speak English as their primary language, but all were instructed in English. With regards to ethnicity, 35% are black, 29% are Hispanic, 29% are Caucasian, and 7% are of another ethnicity. Participants were from the fourth cohort of a larger study in Nashville, TN selected from a number of schools and classrooms. Only this cohort received all the requisite measures evaluated in this study. All participants met a cutoff of >2nd percentile on the Wechsler Abbreviated Scales of Intelligence (WASI; Wechsler, 1999). Participants for this cohort 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), although the means for both measures across all four cohorts of the parent study were similar (e.g., Fuchs et al., 2013). However, there is still good variability in both math and reading performance.

Predictor Variables

PA was measured using the *Elision* task from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgeson, & Rashotte, 1999). In this task, subjects are given a word and asked to repeat the word without one of its sounds (i.e. say “blend” without saying “l”). The subject is initially asked to remove a syllable, and as the subtest progresses, is asked to remove a phoneme. The removed sound varies with regards to where it appears in the word (i.e. rime, onset, middle) and the resulting word is always a real word. As reported by the test developer, the coefficient alpha for 7-year-old children is 0.91.

Numerosity was assessed using the *Panamath* task (Halberda et al., 2008). During this task, participants are presented with series of dots arrays. Each array appears on the screen for 1382 ms and displays between 5 and 21 yellow dots on the left side of the screen and between 5 and 21 blue dots on the right side of the screen. The dots vary in size. Participants are asked to judge which side of the screen displays more dots as quickly as possible. A high-pitched tone (indicating a correct response) or a low-pitched tone (indicating an incorrect response) played immediately after participants pressed a key. One particular advantage of this task is its nonsymbolic and nonverbal design. Many numerosity tasks include either letters or numbers that introduce a symbolic element to the task (i.e. Geary et al., 2010); however, *Panamath* relies solely on nonsymbolic blue and yellow dots. In addition, the task progresses too quickly for students to count the dots, thus ensuring that it measures the ability to approximate quantities as opposed to counting ability (Faulkenberry & Geye, 2014). ANS acuity is typically assessed either with the Weber fraction, which indicates a child's ability to discriminate between two numerosities, or percent correct on the task. Given that both methods of assessing performance on this task are highly correlated with each other (r = -0.85 to -0.87; Libertus, Feigenson, & Halberda, 2014) and accuracy has been shown to be a more reliable outcome variable relative to the Weber fraction (Inglis & Gilmore, 2014), percent correct will be used for this study. Previous studies have reported split-half reliabilities ranging 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 < 50ms or > 7000 ms in addition to accuracy below 50%, or chance).

WM was measured using the three central executive tasks from the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001). These tasks collectively assess the child's ability to remember and manipulate information in WM. All subtests contained six items with spans from 1-6 to 1-9 and children progressed to the next span level after passing four items at the current level. The subtest was stopped when three items were failed at a span level. For Listening Recall, children listen to a series of short sentences and decide if each sentence is true or false. After listening to all of the sentences in a trial, the student recalls the last word of each sentence in order in which they were presented. One point is earned for each correctly recalled sequence of words. For Counting Recall, children are presented with 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 are asked to recall the number of dots presented on each card in the order in which they were presented. For Backward Digit Recall, students listen to the examiner read a list of numbers. After each list, students are then asked to reproduce the list in reverse order. For all subtests, total number of correct trials was the variable selected for use in analyses. The three WMTB-C subtest intercorrelations ranged $r = 0.26$ to 0.31. The subtests were combined into one total score by standardizing the raw score of each subtest relative to the sample mean and averaging the subtest z-scores. Per the test developer, 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).

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, and 60 rows are available. Credit is given when both matching symbols are circled. Total number of correct items was used in the analyses. As reported by the test developer, reliability is 0.72 for 7-year-olds.

Outcome Variables

Untimed math abilities was assessed using the Arithmetic subtest from the Wide Range Achievement Test (WRAT-3; Wilkinson, 1993). This measure assesses a range of computational processes, from symbolic comparison and counting to written arithmetic. Raw scores were used in analyses. Reliability for 7 year 6 month old children is 0.95 (Wilkinson, 1993).

WRAT-3 Reading was used to evaluate untimed reading abilities. This measure assesses a range of reading abilities, from letter identification to reading words and non-words of increasing difficulty. Raw scores were used in analyses. Within this age range, reliability for both the Reading and Arithmetic measures was about 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 measures from the *Math Facts Fluency Assessment* (Fuchs, Hamlett, & Powell, 2003). Included in this study are four speeded measures of addition and subtraction. Each subtest allows students 1 minute to solve as many items as possible, and 25 items are included on each subtest. Both single- and double-digit addition and subtraction problems were included given that previous studies have found accuracy rates between 26 and 72% on complex addition problems in first grade children with and without MD, respectively (Geary, Hoard, Byrd-Craven, & DeSoto, 2004), and at 30% for 2nd grade children (Locuniak & Jordan, 2008), suggesting that floor effects are likely not a concern. Variables included in analyses were total number of problems correct on each subtest.

