Published in final edited form as:
Child Neuropsychol. 2008 November ; 14(6): 525–546. doi:10.1080/09297040701821752.

Memory Functioning in Children with Reading Disabilities and/or Attention-Deficit/Hyperactivity Disorder: A Clinical Investigation of Their Working Memory and Long-term Memory Functioning

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Abstract

We examined memory functioning in children with reading disabilities (RD), ADHD, and RD/ADHD using a clinic sample with a clinical instrument: the Children's Memory Scale, enhancing its generalizability. Participants included 23 children with RD, 30 with ADHD, 30 with RD/ADHD, and 30 controls. Children with RD presented with reduced verbal short-term memory (STM) but intact visual STM, central executive (CE) and long-term memory (LTM) functioning. Their deficit in STM appeared specific to tasks requiring phonetic coding of material. Children with ADHD displayed intact CE and LTM functioning but reduced visual-spatial STM, especially when off stimulant medication. Children with RD/ADHD had deficits consistent with both disorders.

Keywords

dyslexia; reading disorders; ADHD; working memory; memory; children; stimulant medication

There is a high comorbidity between a specific learning disability in reading (RD) and attention-deficit/hyperactivity disorder (ADHD). Approximately 15–35% of children with RD meet criteria for ADHD (Holborow & Berry, 1986; Shaywitz, Fletcher, & Shaywitz, 1995; Willcutt & Pennington, 2000), and about 10–40% of children with ADHD also have RD (Holborow & Berry, 1986; Semrud-Clikeman et al., 1992; Shaywitz et al., 1995). This overlap occurs in both community and clinical samples, suggesting it is not a selection artifact (Willcutt et al., 2001). Both disorders present with working memory and linguistic deficits; however, the manifestation of these deficits may vary between disorders. Despite all that we have learned about memory functioning in these populations over the past few decades, much of this research has focused on community samples and/or has used experimental measures. In contrast, this study examines memory functioning in children with RD, ADHD, and comorbid RD and ADHD using a clinical sample with a clinical instrument: the Children's Memory Scale (CMS; 1997). This study provides greater external validity than is typically published, which will enhance its generalizability to psychologists working in clinical practice. For the purposes of this study, the term working memory (WM) is used when tasks require storage and mental manipulation such as a mental arithmetic task, whereas short-term memory (STM) is used when tasks require brief storage but limited mental manipulation such as when performing a digit span forward task. Long-term memory (LTM) refers to tasks requiring storage over delays of at least 20–30 minutes.

Children with RD frequently present with poor verbal STM despite intact visual STM and intact LTM for both types of material, provided any deficits at initial encoding are controlled (for reviews see (Baddeley & Hitch, 1994; Brady, 1991; Hulme, 1989; Jorm, 1983; Pennington, 1991). Using Baddeley's model of working memory (1986, 2000), many would suggest that the phonological loop is impaired in this population (e.g., Ackerman & Dykman, 1993; Kibby, 2007a; Kibby 2007b; Kibby, Marks, Morgan, & Long, 2004; McDougall, Hulme, Ellis, & Monk, 1994; Roodenrys, Koloski, & Grainger, 2001; Stone & Brady, 1995; and the reviews above). The deficit appears to be specific to the store mechanism of the phonological loop, with an intact subvocal rehearsal mechanism (Jorm, 1983; Kibby, 2007a; Kibby et al., 2004; McDougall et al., 1994; McDougall & Donohoe, 2002). While some would suggest there are central executive (CE; attention regulation system) deficits as well as, or instead of, deficits in the phonological loop (de Jong, 1998; Swanson & Howell, 2001; Swanson & Lee; 2001; Willcutt et al., 2001), others have found the CE to be intact in RD when controlling for verbal storage deficits (Kibby et al., 2004; Roodenry's et al., 2001). A few researchers have found visual STM deficits in RD (Howes, Bigler, Burlingame, & Lawson, 2003; Mauer & Kamhi, 1996; Palmer, 2000), suggesting there is an impaired visual-spatial sketchpad in this population; however, most research suggests that visual-spatial STM is intact in RD when the possibility of verbal coding is minimal (e.g., Jeffries & Everatt, 2004; Jorm, 1983; Kibby, 2007b; Kibby et al. 2004; McDougall, 1994; McDougall et al., 1994).

In addition to verbal STM deficits, children with RD frequently present with poor phonological processing. In fact, deficits in phonological processing are so common that poor phonological processing is believed by many to be the core deficit in RD (Liberman & Shankweiler, 1991; Pennington, Van Orden, Smith, Green, & Haith, 1990; Stanovich, 1988; Wagner, Torgesen, & Rashotte, 1994), even across RD subtypes (Morris et al., 1998). Furthermore, there is a strong association between poor phonological processing and an inability to store verbal material in RD (Kibby, 2007a; Kibby et al., 2004; Mann, Liberman, & Shankweiler, 1980; McDougal et al., 1994; Rapala & Brady, 1990), with it being suggested that a primary reason why verbal short-term storage is impaired in RD is that they fail to use, or make inefficient use of, phonetic coding during initial learning (Brady, 1991; Kibby, 2007a & b; Kibby et al., 2004; Mann et al., 1980; Olson, Davidson, Kliegl, & Davies, 1984). Consistent with this hypothesis, research has found that children with RD present with greater impairment in short-term storage when coding items phonetically or by their sound as opposed to when coding items by their meaning (Dewey, Kaplan, Crawford, & Fisher, 2001; Jorm, 1983; Kibby, 2007a & b; Lee & Obrzut, 1994; Mann et al., 1980).

Prior research has demonstrated that reduced verbal STM plays a role in reading deficits in RD, even when controlling verbal intellect and phonological processing skills (Ackerman & Dykman, 1993; Cormier & Dea, 1997; Hansen & Bowey, 1994). However, some researchers have found that verbal STM does not uniquely contribute to reading ability when phonological processing skills are controlled (McDougall et al., 1994; Pennington, 1991). When analyzing this controversy, Kibby (2007a) found verbal STM, phonological awareness and Verbal IQ were significant predictors of pseudoword decoding, while only phonological awareness and Verbal IQ were significant predictors of word recognition. Therefore, verbal STM appears to make a unique contribution to reading beyond that of phonological awareness when phonological decoding is required, but it may not when stimuli are familiar words that can be identified through a whole word/orthographic approach. Consistent with this notion, Snowling (1991) has stated that verbal WM appears to play a crucial role in the reading process when words are unfamiliar and must be decoded. Under these conditions phonological segmentation and blending are required, and phonemes are likely held in WM during these processes.

