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Memory Functioning in Developmental Dyslexia: An Analysis Using Two Clinical Memory Measures

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Abstract

The goals of this project were threefold: to determine the nature of the memory deficit in children/adolescents with dyslexia, to utilize clinical memory measures in this endeavor, and to determine the extent to which semantic short-term memory (STM) is related to basic reading performance. Two studies were conducted using different samples, one incorporating the Wide Range Assessment of Memory and Learning and the other incorporating the California Verbal Learning Test-Children's Version. Results suggest that phonological STM is deficient in children with dyslexia, but semantic STM and visual–spatial STM are intact. Long-term memory (LTM) for both visual and verbal material also is intact. Regarding reading performance, semantic STM had small correlations with word identification and pseudo-word decoding across studies despite phonological STM being moderately to strongly related to both basic reading skills. Overall, results are consistent with the phonological core deficit model of dyslexia as only phonological STM was affected in dyslexia and related to basic reading skill.

Keywords: Dyslexia; Reading disabilities; Child; Adolescent; Short-term memory; Long-term memory

Introduction

Over the past few decades a great deal of research has been conducted on short-term memory (STM) functioning in children with dyslexia. Although many suggest that verbal STM is impaired in this population (for reviews see Baddeley & Hitch, 1994; Jorm, 1983; McDougall & Hulme, 1994), the findings on visual STM have been disparate. Several researchers have found that visual STM is intact in dyslexia (Jeffries & Everatt, 2004; Kibby & Cohen, 2008; Kibby et al., 2004; McDougall, Hulme, Ellis, & Monk, 1994; for a review see Jorm, 1983; McDougall & Hulme, 1994), whereas others have found that visual STM is impaired even when using stimuli that cannot be verbally coded (Henry, 2001; Howes, Bigler, Burlingame, & Lawson, 2003; Howes, Bigler, Lawson, & Burlingame, 1999; Kaplan, Dewey, Crawford, & Fisher, 1998).

Furthermore, there is debate regarding the nature of the verbal STM deficit in dyslexia. Many suggest that the deficit is a result of difficulty encoding material by its sound (called "phonetic coding" and "phonological STM" for the purposes of this study; Kibby, in press; Kibby & Cohen, 2008; Wagner, Torgesen, & Rashotte, 1994), whereas encoding material by its meaning is intact (called "semantic coding" and "semantic STM" for the purposes of this study; Jorm, 1983; Lee & Obrzut, 1994). Consistent with this belief, poor phonological processing is considered to be the 'core' deficit in dyslexia (Liberman & Shankweiler, 1991; Rack, Snowling, & Olson, 1992; Stanovich, 1988; Wagner et al., 1994), and phonological STM is one component of phonological processing. Nonetheless, some researchers have found semantic STM deficits in dyslexia (Delis, Kramer, Kaplan, & Ober, 1994; Kaplan et al., 1998; Kramer, Knee, & Delis, 1999). Thus, the verbal STM impairment may be more general in nature or specific to phonological coding.

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An issue receiving limited research over the past few decades is whether long-term memory (LTM) is intact in dyslexia when deficits at encoding are controlled. Moreover, the few studies conducted in this area have yielded inconsistent results, with one researcher finding impaired verbal LTM (Kaplan et al., 1998) and others reporting intact verbal and visual LTM (Jorm, 1983; Kibby & Cohen, 2008; Kramer et al., 1999). Another topic requiring further investigation is semantic STM's relation to word identification and decoding skill. Although several researchers have found phonological STM to be predictive of basic reading skill (Cormier & Dea, 1997; Hansen & Bowey, 1994; Kibby, in press; for a review see Bishop & Snowling, 2004), limited research has been conducted on semantic STM's relation to basic reading ability.

Hence, the purposes of this project were threefold: to determine the nature of the memory deficit in children with dyslexia, to utilize clinical measures of memory in this endeavor, and to determine the extent to which semantic STM is related to basic reading performance. In terms of the second purpose, much of the prior research on dyslexia has utilized experimental measures of memory functioning, limiting its generalizability for clinical neuropsychologists at large who use clinical measures. Therefore, the Wide Range Assessment of Memory and Learning (WRAML; Sheslow & Adams, 1990) and the California Verbal Learning Test-Children's Version (CVLT-C; Delis et al., 1994) were used, as the WRAML assesses phonological, semantic, and visual STM, along with LTM, and the CVLT-C assesses semantic coding, STM, and LTM. Two studies were conducted using different samples, one including the WRAML and the other including the CVLT-C. Thus, much of the remainder of the article will discuss the two studies separately.

Study 1

Limited research has been conducted on the WRAML in dyslexia despite its frequent use in clinical practice. Of the research conducted, Kaplan and colleagues (1998) found that children with dyslexia performed worse than controls on STM subtests that foster phonetic coding (Sentence Memory, Sound Symbol, and Number/Letter). They also performed worse than controls on Verbal Learning, a STM measure that allows semantic coding (task entails four learning trials using familiar words that can be recalled in any order). Nonetheless, they still performed within the Average range on this subtest. Children with dyslexia performed comparable to controls on Story Memory, a STM subtest which fosters semantic coding. They also performed comparable to controls on most measures of visual STM except Finger Windows, a measure of serial-order visual–spatial STM. Children with dyslexia performed worse than controls on one measure of LTM (Story Memory savings score). Taken together, the findings of Kaplan and colleagues suggest that the memory deficits in dyslexia may extend beyond phonological STM.