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 $r = 0.88$. The raw score (i.e., total number of words read correctly) of 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 inattention (Swanson et al., 2006). The eighteen items on this measure directly correspond 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 ensuring a normal distribution of scores in the population (Polderman et al., 2007; Swanson et al., 2006). In these analyses, the nine items corresponding to inattention and the nine items corresponding to hyperactivity/impulsivity will be considered separately, per literature that supports the distinction of the two scales (Willcutt et al., 2012). Higher scores indicate lower levels of inattentiveness or hyperactivity. Test/retest reliability of the SWAN was found to be 0.76 (Lakes, Swanson, & Riggs, 2012) and Cronbach's alpha was 0.95 in preschool age children (Lakes et al., 2012). In older children, Cronbach's alpha was 0.95 (Piek et al., 2007).

Analyses

As previously described, partial correlations, multiple regression analyses, multivariate regression analyses, and canonical regression analyses were utilized to assess the relationships between the predictor and outcome variables. For all analyses, the variables were assumed to be linearly related and have normally distributed residuals. In addition, homoscedasticity of the data and homogeneity of variance were assumed.

Partial regression residual plots were analyzed to assess for linearity in multiple and multivariate regression analyses. Graphical evaluation of the residual plots were all consistent with linear relations. In order to assess for normality of residuals, Q-Q plots were consulted. Overall, Anderson-Darling tests of normality were nonsignificant, consistent with Q-Q plots that displayed normal distribution of residuals. All regression results met the assumption for homoscedasticity of the data, as evidenced by visual analysis of residuals plots. Outliers with high leverage as compared to other data points were identified for each analysis by plotting squared residuals against leverage. Analyses were conducted with and without these outliers, and because the pattern of results did not change, outliers were included in all analyses.

In order to determine appropriate covariates to consider, demographic variables were analyzed with respect to their correlations to predictor and outcome variables. Originally, age, reduced/free lunch status, primary race, primary language, and sex were considered. All covariates with the exception of age were significantly correlated with at least 3 predictor or outcome variables; thus, the effects of reduced/free lunch status, race, language, and sex were considered in all subsequent analyses. Because age was unrelated to the outcome variables (likely due to restricted range), it was not considered in future analyses.

The analyses utilized three composites, for WM, timed math, and timed reading. For WM, the three WMTB-C subtest intercorrelations ranged $r = 0.26$ to 0.31; for timed math, the Math Facts Fluency Assessment subtests intercorrelations ranged $r = 0.38$ to 0.80; and for timed reading, *Word Identification Fluency* subtests correlated $r = 0.88$. Composites were created by standardizing the raw score of each subtest relative to the sample mean and averaging the subtest z-scores.

For correlation and multiple regression analyses, outcomes were raw scores or the sample-standardized composites noted above (though results were not different when standard scores were used where available). For multivariate regression analyses, all outcomes were sample-standardized in order to compare contributions of predictors across outcomes. This is necessary so that b values for a given predictor can be compared across multiple dependent variables simultaneously.

The final set of analyses presented are canonical correlations. Canonical correlations evaluate relations between two sets of variables; the maximum number of canonical functions is determined by the number of variables in the smallest set (Thompson, 2000), though not all canonical functions need be significant. Each function is a linear combination of variables (called variates) that maximizes their relationship with one another. This is not the same as a given variate representing the variance that is shared among all the variables within a set, but addresses the allied issue of the overlap between predictors and outcomes. When multiple canonical functions are extracted, they are orthogonal to one another. In the present case, the maximum number of canonical functions is three (as there are three primary outcomes, and four predictors).

Results are presented below. For partial correlation, multiple regression, and canonical correlation analyses, results for untimed academics and inattention are presented first, as these are the primary focus of this study. Then, effects of utilizing timed as opposed to untimed outcomes are explored. Third, results with hyperactivity/impulsivity as opposed to inattention are included. Finally, the role of covariates is considered. For multivariate regression, all results for a given predictor are presented before introducing the subsequent predictor given that many comparisons in the multivariate results involve outcomes from multiple domains (i.e., timed and untimed).

Results

Partial Correlation Analyses

Table 1 shows zero-order correlations among all variables, as well as means and standard deviations. Correlations between outcome variables (timed and untimed) were all significant and ranged from $r(231) = 0.22, p = 0.001$, to $r(231) = 0.76, p < 0.001$.

-Insert Table 1 about here-

Table 2 shows zero-order correlations for untimed academics and inattention with each other, as well as the strength of these same correlations when each of the four predictor variables is partialled. Also presented is the proportion of variance shared among each pair of outcomes (with nothing partialled), followed by variance shared with a given predictor partialled, and the difference between those values. As predicted, PA contributed to the comorbidity between untimed reading and math. For example, walking through the first line in Table 2, untimed reading and math correlate 0.41 (17% overlap), and this correlation is reduced to 0.27 (8% overlap) when PA is partialled, resulting in an absolute change in shared variance of 10%. Also as predicted, partialling for WM also resulted in decreases in the correlation, $pr = 0.28$ (8% overlap), and variance shared between the outcomes (9% decrease). While PS was hypothesized to also contribute to overlap between the outcomes, controlling for PS resulted in a minimal reduction in the correlation, $pr = 0.38$(3% decrease in shared variance). As expected, controlling for numerosity did not result in substantial reductions in the untimed reading and math correlation, *pr* = 0.37 (2% decrease in shared variance).