Children with ADHD also present with subtle language weaknesses as a group (Camarata & Gibson, 1999; Carte, Nigg, & Hinshaw, 1996; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003; Purvis & Tannock, 1997). However, these linguistic weaknesses differ from RD in that phonological processing is typically spared in ADHD (Pennington, Groisser, & Welsh, 1993; Purvis & Tannock, 2000; Shaywitz et al., 1995; Willcutt et al., 2001). In contrast to individuals with RD, many believe the primary deficit in ADHD is executive dysfunction, including poor problem solving, mental flexibility, behavioral and cognitive inhibition, motor control, and self-regulation (Barkley, 1997; Korkman & Pesonen, 1994; Pennington et al., 1993; Reader, Harris, Schuerholz, & Denckla, 1994; Roodenrys et al., 2001; Willicut et al., 2001). Their deficits in executive functioning often involve poor strategy usage and sustained strategic effort (Ackerman, Anhalt, Dykman, & Holcomb, 1986; Douglas & Benezra, 1990; Shallice et al., 2002).

Related to executive dysfunction, children with ADHD often have deficits in WM, particularly in the central executive, with sparing of the phonological loop and visual-spatial sketchpad (Barkley, 1997; Denckla, 1996; Douglas & Benezra, 1990; Korkman & Pesonen, 1994; Mariani & Barkley, 1997; Shue & Douglas, 1992). In fact, in a study by Cornoldi, Barbieri, Gaiani, and Zocchi (1999), it was found that deficits in WM among individuals with ADHD were related to poor strategy usage, and when they were taught to use a strategy they performed comparably to controls, thus demonstrating a link between executive functioning and WM performance. However, not all studies have found reduced CE functioning in ADHD, at least when tasks are verbal in nature (Pallas, 2003; Rucklidge & Tannock, 2002; Willcutt et al., 2001). In addition, despite several researchers not finding STM deficits in ADHD when CE demands are low, a few studies have found deficits in visual STM (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; McInnes et al., 2003) and verbal STM (Pallas, 2003; Stevens, Quittner, Zuckerman, & Moore, 2002). In contrast to WM deficits, individuals with ADHD tend to display intact LTM if the material is encoded successfully (Kaplan, Dewey, Crawford, & Fisher, 1998; Muir-Broaddus, Rosenstein, Medina, & Soderberg, 2002; Plomin & Foch, 1981).

Hence, based upon the work of several researchers, there may be an interesting dichotomy between RD and ADHD, with RD displaying an impaired phonological loop but intact visual-spatial sketchpad and CE, and ADHD displaying an impaired CE but intact phonological loop and visual-spatial sketchpad, although there is controversy in the literature related to this generalization. Researchers tend to agree that neither disorder presents with LTM deficits when the effects of poor encoding at initial learning are controlled. Given this potential dichotomy it is of interest to assess the memory problems of children with comorbid RD and ADHD (RD/ADHD).

A few articles have examined STM/WM functioning in children with RD/ADHD versus RD or ADHD alone. Willcutt and colleagues (2001) and Rucklidge & Tannock (2002) found children with RD/ADHD had poor verbal WM similar to those with RD, with children with ADHD having intact verbal WM. Willcutt, Pennington, Olson, Chhabildas, and Hulslander (2005) found similar results, with the exception that children with ADHD had mild difficulty on one of the verbal WM measures administered, Counting Span, with the rest of the WM measures being intact. Roodenrys and colleagues (2001) used experimental tasks designed to assess the phonological loop and CE components of WM specifically. They found RD/ADHD to be comparable to RD in phonological loop impairment as measured by word span and digit span tasks, but RD/ADHD also had impairment in the CE when using tasks requiring manipulation and generation whereas RD did not show impairment in the CE. This study did not include a group with ADHD alone. It should be noted that none of these studies included a measures of visual STM or WM.

As noted earlier, verbal STM may be directly related to reading performance, especially when predicting decoding skills. Several studies have found WM to be involved with reading comprehension (Perfetti, 1985; Swanson & Ashbaker, 2000; Stone & Brady, 1995; Walczyk & Raska, 1992) and math calculation skills (Denkla, 1996; Hulme & Roodenrys, 1995; Wilson & Swanson, 2001). Walczyk & Raska (1992) found WM to be important for maintaining access to information while reading, allowing for high-level comprehension, and Swanson and Ashbaker (2000) demonstrated that poor readers' word identification and reading comprehension performance is related to central executive functioning independent of the contribution of the phonological loop. In terms of math skills, WM may be important for computations that require problem-solving, direct retrieval of math facts, and/or problem decomposition (Geary, 2004) and for solving mathematical application problems (Swanson & Sachse-Lee, 2001).

Aside from the data provided in the manual (Cohen, 1997), limited research has utilized the Children's Memory Scale (CMS) in children with RD, ADHD, RD/ADHD, and controls, making our study more unique. The CMS is particularly beneficial in the study of memory functioning as it includes measures of focused attention and STM/WM (Numbers Forward, Numbers Backward, Sequences, Picture Locations), visual STM and LTM (Dot Locations, Faces), and verbal STM and LTM (Stories, Word Pairs, Word Lists). For the purpose of this study, tasks involving primarily storage/rehearsal and limited CE demands were considered to be measures of STM. Thus, Numbers Forward, Stories, Word Pairs, and Word Lists were thought to measure verbal STM. Picture Locations, Dot Locations and Faces were thought to measure visual STM. While all STM tasks may require mental manipulation to a lesser extent, only Numbers Backward and Sequences were considered to truly tap the CE and thus measure WM. Within the verbal domain the CMS includes measures of STM/LTM that encourage storage by meaning (Stories) and by sound (Word Lists). Based upon the research highlighted above, it is expected that children with RD will have deficits in verbal short-term storage, particularly on measures encouraging phonetic coding (Numbers Forward and Backward, Sequences, Word Lists). Performance on measures encouraging greater coding by meaning (Stories) will be spared, as will LTM for all measures once encoding deficits are controlled. In addition, they will perform comparably on measures of verbal WM (Numbers Backward, Sequences) and verbal span (Numbers Forward), as deficits will be due to coding/storage of phonetic material as opposed to mental manipulation, demonstrating an intact CE. In terms of ADHD, it is expected that they will have deficits in WM (Numbers Backward, Sequences), with spared verbal and visual STM and LTM. For those with RD/ADHD, they are expected to have deficits consistent with RD and ADHD, without additional deficits. In addition, when combining clinical groups it is expected that verbal WM (Sequences) will be predictive of reading and math performance, even after controlling verbal intelligence, phonological awareness, and verbal span/phonological loop functioning (Numbers). As we do not have a measure of phonetic word attack/decoding in this study, verbal span may not predict reading ability.

Method

Participants

113 children ages 6–15 years participated in the study. 23 children had RD, 30 had ADHD, 30 had RD/ADHD, and 30 were typically developing controls. All the participants except controls were seen as outpatients in a medical center pediatric neuropsychological clinic, representing a clinical sample. The procedure used to obtain controls is described below. Participants were excluded from all groups if they had comorbid psychiatric (e.g., Major Depression, Generalized Anxiety Disorder, Conduct Disorder) or neurological (e.g., traumatic brain injury, epilepsy)

disorders or had low measured intelligence (IQ < 80). The diagnostic procedures used for this study are as follows.

RD—To be diagnosed as RD (RD, RD/ADHD), participants had to meet State of Georgia criteria for a learning disability in reading. More specifically, for the purposes of our study this required word identification to be at least 20 standard score points below the best measure of intelligence. As this was a clinical setting, multiple measures of intelligence and reading performance were used. Intelligence was measured with the Wechsler Intelligence Scale for Children-Third Edition (WISC-III; Wechsler, 1991) at the start of the study, but the clinic switched to the Fourth Edition (WISC-IV; Wechsler, 2003) when it was published. The best measure of intelligence was considered to be Full Scale IQ (FSIQ) unless a significant discrepancy occurred between the Verbal IQ (VIQ) and Performance IQ (PIQ; WISC-III) or Verbal Comprehension (VCI) and Perceptual Reasoning Indices (PRI; WISC-IV); in this case the higher of the two scores was used. As RD is a heterogeneous disorder, some children have commensurate verbal and nonverbal intelligence, whereas others have deficits in VIQ/VCI due to poor expressive language abilities and some have deficits in PIQ/PRI due to poor visual perception/construction or slow processing speed despite intact reasoning abilities. Thus, there is no one measure that adequately represents the intelligence of all children with RD. Therefore, the “best” IQ score was used to diagnose RD rather than exclusively FSIQ. It is important to note that while the best IQ was used for diagnostic purposes, groups were equated on FSIQ, VCI, and PRI/Perceptual Organization Index (POI). Reading was assessed with a variety of measures, including the Wide Range Achievement Test – Third (WRAT-3; Wilkinson, 1993) or Fourth Edition (WRAT-4; Wilkinson & Robertson, 2004) Reading score; Gray Oral Reading Test – Third (GORT-3; Wiederholt & Bryant, 1992) or Fourth Edition (GORT-4; Wiederholt & Bryant, 2001) Passage/Fluency and Comprehension standard scores; Woodcock-Johnson Tests of Achievement – Third Edition (WJ-III; Woodcock, McGrew, & Mather, 2001) Letter-Word Identification and Passage Comprehension standard scores; and the Weschler Individual Achievement Test – First (WIAT; Wechsler, 1992) or Second Edition (WIAT-II; Psychological Corporation, 2001) Word Recognition and Reading Comprehension standard scores. As children did not receive all achievement measures listed but most received the WRAT-3/4, it was the primary measure of word identification used for diagnostic purposes for this study. WRAT-3/4 Arithmetic and Spelling also were administered to most clinic children.

The use of a discrepancy definition has become a source of great debate in the RD/dyslexia literature. The discrepancy definition was used instead of a poor reader definition as our data was conducted in a clinical setting and local school systems followed the State of Georgia criteria, which includes a discrepancy. State of Georgia criteria were consistent with the *Individuals with Disabilities Education Act* (IDEA) at the time of data collection. In 2004 IDEA criteria were modified to include alternate methodologies of identifying RD such as a response to intervention paradigm. Use of IQ in the definition is relevant to this project as there is evidence to suggest that IQ and memory functioning are related (Buehner, Krumm, Ziegler, & Pluecken, 2006; Burgess, 2006; de Ribaupierre & Lecerf, 2006; Fuchs & Young, 2006). Moreover, while poor readers who do and do not meet a discrepancy definition are comparable in phonological awareness abilities, some research suggests that children who meet a discrepancy definition may be different from those who do not in other areas such as rapid naming skills (Badian, 1997; Wolf, 1991), cerebellar functioning (Fawcett, Nicolson, & Maclagan, 2001), and response to intervention (Fuchs & Young, 2006; Jimenez et al., 2003). The State of Georgia definition was used instead of the DSM-IV criteria for a Reading Disorder as most school systems in the United States prefer the IDEA definition over the DSM.

ADHD—ADHD was diagnosed using a multi-faceted process. Clinical interview was conducted with the child’s parent/guardian to ensure participants met DSM-IV criteria (American Psychiatric Association, 1994), including age of symptom onset; number, duration, and severity of symptoms; presence of impairment in daily life, and presence of symptoms across settings. The child's parent and teacher also provided input through questionnaires including the Behavior Assessment System for Children, Parent and Teacher forms (BASC or BASC-2; Reynolds & Kamphaus, 1993, 2004); the Conner's Parent (48 items; Cohen, 1988) and Teacher (39 items; Cohen & Hynd, 1986) Rating Scales. As there were more children with ADHD than children with RD/ADHD in the original sample (original ADHD $\underline{n} = 44$), children with ADHD were matched as closely as possible to children with RD/ADHD in ADHD severity (as measured by the parent and teacher questionnaires) and subtype (Predominately Inattentive versus Combined type), age, gender, FSIQ, and ethnicity in order to have comparable cell sizes. This was done blind to CMS scores. In the resulting sample, 19 children had ADHD-PI type and 11 had ADHD-Combined type in the ADHD group. In the RD/ADHD group 17 children had ADHD-PI type and 13 had ADHD-Combined type. There were no significant differences between groups in ADHD subtype ($\underline{X}^2 = 0.28$, $\underline{p} > .10$). Overall ADHD severity was mild for both groups, RD/ADHD and ADHD. On the day of testing 14 children with RD/ADHD and 13 children with ADHD were on medication; hence, the two groups were not significantly different in medication usage ($\underline{X}^2 = .07$, $\underline{p} > .10$). The medications used were stimulants.

Controls—Control children were selected from the Linking Sample of the Children's Memory Scale (i.e., portion of the Standardization Sample where children were administered both the CMS and WISC-III; n = 230). Specifically, 30 children were selected for this study from the CMS/WISC-III Linking Sample who were comparable to the clinical group in age, FSIQ, VCI, PRI/POI, gender, and ethnicity. This selection process was done blind to the CMS data. The children comprising the linking sample were drawn from public and private schools. Since these children were part of the Standardization Sample they could not: be reading below grade level; have repeated a grade; be referred to, or already be receiving, special education or Chapter/Title 1 remedial services; be diagnosed with a neurological disorder; or have sustained a brain injury.

Measures

All children were administered the Children's Memory Scale (CMS), either as part of the CMS Linking Sample (controls) or as part of a comprehensive neuropsychological battery (clinical groups). The CMS was designed to assess immediate, short-term and long-term memory in children and has been described as "a novel measure of new learning and memory" (Hildebran & Ledbetter, 2001, p. 21). The CMS is comprised of six core subtests (Dot Locations, Faces, Stories, Word Pairs, Numbers, and Sequences), and three optional subtests (Family Pictures, Word Lists, and Picture Locations) that yield seven indexes, three domains, and an overall General Memory score. Of the subtests, six have delayed recall components (Dot Locations, Faces, Family Pictures, Stories, Word Pairs, and Word Lists) that are administered approximately 30 minutes following the initial presentation, with the verbal subtests including measures of both recall and recognition. As this study is focused on the subtests and what they measure (e.g., coding by sound versus meaning) when comparing groups, it will not assess the index/domain level which would amalgamate these skills. The reader is referred to the Appendix for a more detailed description of the individual subtests that are used for this project.