-Insert Table 2 about here-

Untimed reading and inattention correlate 0.46 (21% overlap), which, as expected, is reduced after controlling for WM, *pr* = 0.31 (11% decrease in shared variance). Contrary to hypotheses, only minor reductions were found after controlling for PS, *pr* = 0.40 (5% decrease in shared variance), and more substantial reductions were found after controlling for PA, *pr* = 0.31 (11% decrease in shared variance). Smaller decreases were observed after controlling for numerosity (2% decrease in shared variance), consistent with predictions.

Untimed math and inattention correlate 0.44 (20% overlap), which, as expected, is reduced after controlling for WM, *pr* = 0.33 (9% decrease). While decreases were found after controlling for PS, *pr* = 0.40 (4% decrease), a more significant role of this cognition 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 is analogous to Table 2, but presents results for timed (rather than untimed) academics. Original hypotheses posited similar results with both timed and untimed outcomes; however, with timed outcomes, decreases in r^2 due to WM were smaller for all comorbidities, now accounting for 5% to 10% of the shared variance (as compared to 9 to 11% for untimed outcomes). Decreases in shared variance after controlling for other predictor variables for timed academics (PA, numerosity, and PS) were similar to those found for untimed academics.

-Insert Table 3 about here-

Finally, Table 4 is analogous to Tables 2 and 3, but presents timed and untimed results with the hyperactivity/impulsivity (rather than inattention) scale of the SWAN. As expected, the trend was for zero-order correlations to be lower between hyperactivity and academic skill, relative to those of inattention. Furthermore, reductions in shared variance were also lower for comorbidities involving hyperactivity (ranging from 2% to 5%) relative to inattention (ranging from 0% to 11%).

-Insert Table 4 about here-

Finally, inclusion of covariates (race/ethnicity, primary language, sex, and reduced/free lunch status) did not substantively change the pattern or general level of results, although in a few cases, smaller decreases in r^2 were observed after including covariates; the largest such decrease was for PS being partialled out of the (untimed) reading and math relationship (from 3% reduction without covariates, and 1% reduction with covariates). In addition, due to the potential role of general language ability on performance on cognitive tasks (Fletcher et al., 1996), partial correlation analyses were also conducted while controlling for performance on a vocabulary measure in addition to the predictor variable (i.e., PA). This did not affect the pattern of results.

Multiple Regression Analyses

Multiple regression results appear in Table 5, with all cognitive variables included as predictors for each outcome. The overall model for untimed reading was significant, $F(4, 228) = 36.82$, $p < 0.001$, $R^2 = 0.39$. Unique predictors of untimed reading included PA, $p < 0.001$, and WM, $p = 0.001$. The overall untimed math model was significant, $F(4, 228) = 21.03$, $p < 0.001$, $R^2 = 0.27$, and was also uniquely predicted by PA, $p = 0.002$, and WM, $p = 0.002$, but also numerosity, $p = 0.002$. Inattention also had a significant overall model, F(4,

228) = 25.24, $p < 0.001$, $R^2 = 0.31$. Inattention was significantly predicted by all of the cognitive predictors, $p = 0.001$ to $p = 0.003$.

-Insert Table 5 about here-

Prediction of timed outcomes appears in Table 6. The pattern of unique predictive variables was consistent for timed versus untimed reading, although R^2 values were less 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 predictor, $p = 0.007$, whereas WM was not a unique predictor, $p = 0.608$; 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.

-Insert Table 6 about here-

Results for hyperactivity (also Table 6), showed that instead of all predictors showing a unique contribution, now only PA, $p = 0.037$, and numerosity, $p = 0.007$, remained significant. The overall model, , $F(4, 228) = 8.75$, $p < 0.001$, $R^2 = 0.13$, was weaker relative to the model for inattention ($R^2 = 0.31$).

Including covariates did not significantly change the results of any multiple regression analyses. That is, when race/ethnicity, primary language, sex, and reduced/free lunch status were added to each of the models, the same set of predictors remained. However, adding covariates aacross the six models, R^2 values for the full models did increase an average of R^2 =0.07 (range from 0.02 to 0.12). In addition, controlling for vocabulary in addition to all other predictors did not affect the results.

Multivariate Regression Analyses

Multivariate regression results appear in Table 7. For these analyses, models included all predictor cognitive variables as well as all outcomes; thus, the results compare the contribution of each predictor across multiple outcomes while controlling for the effects of the other predictors. Including covariates in the model did not change any results. In multivariate regression, results for any given outcome are highly similar to those of multiple regression; relationships among outcomes do not impact relative predictor contribution (other than where individuals have missing data). However, the key contribution of these analyses is the ability to directly statistically compare the role of a given predictor for one outcome relative to another – the determination of whether a predictor is a unique contributor to a given outcome can be found in the multiple regression section.