As noted above, the CMS includes three domains: (a) Verbal STM and LTM (b) Visual STM and LTM and (c) Attention/Concentration: focused attention/concentration and STM/WM. Each domain is comprised of several indices, such as immediate recall and delayed recall (for "a" and "b") and delayed recognition (for "a"). The General Memory Index is derived from the Verbal and Visual Immediate and Delayed Memory Indexes and represents global memory functioning (Cohen, 1997). The CMS demonstrates good reliability over time. Specifically, inter-rater reliability, based on intra-class correlation, was found to be high (Cohen, 1997). Concurrent validity of the CMS also is good, as assessed through correlations between CMS scores and various measures of cognitive and intellectual ability (Cohen, 1997; Elliot, 1990; Otis & Lennon, 1996; Stein, 2001; Wechsler, 2003). These results support the position that there are at least moderate relations between measures of memory functioning and intelligence/ cognition. For example, the CMS General Memory Index is positively, and at least moderately, correlated with many cognitive abilities, such as IQ, academic achievement, language functioning, and executive functioning (Cohen, 1997; Elliot, 1990; Otis & Lennon, 1996; Stein, 2001; Wechsler, 2003). Concurrent validity with other memory scales also has been demonstrated. When the CMS and Wechsler Memory Scale-Third Edition were compared, corresponding indexes were found to have moderate to strong relationships, suggesting that the two instruments measure the construct of memory consistently throughout the lifespan (Wechsler, 1997). The CMS also is moderately to strongly correlated with the WRAML and CVLT-C when corresponding indices are compared (Cohen, 1997). In terms of convergent/ divergent validity, the CMS has good differential sensitivity to detect memory problems where expected in children with neurodevelopmental disorders (Cohen, 1997).

Other measures were obtained as part of the neuropsychological battery to assess linguistic functioning. These include the WISC-III/IV Verbal Comprehension Index (VCI) and NEPSY Phonological Processing. The VCI is used as a measure of acquired knowledge and verbal intelligence for this study. NEPSY Phonological Processing is used as a measure of phonological awareness as this subtest assesses analysis and synthesis of items at the syllable and phoneme level (e.g. when hearing an item participants need to remove a syllable/phoneme and then say what remains after blending it together)

Results

Preliminary results

All groups were comparable in age, gender, and race/ethnicity, $Fs(3, 109) < 1.0$, $ps > .10$. They also were comparable in FSIQ [$F(3, 109) < 1.0$, $p > .10$], as well as Verbal Comprehension [VCI; $F(3,109) < 1.0$] and Perceptual Reasoning/Organization [PRI/POI; $F(3, 109) = 2.39$, $p > .05$] index scores. Descriptive data is presented in Table 1.

Academic achievement and questionnaire data were not available on the controls. The three clinical groups (RD, ADHD, RD/ADHD) were discrepant in word identification [$F(2,80) = 40.68$, $p < .001$], reading comprehension [$F(2,72) = 16.95$, $p < .001$], and spelling [$F(2,79) = 23.70$, $p < .001$]. Follow-up comparisons using Games-Howell revealed RD and RD/ADHD performed significantly worse than ADHD but comparably to each other ($ps > .10$) in all three areas. The three clinical groups were comparable in math calculation skills, $F(2,80) = 2.26$, $p > .10$. Groups also differed in BASC Attention Problems and Hyperactivity scales when using parent informants [$F(2,80) = 9.76$, $p < .001$ and $F(2,80) = 3.64$, $p < .05$, respectively] and teacher informants [$F(2,80) = 15.11$, $p < .001$ and $F(2,80) = 5.47$, $p < .01$, respectively]. Follow-up analyses revealed RD/ADHD and ADHD groups were comparable in Attention Problems and Hyperactivity across informants ($ps > .10$). RD had less Attention Problems and Hyperactivity than RD/ADHD across informants. RD had fewer parent and teacher rated Attention Problems than ADHD. Using the modified Conner's Parent and Teacher Rating Scales, clinical groups differed on the Attention-Deficit/Hyperactivity Disorder factor (AD) for parent [$F(2, 79) = 8.64$, $p < .001$] and teacher [$F(2, 79) = 10.13$, $p < .001$] informants. Follow-up analyses revealed ADHD and RD/ADHD groups were comparable across informants ($ps > .10$), and RD had significantly fewer symptoms than ADHD and RD/ADHD. Academic achievement and questionnaire descriptive data from the clinical groups are presented in Table 2.

Results

Group differences—Three 2 (RD, no-RD) X 2 (ADHD, no ADHD) MANOVAs were used to compare groups on the verbal STM and LTM, visual STM and LTM, and attention/concentration measures. A 2 X 2 MANOVA was used to determine if double disassociations or interactions exist between the two disorders. A more detailed rationale for such an approach is provided by Wilcutt et al. (2001, 2005). When main effects or the interactions were significant, follow-up comparisons were conducted, comparing the four groups in one factor using Games-Howell to control for unequal ns.

In terms of the verbal measures, the main effects were not significant for Stories and Word Pairs STM, LTM recall, and LTM recognition (omnibus tests $ps > .10$). The interactions also were not significant (omnibus tests $ps > .10$). In terms of the visual measures, main effects were significant for ADHD (omnibus tests $ps < .001$) but not for RD (omnibus tests $ps > .05$). The interactions were not significant (omnibus tests $ps > .10$). Upon analyzing the univariate tests on ADHD, it was found that Dot Locations Learning [$F(1, 107) = 4.75$, $p < .05$] and Faces Delayed were significant [$F(1, 107) = 7.14$, $p < .01$]. Follow-up analysis revealed the ADHD group outperformed controls on Faces Delayed ($p < .05$). Nonetheless, when using a paired t-test, performance on Faces Immediate and Delayed did not differ in controls [$t(30) = 1.60$, $p > .10$], suggesting their LTM was intact. In terms of Dot Locations Learning, both groups with ADHD (ADHD and RD/ADHD) performed worse than RD and controls.

Main effects for RD and ADHD were significant for the Attention/Concentration measures (omnibus tests $ps < .001$) but the interactions were not significant (omnibus tests $ps > .05$). At the univariate level, those with and without RD differed on all verbal measures: Numbers Forward [$F(1,104) = 19.18$, $p < .001$], Numbers Backward [$F(1,104) = 14.64$, $p < .001$], and Sequences [$F(1,104) = 21.96$, $p < .001$] but were very comparable on Picture Locations [$F(1,104) < 1.0$, $p > .10$]. In terms of ADHD, groups differed on Numbers Forward [$F(1,104) = 12.34$, $p =.001$], Picture Locations [$F(1,104) = 10.09$, $p < .01$], and Sequences [$F(1,104) = 5.22$, $p < .05$]. Follow-up analyses revealed controls performed better than all three clinical groups on Numbers Forward ($ps \leq .001$). The three clinical groups were comparable. Controls also performed better than both RD groups on Sequences ($ps < .001$), and the ADHD group outperformed the RD/ADHD group ($p < .05$). ADHD performed better than both RD groups on Numbers Backward ($ps < .05$). In terms of Picture Locations, controls performed better than those with ADHD. To assess the central executive more specifically, performance on a simple span task (Numbers Forward) was subtracted from performance on a task requiring span plus CE functioning (Sequences or Numbers Backward). The four groups were comparable on the subtraction involving Sequences [$F(3,109) = 1.69$, $p > .10$] but differed on the subtraction comparing Numbers Forward and Backward [$F(3,109) = 8.07$, $p < .001$]. When inspecting the means, all three clinical groups performed better on Numbers Backward than Forward; this difference reached significance for the two ADHD groups as compared to controls. See Table 3 for descriptive data on the CMS.

Since this was a clinic sample, not all participants were given all measures. Many children in the clinical groups did not complete Word Lists. As a result, the two RD groups were combined, and the ADHD group was combined with the control group following visual inspection of the means. This method of grouping was used in order to compare those with and without RD on Word Lists, as children with RD were hypothesized to perform poorly on this measure. There were 24 children with RD and 37 without it who completed Word Lists. MANOVA was used to compare the two groups on Word Lists Learning, Delayed Recall, and Delayed Recognition. Significant differences occurred at the omnibus level ($ps < .05$), as well as the univariate level for all three subtests [$F(1,59) = 8.61$, $p < .01$; $F(1,59) = 4.50$, $p < .05$; and $F(1,59) = 8.03$, $p < .01$, respectively]. To check for specificity of this affect, those with and without ADHD also were compared. These groups did not differ on Word Lists Learning, Delayed Recall or

Delayed Recognition; $ps > .10$. Descriptive data is presented in Table 3. It was of interest to determine whether children with RD performed worse than those without it on this measure due to poor encoding, poor retention/consolidation over time, and/or poor retrieval after a delay. Hence, three variables were created: Learning minus Delayed Recall, Learning minus Delayed Recognition, and Delayed Recognition minus Delayed Recall. Using MANOVA, those with and without RD did not differ on these variables ($ps > .10$) suggesting the effect was specific to encoding.

As it is believed that the various CMS verbal measures require different levels of phonological processing, it was of interest to assess how well acquired knowledge versus phonological processing measures predicted performance on the verbal STM measures. Stepwise regression equations were run using the clinical sample as NEPSY Phonological Processing was not administered to the controls. Independent variables included NEPSY Phonological Processing and WISC VCI. Stories Immediate was predicted by VCI (adjusted $r^2 = .328$, $\beta = .584$, $p < .001$). Word Pairs Learning was predicted by both VCI and Phonological Processing (adjusted $R^2 = .247$; Phonological Processing $\beta = .279$, VCI $\beta = .341$, $p < .001$). Word Lists Learning was predicted by Phonological Processing (adjusted $r^2 = .461$, $\beta = .714$, $p < .001$). Given our next analysis, these results were verified in those with RD (RD and RD/ADHD). Children with RD had similar results (Stories Immediate was predicted by VCI [adjusted $r^2 = .296$, $\beta = .544$, $p = .001$] and Word Lists Learning was predicted by Phonological Processing [adjusted $r^2 = .494$, $\beta = .703$, $p < .05$]). Based upon our findings and the prior literature, it was of interest to determine if children with RD performed better on a STM measure encouraging coding by meaning/content (Stories) compared to a measure encouraging coding by sound/phonemes (Word Lists). Hence, the variable Stories Immediate minus Word Lists Learning was created. Using ANOVA, children with RD had a greater difference between Stories Immediate and Word Lists Learning than those without RD, $F(1,59) = 9.87$, $p < .01$.

Medication effects—It is possible that our ADHD findings may be related to medication usage, as about half of the children with RD/ADHD and ADHD were being treated with stimulant medication on the day of testing (none of the children without ADHD were on medication). To test this possibility, children with ADHD (RD/ADHD, ADHD) who took stimulant medication on the day of testing were compared with children with ADHD (RD/ADHD, ADHD) who did not on the measures found sensitive to ADHD. Children on and off medication did not differ on Picture Locations or Numbers Forward ($Fs < 1.0$). However, they did differ on Dot Locations Learning, $F(1,58) = 6.32$, $p < .05$. Those on medication ($M = 102.04$, $SD = 15.89$) performed better than those off medication ($M = 92.73$, $SD = 12.81$). To check for specificity of the medication effect, other measures were compared using MANOVA: Sequences; Numbers Backward; Faces Immediate and Delayed; Dot Locations Short- and Long-Delay; Stories Immediate, Delayed Recall and Delayed Recognition; and Word Pairs Learning, Immediate Recall, Delayed Recall, and Delayed Recognition. The MANOVA was not significant, and at the univariate level only Dot Locations Short Delay was significant ($p < .05$). The Word Lists subtests were analyzed separately using t-tests given the small n. The two groups were very comparable on Word List Learning, Delayed Recall and Delayed Recognition, $ps > .10$.

Academic achievement—Hierarchical regression was used to assess how well verbal WM predicted academic achievement when controlling verbal intellect, phonological processing ability, and verbal span. For each dependent variable, independent variables were entered into the equation in the following order: WISC VCI, NEPSY Phonological Processing, Numbers Forward, and Sequences. Analyses were performed using the clinic sample as measures of phonological processing were not available for the controls. When predicting word identification and reading comprehension, all but Numbers Forward were significant (see

Tables 4 and 5). Only Sequences was a significant predictor of math calculation skill (see Table 6).

Discussion

The purpose of this study was to examine memory functioning in children with RD, ADHD, RD/ADHD, and controls in a clinic sample using the CMS. There is limited research utilizing the CMS in the study of children with RD and/or ADHD, making our study more unique.

Reading Disability

Consistent with prior literature and our hypotheses regarding RD, children with RD and RD/ADHD performed worse than controls on verbal STM/WM measures emphasizing phonetic coding (Numbers Forwards, Sequences, Word Lists) but demonstrated intact coding by meaning (Stories). They also performed significantly worse on a measure emphasizing phonetic coding (Word Lists) than on the measure emphasizing coding by meaning (Stories), despite both measures using words. In contrast, visual STM and LTM, verbal LTM, and the CE were intact. These findings support prior research suggesting the WM deficit in RD is specific to the phonological loop with an intact CE and visual-spatial sketchpad (Kibby et al., 2004; McDougall et al., 1994; Roodenrys et al., 2001 when assessing RD without ADHD). As Baddeley (1986) proposed that the store mechanism of the phonological loop utilizes phonetic codes and others have argued for separate phonological and semantic stores (Jonides et al., 1998; Martin & Chao, 2001), our data is consistent with reduced STM functioning being specific to phonological coding/storage, similar to the findings of Kibby, 2007a&b and Lee & Obrzut, 1994.