-Insert Table 7 about here-

As predicted, PA was significantly more predictive of untimed reading than each of the other outcomes [untimed math, $F(4, 226) = 8.88$, $p = 0.003$; timed reading, $F(4, 226) = 6.15$, $p = 0.014$; inattention, $F(4, 226) = 8.23$, $p = 0.005$]. Contrary to our original hypotheses, we did not find a stronger contribution of PA to timed reading relative to timed math, instead finding no difference, $F(4, 226) = 0.23$, $p = 0.634$. PA was however more strongly predictive of timed relative to untimed math, $F(4, 226) = 5.49$, $p = 0.020$. No differences were found in the relation of PA to untimed math versus inattention, $F(4, 226) = 0.03$, $p = 0.860$, timed math versus inattention, $F(4, 226) = 2.76$, $p = 0.098$, and timed reading versus inattention, $F(4, 226) = 1.51$, $p = 0.220$. Results were largely consistent when considering hyperactivity instead of inattention, with the exception of PA more strongly predicting timed math as compared to hyperactivity, $F(4, 226) = 4.89$, $p = 0.028$.

Contrary to predictions, numerosity was not significantly more predictive of untimed relative to timed math, $F(4, 226) =2.69$, $p = 0.102$. However, as expected, numerosity was more predictive of untimed math as compared to untimed reading, $F(4, 226) = 10.78$, $p =$

0.001, as well as timed math relative to timed reading, $F(4, 226) = 7.93$, $p = 0.005$. No differences were found for the contribution of numerosity to untimed math relative to inattention, $F(4, 226) = 3.00$, $p = 0.085$, and timed math to inattention, $F(4, 226) = 0.14$, $p = 0.709$, despite predictions that math outcomes would be more strongly predicted versus inattention. Hyperactivity results were consistent with inattention results.

As predicted, WM was similarly (and significantly) predictive of untimed reading vs. inattention, $F(4, 226) = 0.01$, $p = 0.098$, untimed math vs. inattention, $F(4, 226) = 0.02$, $p = 0.894$, and untimed math vs. reading, $F(4, 226) = 0.00$, $p = 0.984$. Also consistent with predictions, WM was a stronger predictor of untimed math versus timed math, $F(4, 226) = 7.47$, $p = 0.007$. However, no difference was found when comparing untimed vs. timed reading, $F(4, 226) = 0.00$, $p = 0.951$. No differences were noted when hyperactivity was included in comparisons instead of inattention.

Contrary to what we hypothesized, PS was not significantly more predictive of timed versus untimed reading, $F(4, 226) = 0.14$, $p = 0.708$, or timed versus untimed math, $F(4, 226) = 3.11$, $p = 0.079$.

Canonical Correlation Analyses

Canonical correlation analyses evaluate relations between two sets of variables. Since our smallest set of variables (in this case, outcome variables) consisted of three variables, three canonical functions were produced, each consisting of two canonical variates (one academic and one cognitive) generated such that canonical correlations (i.e., correlations between variates in a function) are maximized. However, we only had hypotheses regarding a dominant canonical function. We were primarily interested in the magnitude of the overall relationship, as well as how the individual predictor variables contributed to the outcome variate.

First, the significance of the three canonical variates were 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 are 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, and the findings from these variates are the focus of the results presented below.

Various statistics were considered in order to assess the interpretability of the canonical correlation results. The correlation between the first set of canonical variates is 0.70 and, consequently, the first canonical function accounts for 49% of variance shared between the cognitive (or predictor) and academic (or outcome) variates (i.e., canonical R^2). The second canonical correlation is 0.28 and accounts for 8% of shared variance.

Tables 8 and 9 provide correlations between the cognitive predictor and untimed academic outcome variables and the cognitive and academic canonical variates. First, contributions of the outcome (academic) 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 inattention, $r = 0.76$, indirectly supporting the hypothesis that all three outcomes were related to one another. Furthermore, consistent with hypotheses, this academic variate was also 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 academic variate; while this relation was not hypothesized, it is consistent with other analyses. Numerosity, $r = 0.29$, also correlated with the first academic variate, which was not expected.

-Insert Table 8 about here-

-Insert Table 9 about here-

Secondary results, for the first cognitive variate, showed that it was strongly and positively correlated with PA and WM, with more moderate positive relations with numerosity and PS. The first cognitive variate was also positively correlated similarly with untimed reading, untimed math, and inattention (see Table 8).

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

Results for the second cognitive variate are highly consistent with results from the second academic variate, with positive relations to math and attention as well as negative relations to reading. In addition, this variate was defined by a strong, positive correlation to numerosity and a strong, negative correlation to PA, alongside smaller and positive relations to PS, and WM. However, the effect size was small for this canonical function.