ADHD

Children with ADHD performed comparably to controls on most measures of verbal STM, consistent with hypotheses. In contrast, visual-spatial STM (Dot Locations) may be mildly affected in ADHD, especially when off medication. Some prior research also has found reduced visual-spatial STM in ADHD (Martinussen et al., 2005; McInnes et al., 2003). In addition, prior research has found reduced spatial WM in medication-naïve participants with ADHD but intact spatial WM in participants with ADHD who were on stimulant medication (Barnett et al., 2001). Hence, future research should further investigate the role of medication in ADHD in terms of visual-spatial STM and WM. In contrast to visual-spatial STM, children with ADHD and RD/ADHD demonstrated similar performance to controls on Faces Immediate, suggesting visual STM is intact when spatial demands are low. Children with ADHD did not have deficits in LTM, consistent with hypotheses. The CE also appears to be intact in ADHD when controlling for deficits in focused attention/simple span, which was not consistent with hypotheses. Nonetheless, some prior research also has found intact verbal WM functioning in ADHD (Pallas, 2003; Rucklidge & Tannock, 2002; Willcutt et al., 2001). Future research is necessary assessing the CE with visual-spatial tasks, as the CMS only includes measures of verbal WM.

When using Baddeley's model, it appears that children with ADHD have an intact CE when using verbal measures but a mildly impaired visual-spatial sketchpad when off medication and spatial tasks are used. In terms of the phonological loop, it is difficult to firmly assert presence or absence of deficits in ADHD. Of note, performance on most verbal STM measures was intact in ADHD, including Stories, Word Pairs, and Word Lists. In contrast, they had mild difficulty on a measure of simple span (Numbers Forward), a task often used to assess phonological loop functioning in the literature. Further research is indicated to discern whether children with ADHD have difficulty with verbal span due to reduced STM or due to poor attention during stimulus presentation when items are rote, brief and presented only once.

Perhaps the phonological loop is intact in ADHD when tasks are more forgiving, such as when lists/stories are longer, allowing for brief fluctuations in attention. Consistent with this notion, we found children with ADHD performed comparably to those without ADHD on the first trial of each list learning task (Word Pairs, Word Lists; ps > .10), suggesting verbal STM is intact when they have a sufficient amount of material to encode (i.e., if they lose focus briefly it doesn't dramatically hurt their performance). Also consistent with this hypothesis is that children with ADHD performed better on Numbers Backward than Numbers Forward and in the Average range. Hence, their span appears to be intact when they perceive the task to be sufficiently challenging and are more driven by task demands. Prior research is inconclusive on verbal STM functioning in ADHD, with some finding STM to be intact (Douglas & Benezra, 1990; Korkman & Pesonen, 1994; Mariani & Barkley, 1997; Shue & Douglas, 1992) and others finding reduced verbal STM (Pallas, 2003; Stevens et al., 2002). Clearly more research is indicated in this area.

RD/ADHD

Children with RD/ADHD were hypothesized to present with deficits consistent with RD and ADHD, without additional deficits. Based upon our 2 X 2 MANOVA results indicating no significant interactions, our data is consistent with this hypothesis. Children with RD/ADHD presented with poor phonological STM on all the same measures as children with RD alone. Children with RD/ADHD also presented with mildly reduced performance on Dot Locations, similar to ADHD. On occasion children with RD/ADHD presented with the lowest scores of all four groups (RD, ADHD, RD/ADHD, controls), such as on Numbers Forward and Sequences, but this trend was not significant. Hence, in general, children with RD/ADHD present with deficits consistent with both disorders but not additional deficits.

There have been several theories regarding the etiological nature of RD/ADHD. For example, Pennington and colleagues (1993) found RD/ADHD to be similar to RD on phonological processing measures but not to have executive dysfunction, whereas those with ADHD had executive dysfunction. They concluded that RD/ADHD may be a phenotype of RD in that RD causes the symptoms in those with RD/ADHD rather than ADHD. While the work of Shaywitz et al. (1995) at least partially supported the phenotype hypothesis, several subsequent studies have not supported it, finding those with RD/ADHD have problems associated with both RD (poor phonological processing) and ADHD (executive dysfunction) (Narhi & Ahonen, 1995; Nigg, 1999; Rucklidge & Tannock, 2002; Willcutt, et al., 2001 & 2005).

Two other theories have been proposed regarding the etiology of RD/ADHD more recently. Rucklidge & Tannock (2002) found children with RD/ADHD to have deficits consistent with the additive effect of both disorders, along with additional impairments that went beyond what could be accounted for by RD or ADHD alone, potentially representing a subtype of the two disorders. This "cognitive subtype hypothesis" has not been supported by Willcutt and colleagues (2001 & 2005), however. They found children with RD/ADHD to have the additive combination of deficits of RD and ADHD, without additional deficits. Willcutt and colleagues (2001) have proposed a "common etiology hypothesis" of RD/ADHD which better fits their data (2001, 2005). In this hypothesis RD and ADHD may share a small, but significant, common cause, such as reduced verbal WM, slower response speed, or executive dysfunction given their high comorbidity. It is expected that the common etiology would contribute to most cases of the two disorders, and that children with RD/ADHD would present with this shared cause as well as those deficits specific to each disorder. Of these three theories on RD/ADHD, our data is most consistent with Wilcutt and colleagues (2001, 2005). Children with RD/ADHD had deficits consistent with both RD and ADHD, without additional deficits. As Numbers Forward tended to be reduced in all three groups (RD, ADHD, RD/ADHD), poor focused attention/verbal span is one candidate for the "common etiology" between RD and ADHD.

Academic Achievement

It was hypothesized that verbal WM/CE functioning (Sequences) would be predictive of reading and math performance, even after controlling verbal intelligence, phonological awareness, and verbal span/phonological loop functioning (Numbers Forward). Our findings were supportive of our hypotheses and suggest that CE functioning is related to reading and math success, consistent with prior research (Geary, 2004; Swanson & Ashbaker, 2000; Walczyk & Raska, 1992; Wilson & Swanson, 2001). Not surprisingly, verbal intellect and phonological awareness also were related to reading ability. Verbal span was not predictive of word identification or reading comprehension when controlling phonological awareness, consistent with prior research (Kibby, 2007a; McDougall et al., 1994). As we did not have a measure of phonetic word attack/decoding in this study, future research is needed to assess whether verbal span is predictive of decoding skill, as suggested by Kibby (2007a).