Tables 10 and 11 display results with timed as opposed to untimed academic outcomes, and Tables 12 and 13 portray results for hyperactivity instead of inattention. 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 hyperactivity instead of inattention or when covariates were included in the model.

-Insert Table 10 about here-

-Insert Table 11 about here-

-Insert Table 12 about here-

-Insert Table 13 about here-

Discussion

The overall aim of this study was to determine shared cognitive factors underlying comorbidities between RD, MD, and ADHD as well as to elucidate cognitive factors that are unique to one disorder. While previous studies have considered these disorders in isolation or in pairs, no known published studies have looked at all three disorders together; considered reading, math, and attentional abilities on a dimensional scale; and compared academic timed and untimed outcomes as well as inattention and hyperactivity outcomes. Findings relating predictors to individual outcomes are considered first, followed by comorbidity-related findings. Finally, additional findings, including results from timed outcomes and hyperactivity, are discussed.

Predictors Relating to Individual Outcomes

We originally hypothesized that PA would be the strongest predictor for reading, numerosity would most strongly predict math, and WM would be the strongest predictor for attention. As expected, PA was the strongest predictor of untimed reading outcomes, consistent with a wealth of literature emphasizing the importance of PA in reading skill development (e.g., Catts, Fey, Tomblin, & Zhang, 2002; Olson, Wise, Conners, Rack, & Fulker, 1989; Stanovich, 1988).

However, our predictions regarding the degree to which numerosity and WM would relate to math and attention were only partially supported. While numerosity did significantly predict untimed math and failed to predict reading outcomes, supporting its role as a foundational skill that contributes to 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, instead of representing the primary cognition associated with math outcomes (analogous to PA for reading), it was a more equitable, though still significant, predictor relative to other cognitions. However, this finding of significant, but not large, relations between nonsymbolic number sense and math performance is consistent with meta-analytic findings by Chen and Li (2014), in addition to their assertion that assessment of number sense alone is likely not significant to identify significant math problems in school age children.

Similarly, while WM was significantly related to attention outcomes along with PS, as expected (Martinussen et al., 2005; Shanahan et al., 2006; Willcutt, Doyle, et al., 2005; Willcutt et al., 2008), PA and numerosity were also predictive of attention to similar degrees. The implications of these findings are explored in more depth below.

Predictors Relating to Multiple Outcomes

We originally expected to find that PS and WM would relate to all outcomes and, thus, all comorbidities, with PA contributing to the overlap between reading and math. Numerosity was not expected to contribute to comorbidities. Consistent with these hypotheses, WM did contribute to each individual outcome (with the exception of hyperactivity), each pairwise comorbidity, and the linear combination of all three outcomes. Overall, this supports existing literature suggesting that WM is a candidate for a domain-general cognition contributing to the development of RD, MD, and ADHD as well as their comorbidities (Moll et al., 2014; Willcutt et al., 2013). In contrast, PS was only modestly related to timed and untimed reading/math/inattention comorbidities and solely uniquely predicted timed math and inattention (although findings approached significance with timed reading, $p = 0.053$), despite evidence implicating that PS plays an equivalent role as WM (Willcutt et al., 2013), if not stronger (Peterson et al., in press), in these comorbidities.

The limited role of PS in comorbidities found here, 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 chosen for this study. Our findings are consistent with previous literature that also failed to find non-linguistic PS deficits in children with RD (Bonifacci & Snowling, 2008; Moll et al., 2014) or MD (Moll et al., 2014) while using relatively simple PS tasks (i.e., symbol scanning and cancellation). While other studies have found significant relations between PS and academic outcomes, these studies generally utilized tasks that included a linguistic component or were more complex (Shanahan et al., 2006); however, the WJ Cross-Out task was selected for this study due to the lack of linguistic elements that may inflate the relation between PS and reading or math outcomes. Thus, it is possible that comorbidities between academic/attention outcomes are more strongly predicted by PS measures with verbal elements or additional complexity, while relations to simple PS measures are limited. This is congruent with prior research that has found that PS as it is typically conceptualized loads onto two factors representing simple vs. complex PS skills (Chiaravalloti, Christodoulou, Demaree, & DeLuca, 2003). In addition, there is also evidence that linguistic and nonlinguistic PS tasks load onto separate factors (Shanahan et al., 2006), with stronger relations of linguistic relative to nonlinguistic PS to MD/RD comorbidity (Moll et al., 2014). These findings collectively suggest that PS as it is typically defined can, in fact, be subdivided into a number of constructs that relate to academic/attention outcomes in unique ways. This has implications for how PS is conceptualized in future LD and ADHD comorbidity studies.

PA accounted for overlap between reading and math, as expected, supporting the role of this cognition in the development of adequate reading and math abilities. In addition, our results affirmed that numerosity is a domain-specific skill that contributes to math, but not reading outcomes, although given that the relative strengths of the predictors differ across outcomes (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 predictors within an outcome. However, both cognitions exhibited relations with inattention that were not originally hypothesized. Specifically, PA was related to comorbidities involving inattention in addition to being implicated in the comorbidity between all three outcomes, and significant relations were found between numerosity and the comorbidity between inattention and timed/untimed math (Cirino, Fletcher, Ewing-Cobbs, Barnes, & Fuchs, 2007). These unexpected relations between PA, numerosity, and attention are consistent with studies that have explored potential bidirectional relations between academic achievement and attention. One such study found that improvements in attention predict later reading and math skills, in addition to improvements in math (but not reading) predicting later attentional abilities (Claessens & Dowsett, 2014). Other studies have also found that inattention in kindergarten significantly predicts later reading decoding skills (Dally, 2006; Rabiner & Coie, 2000), even when controlling for previous reading ability (Rabiner & Coie, 2000). Collectively, these results suggest that inattention 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, given the limitations of this study (i.e., the design was not longitudinal, and the models were designed to assess if cognitions predict academic outcomes and not the reverse), this interpretation should be considered with caution.

Additional Findings

When considering timed relative to untimed outcomes, PS was expected to be a strong predictor for both timed reading and math due to the speeded nature of these tasks. However, PS did not uniquely predict timed reading and, while it did significantly predict timed math, it had lower predictive value relative to PA and was similarly predictive as numerosity. This surprisingly weak relation of PS to timed outcomes parallels results for untimed academic outcomes and may also be attributable to 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 predicted by numerosity when, instead, numerosity was similarly predictive to PS and less predictive than PA. This also echoes earlier untimed findings suggesting a significant, although not larger than other cognitive predictors, relation of numerosity to math outcomes.

A majority of other timed academics results are consistent with findings already addressed, suggesting that overall, similar cognitive abilities are required for both timed and untimed reading and math tasks. Specifically, there are no differences in the predictive value of numerosity, WM, or PS when considering untimed versus timed math and reading outcomes. In addition, comorbidity results did not significantly differ between untimed and timed outcomes, as expected. This may, in part, be attributable to the fact that the 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 appropriately assess the age or grade level of the child. In second grade children, however, the discrepancy between the difficulty levels of these two tasks is relatively small or nonexistent. Thus, 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 cognitions predicting the two types of task (i.e., Barnes et al., 2014; Swanson & Jerman, 2007).

However, a few discrepancies between the two sets of outcomes are evident. While both timed and untimed math outcomes are predicted by PA and numerosity, untimed outcomes are predicted by WM, and not PS, while timed math is predicted by PS, not WM. Analyses also confirm that WM is more strongly predictive of untimed versus timed outcomes, and while there is not a significant difference in PS's role for these outcomes, results suggest a larger role for timed versus untimed math. These findings 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, while this ability is not as necessary for an untimed math task.

In general, results with regards to hyperactivity as compared to inattention are also largely consistent with original predictions. Overall, cognitive predictors explained less variance overall in models including hyperactivity as an outcome relative to models with inattention in addition to each cognitive predictor individually accounting for less variance (i.e., smaller β values), suggesting that inattention is generally more strongly associated with other academic abilities as well as cognitive predictors relative to hyperactivity (McGrath et al., 2011). Consistent with inattention results (although contrary to hypotheses), PA and numerosity were significantly related to hyperactivity. Given similar results with inattention, results from this study generally suggest a link between behavioral factors, including inattention and hyperactivity, and early cognitive skills that are foundational for later academic proficiency.

Finally, when considering the second canonical variate, a novel finding suggests that a small portion of the variance when assessing relations between linear combinations of predictor and outcome variables is related to a pattern of relative strengths and weaknesses. More specifically, the second academic outcome 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

Limitations should be considered when reviewing the results of the study. First of all, this sample had a higher concentration of children with lower math than reading scores (see Table 1). However, while it would be ideal to have a sample of children with relatively equivalent math and reading skills, there was still significant variability in math outcomes in this study.

In addition, each cognition and outcome explored was defined using one variable. In order to improve the robustness of the results as well as verify the constructs being studied, future studies should explore these research questions using similar domains, but including multiple measures of each construct and employing latent variable analysis to ensure the measures do, in fact, load onto the same construct. In addition, we chose to use WM as a primary predictor of inattention outcomes; while using or including other cognitions, such as inhibition, would have been informative, it is likely that ADHD is relatively equally predicted by multiple predictors as opposed to primarily having one very strong predictor.

Furthermore, the measures selected for each cognition and academic outcome were more simplistic than many other available measures (i.e., selecting a simple non-linguistic PS task rather than a PS task that required higher-order levels of cognition). On the one hand, this 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 form of our hypotheses. In addition, 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.

In terms of our measure of inattention and hyperactivity, some limitations arise. First of all, this measure was a teacher-report measure, as opposed to a parent-report measure, direct behavioral observation, or experimental task, and it was the only indicator of these behaviors. However, given that teachers interact with children in the academic setting, their report of a child's inattentive or hyperactive behavior is likely more relevant to their academic performance outcomes as opposed to a parent report measure. In addition, the findings that teacher report measures of inattention are significantly related to many other variables, including math and reading skills, suggests that behavioral ratings may also be indicative of academic performance. Nonetheless, future studies could explore the relative value of multiple informants regarding these relations.