Conclusion

Children with RD present with reduced verbal STM but intact visual STM, CE, and LTM functioning. Their deficit in STM appears specific to tasks encouraging phonetic coding/storage of material. Children with ADHD have intact verbal WM and LTM functioning, along with most aspects of STM. They tend to have mild deficits in visual-spatial STM and verbal span, with the latter possibly being due to factors other than span per se (e.g., fluctuating attention). Children with RD/ADHD have deficits consistent with both disorders without additional deficits. Hence, when working with children with RD, it is important to put verbal material in a context during initial learning and link it to what they already know, to reduce the need for phonetic coding by the individual. Another alternative would be to supplement verbal instruction with visual aides and demonstrations. For children with ADHD, it would be important to provide repetition during initial learning, so that if they miss material the first time, they are more likely to encode it during the next presentation. Stimulant medication may ameliorate their visual-spatial STM deficit. For the entire clinical sample CE functioning was related to academic success. Hence, children may benefit from written instruction and notes (when they can read) to supplement oral instruction so that they do not have to maintain excessive information in their WM. They also may benefit from exercises/techniques designed to enhance WM.

Certain limitations of this study should be noted. In view of the relatively small sample size per group, results should be confirmed with a larger sample. Future research also should include measures of visual WM and pseudoword decoding/word attack. In addition, future research should include a control sample that completes all the same measures as the clinical sample and a clinical sample that completes all of the same measures, including the same version of the IQ test. It also should include better control of medication usage, and should compare dyslexia definitions to see if memory functioning differs for those identified under an IDEA discrepancy definition versus a DSM or poor reader definition. Nonetheless, a strength of this study is that it uses a clinic sample and a clinical measure of memory functioning, enhancing the generalizability of its findings. Many clinic studies do not have access to typically developing controls, and many individuals in clinics are not administered all of the same measures. Another limitation of this study is that we do not know the number of first-time diagnoses of ADHD in our sample. This information was not coded. Hence, some of the children tested off medication were diagnosed for the first time on the basis of our testing (i.e., they were medication naïve), whereas others were tested off medication because of the referral question. It would be interesting to compare these groups in future research. Future research should examine the role of stimulant medication in ADHD STM/WM performance, as we found an effect specific to visual-spatial STM.

Acknowledgements

This study was supported in part by a grant (1 R03 HD048752-01) awarded to the first author (MYK) from the National Institute of Child Health and Human Development (NICHD), National Institutes of Health. Portions of this data were presented at the annual meeting of the International Neuropsychological Society, February 2006 conference.

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Appendix

CMS Subtest	Description of Subtests
Verbal	
Stories	In Stories Immediate two stories are read to the child, and the child is asked to repeat each story immediately after it is told. In Stories Delayed the child is asked to retell each story after a delay of about 30 minutes. In Stories Delayed Recognition the child is asked yes/no questions about each story.
Word Pairs	In Word Pairs Learning the child is read a list of paired words and then asked to say the second word after being told the first. The list is presented three times in this fashion. After the third list/cued recall trial the child is asked to tell the examiner as many word pairs as he can with no cues (Word Pairs Immediate). After about 30 minutes the child

CMS Subtest	Description of Subtests
	is given the cued recall trial again (Word Pairs Delayed). Then the child is asked whether or not various pairs were on the list (Word Pairs Delayed Recognition).
Word Lists	Word Lists Learning uses a selective reminding procedure; the list is presented 4 times. After the fourth presentation of the first list, a distracter list is presented (unscored), then the child is asked to recall the first list again (part of Word Lists Total – not used for this study). After about a 30 minute delay, the child is asked to recall the first list again (Word Lists Delayed), then he/she is asked whether or not various words were on the first list (Word Lists Delayed Recognition).
Visual	
Dot Locations	Dot Locations Learning presents an array of dots (6 or 8 positions depending upon the child's age), which is learned over 3 trials. Next, a distracter array is presented (unscored). Immediately after this the child is asked to reproduce the initial array of dots (Dot Locations Short Delay). Following about a 30 minute delay the child is asked to reproduce the initial array again (Dot Locations Delayed)
Faces	In Faces Immediate a series of faces are presented one at a time. Next, the child is asked to say yes or no if the face being presented was one of the faces from the initial list. In Faces Delayed, about 30 minutes later the child is asked whether or not each face was one of the faces on the initial list.
Attention/Concentration	
Numbers	Numbers Forward requires a child to repeat a series of numbers of gradually increasing length. Numbers Backward requires a child to repeat the series of numbers in reverse order. This task is similar to Digit Span (WISC-III).
Picture Locations	This subtest presents an array of items (animals or vehicles), with the array gradually increasing in item number. Each array is presented for 2 seconds in contrast to Dot Locations where it is presented for 5 seconds.
Sequences	This subtest measures the ability to mentally manipulate verbal material. Items include saying the days of the week backward and alternating counting with saying the alphabet.

Note. For all subtests each component is scored separately (i.e., Immediate, Delayed, Delayed Recognition).

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Table 1

Participant Demographic Data

Variable	Controls		Reading Disability		RD/ADHD		ADHD	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	9.40	2.14	9.18	2.59	9.44	2.47	9.67	2.28
WISC-III/IV FSIQ	100.93	10.05	100.30	10.22	96.47	11.19	99.83	13.17
VCI	99.30	10.51	97.91	10.27	96.63	12.62	101.52	14.49
PRI/POI	100.67	11.16	108.48	11.81	101.53	13.06	100.17	13.44
WMI/FDI	104.43[a,b]	12.32	91.26[b,d]	10.43	89.23[a,c]	14.21	100.07[c,d]	12.03
PSI	108.03[c,d]	14.33	96.78[d]	11.60	94.86[c]	15.42	98.93	14.14
Gender	73% male		70% male		87% male		70% male	
Race	95% Caucasian		96% Caucasian		97% Caucasian		90% Caucasian	

Note. This study used the WISC-III until the WISC-IV became available.

[a] $p < .001$;

[b] $p = .001$;

[c] $p \leq .01$;

[d] $p < .05$

Table 2

Academic Achievement and Questionnaire Descriptive Data

Variable	Reading Disability		RD/ADHD		ADHD	
	Mean	SD	Mean	SD	Mean	SD
Word Identification	80.17[a]	10.51	79.48[b]	10.29	102.50[d]	11.94
Reading Comprehension	87.42[a]	15.18	81.24[b]	15.75	104.21[a,b]	14.26
Spelling	83.18[a]	10.70	82.33[b]	10.58	100.27[a,b]	11.97
Math Calculation	95.74	16.44	90.93	17.22	99.57	13.47
BASC Parent form						
Attention Problems	57.48[a,b]	9.48	67.27[a]	9.39	67.07[b]	8.02
Hyperactivity	50.78[d]	15.99	60.72[d]	12.82	56.10	11.04
BASC Teacher form						
Attention Problems	56.13[a,b]	8.05	66.17[a]	5.97	66.10[b]	8.19
Hyperactivity	50.22[c]	5.82	57.53[c]	9.31	52.10	9.38
Conner's Rating Scales						
Parent form AD	7.59[a,c]	5.82	14.17[a]	5.59	12.77[c]	6.04
Teacher form AD	8.77[a,c]	5.09	15.97[a]	5.24	14.77[c]	7.13

Note. This data was not available on controls. Word Identification was measured by one of the following: WRAT-3/4 Reading, WJ-III Letter-Word Identification, WIAT/WIAT-II Word Recognition, or GORT-3/4 Passage/Fluency, but typically WRAT-3/4 Reading.

Reading Comprehension was measured by one of the following: GORT Comprehension, WJ-III Passage Comprehension, or WIAT Reading Comprehension, but typically GORT Comprehension. Spelling was measured by one of the following: WRAT Spelling or WIAT Spelling, but typically WRAT Spelling. Math Calculation was measured by one of the following: WRAT Arithmetic, WJ-III Calculation, or WIAT Numerical Operations, but typically WRAT Arithmetic. All of the academic achievement data is in standard scores. BASC data is in T-scores. Conner's Parent and Teacher Rating Scales were modified by Cohen (Cohen, 1988; Cohen & Hynd; 1986). AD stand for Attention-Deficit/Hyperactivity Disorder factor and is reported in raw scores.

[a] $p \leq .001$;

[b] $p \leq .001$;

[c] $p < .01$;

[d] $p = .05$

Table 3

Children's Memory Scale Descriptive Data

Variable	Controls		Reading Disability		RD/ADHD		ADHD	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Verbal Measures								
Stories I	98.67	16.24	103.48	9.22	99.67	14.68	103.33	17.34
Stories D	102.83	18.13	104.13	9.96	99.33	14.96	103.83	16.85
Stories DR	100.17	11.18	100.89	12.31	96.67	16.78	106.90	16.71
Word Pairs L	99.33	15.63	95.87	14.35	94.33	14.84	98.00	14.54
Word Pairs I	94.83	13.55	98.70	13.33	95.33	14.40	99.33	11.87
Word Pairs D	100.83	13.71	95.87	16.63	89.83	18.31	97.00	13.43
Word Pairs DR	97.33	13.82	96.74	17.23	88.50	20.31	97.93	17.35
Word Lists L[b]	100.50	16.58	87.78	13.72	87.67	13.07	94.29	15.12
Word Lists D[a]	103.83	13.56	93.33	14.36	94.67	14.45	97.14	23.42
Word Lists DR[b]	99.33	15.74	90.00	17.68	86.00	18.73	101.43	14.64
Visual Measures								
Dot Locations L[c]	103.50	11.61	102.61	12.42	97.67	15.01	96.17	15.01
Dot Locations SD	102.17	10.64	104.78	15.19	107.17	12.01	102.17	13.56
Dot Locations D	105.33	11.74	104.57	12.51	102.17	11.72	100.00	15.03
Faces I	96.83	11.63	94.78	11.43	90.83	15.60	100.00	11.65
Faces D[d]	93.50	13.01	95.00	10.98	98.97	14.78	102.59	11.70
Attention/Concentration Measures								
Numbers Forward[e,f]	106.67	9.32	90.43	12.70	87.50	11.94	93.33	15.67
Numbers Backward[e]	100.00	10.99	93.70	11.40	92.83	12.43	105.83	13.33
Sequences[e,c]	102.00	11.42	88.48	14.26	83.83	13.50	97.17	14.12
Picture Locations[d]	105.33	15.48	102.27	14.45	94.66	16.85	93.70	15.35

Note. L refers to Learning; I refers to Immediate recall; SD refers to Short-Delay recall; D refers to Delayed recall; DR refers to Delayed Recognition. Significance levels are in terms of main effects (RD vs. No RD; ADHD vs. No ADHD) from the MANOVAs.

[a]RD at $p < .05$.

[b]RD at $p < .01$.

[c]ADHD at $p < .05$.

[d] ADHD at $p < .01$.

[e] RD at $p < .001$.

[f] ADHD at $p = .001$.

Table 4

Summary of Hierarchical Regression Analysis on Variables Predicting Word Identification

Variable	B	SE B	β
Step 1			
WISC VCI	0.59	0.15	.49***
Step 2			
WISC VCI	0.30	0.13	.24*
NEPSY Phonological	0.61	0.11	.60***
Step 3			
WISC VCI	0.29	0.13	.24*
NEPSY Phonological	0.61	0.11	.59***
CMS Numbers Forward	0.01	0.11	.01
Step 4			
WISC VCI	0.32	0.12	.27**
NEPSY Phonological	0.44	0.11	.43***
CMS Numbers Forward	−0.02	0.10	−.02
CMS Sequences	0.35	0.10	.34**

Note. Step 1 $r^2 = .24$, $p < .001$; Step 2 $\Delta R^2 = .29$, $p < .001$; Step 3 $\Delta R^2 = .00$, $p > .10$; Step 4 $\Delta R^2 = .09$, $p < .01$.

* $p < .05$.

** $p \leq .01$.

*** $p < .001$.

Table 5

Summary of Hierarchical Regression Analysis on Variables Predicting Reading Comprehension

Variable	B	SE B	β
Step 1			
WISC VCI	0.81	0.19	.53***
Step 2			
WISC VCI	0.48	0.18	.31*
NEPSY Phonological	0.60	0.15	.49***
Step 3			
WISC VCI	0.50	0.19	.33**
NEPSY Phonological	0.61	0.15	.49***
CMS Numbers Forward	−0.09	0.15	−.07
Step 4			
WISC VCI	0.55	0.18	.36**
NEPSY Phonological	0.39	0.16	.32*
CMS Numbers Forward	−0.10	0.14	−.07
CMS Sequences	0.43	0.16	.33**

Note. Step 1 $r^2 = .28$, $p < .001$; Step 2 $\Delta R^2 = .19$, $p < .001$; Step 3 $\Delta R^2 = .00$, $p > .10$; Step 4 $\Delta R^2 = .08$, $p < .01$.

* $p < .05$.

** $p \leq .01$.

*** $p < .001$.

Table 6

Summary of Hierarchical Regression Analysis on Variables Predicting Math Calculation

Variable	B	SE B	β
Step 1			
WISC VCI	0.45	0.17	.35**
Step 2			
WISC VCI	0.31	0.18	.24
NEPSY Phonological	0.29	0.16	.27
Step 3			
WISC VCI	0.29	0.19	.23
NEPSY Phonological	0.29	0.16	.26
CMS Numbers Forward	0.06	0.16	.05
Step 4			
WISC VCI	0.34	0.18	.26
NEPSY Phonological	0.08	0.16	.07
CMS Numbers Forward	0.02	0.15	.01
CMS Sequences	0.44	0.15	.40**

Note. Step 1 $r^2 = .12$, $p = .01$; Step 2 $\Delta R^2 = .06$, $p < .10$; Step 3 $\Delta R^2 = .00$, $p > .10$; Step 4 $\Delta R^2 = .13$, $p < .01$.

* $p < .05$.

** $p \leq .01$.