Finally, this study focused on 2nd grade children, which may have limited the gap in difficulty between the timed and untimed reading and math tasks selected and, thus, limited our ability to detect potential differences in performance between tasks as well as patterns of relations between predictors and outcomes. While the results still provide valuable insight into the relations between predictors and outcomes in this age range, it would also be beneficial to explore these relations in older children where timed skills are more automatized and untimed skills are more advanced.

Conclusions

In spite of the aforementioned limitations, this study found evidence for the contribution of WM and PA to comorbidities between reading, math, and attention outcomes, with a surprisingly weak role of PS. Relations were also found between numerosity and math/inattention outcomes. These results help to elucidate how cognitive deficits can predispose children to multiple learning disabilities in addition to informing 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 results.

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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

Zero-Order, Partial Correlations, and Changes in r^2 between Untimed 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
Untimed Reading & Math	0.41***	0.17	0.27***	0.08	-0.10	0.39***	0.15	-0.02	0.28***	0.08	-0.09	0.38***	0.14	-0.03
Untimed 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
Untimed 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

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 3

Zero-Order, Partial Correlations, and Changes in r^2 between 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
Timed Reading & Math	0.29***	0.09	0.12	0.01	-0.07	0.28***	0.08	-0.01	0.18**	0.03	-0.05	0.24***	0.06	-0.03
Timed Reading & Inattention	0.44***	0.19	0.32***	0.10	-0.09	0.44***	0.19	0.00	0.31***	0.09	-0.10	0.38***	0.15	-0.05
Timed Math & Inattention	0.40***	0.16	0.28***	0.08	-0.08	0.35***	0.12	-0.04	0.31***	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

Zero-Order, Partial Correlations, and Changes in r^2 between Reading, Math, and Hyperactivity 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
Untimed														
Reading & Hyperactivity	0.32***	0.10	0.21**	0.05	-0.05	0.29***	0.08	-0.02	0.22**	0.05	-0.05	0.28***	0.08	-0.02
Math & Hyperactivity	0.22***	0.05	0.15*	0.02	-0.03	0.16*	0.03	-0.02	0.14*	0.02	-0.03	0.18**	0.03	-0.02
Timed														
Reading & Hyperactivity	0.24***	0.06	0.14*	0.02	-0.04	0.22***	0.05	-0.01	0.14*	0.02	-0.04	0.20**	0.04	-0.02
Math & Hyperactivity	0.22***	0.05	0.12	0.02	-0.03	0.16*	0.03	-0.02	0.15*	0.02	-0.03	0.17**	0.03	-0.02

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 5

Multiple Regression Results for Untimed Reading, Untimed Math, and Inattention

		B	SE(B)	β	p	η^2
Untimed	PA	0.51	0.07	0.44	<.001	0.19
Reading	Numerosity	0.02	0.02	0.05	0.400	0.00
	WM	1.35	0.40	0.22	0.001	0.05
	PS	0.18	0.10	0.10	0.067	0.01
Untimed	PA	0.14	0.05	0.20	0.002	0.04
Math	Numerosity	0.06	0.01	0.28	<.001	0.09
	WM	0.81	0.25	0.22	0.002	0.04
	PS	0.06	0.06	0.06	0.330	0.00
Inattention	PA	0.05	0.02	0.22	0.001	0.05
	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

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 6
Multiple Regression Results for Timed Reading, Timed Math, and Hyperactivity

		B	SE(B)	β	p	η^2
Timed Reading	PA	0.08	0.02	0.32	<.001	0.10
	Numerosity	0.00	0.01	-0.03	0.629	0.00
	WM	0.31	0.09	0.23	0.001	0.05
	PS	0.05	0.02	0.12	0.053	0.02
Timed Math	PA	0.08	0.01	0.36	<.001	0.11
	Numerosity	0.01	0.00	0.20	0.001	0.05
	WM	0.04	0.08	0.04	0.608	0.00
	PS	0.05	0.02	0.17	0.007	0.03
Hyperactivity	PA	0.04	0.02	0.15	0.037	0.02
	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 7
Multivariate Regression Results

		B	SE(B)	β	p	η^2
Phonological Awareness	Untimed Reading	0.51	0.07	0.44	<.001	0.19
	Timed Reading	0.08	0.02	0.32	<.001	0.10
	Untimed Math	0.14	0.04	0.20	0.002	0.04
	Timed Math	0.08	0.01	0.36	<.001	0.11
	Inattention	0.05	0.02	0.22	0.001	0.05
	Hyperactivity	0.03	0.02	0.15	0.045	0.02
Numerosity	Untimed Reading	0.02	0.02	0.05	0.335	0.00
	Timed Reading	0.00	0.00	-0.03	0.571	0.00
	Untimed Math	0.06	0.01	0.28	<.001	0.09
	Timed Math	0.01	0.00	0.19	0.002	0.04
	Inattention	0.01	0.00	0.16	0.005	0.03
	Hyperactivity	0.01	0.01	0.15	0.017	0.02
Working Memory	Untimed Reading	1.37	0.40	0.22	0.001	0.05
	Timed Reading	0.30	0.09	0.22	0.002	0.04
	Untimed Math	0.81	0.25	0.22	0.002	0.04
	Timed Math	0.04	0.08	0.03	0.652	0.00
	Inattention	0.26	0.09	0.21	0.002	0.04
	Hyperactivity	0.14	0.10	0.11	0.147	0.01
Processing Speed	Untimed Reading	0.17	0.10	0.10	0.092	0.01
	Timed Reading	0.06	0.06	0.06	0.330	0.02
	Untimed Math	0.04	0.02	0.12	0.060	0.00
	Timed Math	0.05	0.02	0.17	0.007	0.03
	Inattention	0.08	0.02	0.22	0.001	0.05
	Hyperactivity	0.04	0.02	0.11	0.107	0.01

Note. B = unstandardized regression coefficient; β = standardized regression coefficient; η^2 = eta-squared, a measure of effect size. See note for Table 1 for measures used to assess academic/attention variables (i.e., untimed reading)

Table 8

Canonical Correlation Results for Cognitive Variates

Cognitive Variables	Cognitive Variate 1	Cognitive Variate 2
PA	0.83	-0.45
Numerosity	0.42	0.80
WM	0.80	0.01
PS	0.50	0.24
Academic Variables		
Untimed reading	0.61	-0.13
Untimed math	0.49	0.15
Inattention	0.53	0.09

Note. PA = phonological awareness; WM = working memory; PS = processing speed. See note for Table 1 for measures used to assess academic/attention variables (i.e., untimed reading)

Table 9
Canonical Correlation Results for Academic Variates

Cognitive Variables	Academic Variate 1	Academic Variate 2
PA	0.58	-0.13
Numerosity	0.29	0.22
WM	0.56	0.00
PS	0.35	0.07
Academic Variables		
Untimed reading	0.88	-0.47
Untimed math	0.71	0.55
Inattention	0.76	0.31

Note. PA = phonological awareness; WM = working memory; PS = processing speed. See note for Table 1 for measures used to assess academic/attention variables (i.e., untimed reading)

Table 10
Canonical Correlation Results for Cognitive Variates with Timed Outcomes

Cognitive Variables	Cognitive Variate 1	Cognitive Variate 2
PA	0.82	-0.27
Numerosity	0.42	0.83
WM	0.77	-0.31
PS	0.58	0.21
Academic Variables		
Timed reading	0.50	-0.16
Timed math	0.50	0.09
Inattention	0.54	0.06

Note. PA = phonological awareness; WM = working memory; PS = processing speed. See note for Table 1 for measures used to assess academic/attention variables (i.e., untimed reading)

Table 11
Canonical Correlation Results for Academic Variates with Timed Outcomes

Cognitive Variables	Academic Variate 1	Academic Variate 2
PA	0.56	-0.06
Numerosity	0.29	0.19
WM	0.52	-0.07
PS	0.39	0.05
Academic Variables		
Timed reading	0.74	-0.67
Timed math	0.75	0.38
Inattention	0.81	0.25

Note. PA = phonological awareness; WM = working memory; PS = processing speed. See note for Table 1 for measures used to assess academic/attention variables (i.e., untimed reading)

Table 12
Canonical Correlation Results for Cognitive Variates with Hyperactivity

	Untimed Outcomes		*Timed Outcomes*	
Cognitive Variables	Cognitive Variate 1	Cognitive Variate 2	Cognitive Variate 1	Cognitive Variate 2
PA	0.85	-0.40	0.86	-0.17
Numerosity	0.42	0.85	0.41	0.84
WM	0.78	-0.02	0.75	-0.37
PS	0.45	0.14	0.53	0.08
Academic Variables				
Reading	0.61	-0.12	0.50	-0.15
Math	0.49	0.16	0.51	0.11
Hyperactivity	0.33	0.09	0.35	0.08

Note. PA = phonological awareness; WM = working memory; PS = processing speed. See note for Table 1 for measures used to assess academic/attention variables (i.e., untimed reading)

Table 13
Canonical Correlation Results for Academic Variates with Hyperactivity

	Untimed Outcomes		*Timed Outcomes*	
Cognitive Variables	Academic Variate 1	Academic Variate 2	Academic Variate 1	Academic Variate 2
PA	0.58	-0.11	0.56	-0.04
Numerosity	0.29	0.24	0.27	0.20
WM	0.53	-0.01	0.49	-0.09
PS	0.31	0.04	0.35	0.02
Academic Variables				
Reading	0.90	-0.43	0.77	-0.63
Math	0.73	0.58	0.78	0.44
Hyperactivity	0.48	0.30	0.53	0.34

Note. PA = phonological awareness; WM = working memory; PS = processing speed. See note for Table 1 for measures used to assess academic/attention variables (i.e., untimed reading)