Despite the findings of Kaplan and colleagues (1998), it was hypothesized that children with dyslexia would perform worse than controls on the phonological STM subtests only; performance on the rest of the measures would be intact given the literature reviewed in the general introduction. It was also hypothesized that phonological STM (Number/Letter) would be related to Word Attack but semantic STM (Story Memory) would not due to the phonological nature of decoding. Examination of semantic STM's relation to word identification was exploratory, given the limited research examining the relation between the two skills.

Materials and Methods

Participants

Twenty children with dyslexia and 20 controls, ages 9–13 years, were tested with the WRAML. These data were collected during an earlier study (Kibby, Marks, Morgan, & Long, 2004). Sixty percent of the dyslexia group were male, and 45% of the control group were male. Groups were equated on prior diagnosis of Attention-Deficit/Hyperactivity Disorder (ADHD), age, grade level, gender, and socio-economic status (SES). Children with a prior diagnosis of ADHD were included in the study due to the high comorbidity between dyslexia and ADHD (Holborow & Berry, 1986; Shaywitz, Fletcher, & Shaywitz, 1994). However, parents of children with ADHD reported that their child had sufficiently mild ADHD so as to not warrant medication. Presence of ADHD was equated across the groups: three children in the dyslexia group and two children in the control group.

Dyslexia was diagnosed according to State of Tennessee criteria for a specific learning disability in reading, as children with dyslexia were recruited through the local school system. To be diagnosed with a learning disability by the State at the time of data collection, children had to be of normal intelligence, reading below grade level, and have at least a 1 *SD* discrepancy between their reading ability and measured intelligence. In addition, their reading problems could not be better accounted for by a medical/neurological condition, sensory or motor impairment, emotional disturbance, or quality of education. Children were selected for this study through review of school records once school and parental permission were obtained.

To be included in the dyslexia group, there had to be at least a standard deviation discrepancy between the child's measured intellect and his/her word identification standard score given State learning disability criteria. Poor word identification was chosen as the defining feature as opposed to poor reading comprehension because poor decoding skills are the central deficit in most definitions of dyslexia/reading disability (Lyon, Fletcher, & Barnes, 2003). Intelligence and academic achievement scores were obtained from school records. All the State's school psychologists used the Wechsler Intelligence Scale for Children-Third Edition (WISC-III) to measure intelligence. They used one of the following measures to assess academic achievement: Wide Range Achievement Test-Revised, Wechsler Individual Achievement Test, or the Woodcock-Johnson-Revised Tests of Achievement (WJ-R). As the discrepancy level required by the State was small, some children had a mild form of dyslexia. Nonetheless, the mean discrepancy in the dyslexia group was 25.70 standard score points (range: 15–55).

Controls were recruited through the University's subject pool (undergraduates brought them in for testing with parental consent), as well as through flyers and advertisements in the local community. A screening version of the WISC-III was administered to the control group to reduce testing time. The screening version included Information, Vocabulary, Picture Completion, and Block Design. This short-form is highly correlated ($r = .94$) with the full battery (Sattler, 1992). IQ scores were prorated from this battery, with Verbal IQ (VIQ) being prorated from Vocabulary and Information and Performance IQ (PIQ) being prorated from Picture Completion and Block Design. Academic achievement was screened with the Wide Range Achievement Test-Third Edition (WRAT-3) to verify that controls did not have an IQ/word identification discrepancy. Controls also were screened for prior special education evaluation and assistance and for repetition of grade levels to ensure that they did not have a history of learning problems. All children were administered the WJ-R Word Attack subtest to assess their phonological decoding skill. The mean prorated Full-Scale IQ/WRAT-3 Reading discrepancy for the control group was −7.10 (range: −39 to +10). There was an overlap in reading ability between the two groups for two controls whose WRAT-3 Reading scores were 85 and 92, as the highest word identification standard scores for the dyslexia group were in the 90s. The rest of the controls had WRAT-3 Reading standard scores that were greater than 100.

All children were screened for uncorrected sensory impairment, medical conditions, neurological conditions (including seizures and traumatic brain injury), and psychiatric disorders through a questionnaire completed by the parent. Children were excluded from the study if they had any of these conditions, except for allergies or mild ADHD. No child was prescribed mood altering or stimulant medication. All children were fluent in English. All children also had a measured intellect of 80 or above.

The two groups were compared to assess how well they were equated on age, grade level, gender, SES, and IQ. Groups were comparable in age, grade, FSIQ, PIQ, and VIQ using ANOVA (p's $> .10$). They also were comparable in gender, SES, and presence of ADHD using chi square (ps $> .10$). Groups differed in word identification [$F(1, 37) = 65.83$, $p < .001$], WJ-R Word Attack [$F(1, 37) = 44.17$, $p < .001$], and spelling ability [$F(1, 35) = 23.04$, $p < .001$] but were comparable in math calculation skills [$F(1, 36) = 3.18$, $p > .05$]. See Table 1 for descriptive data.

Measures

The WRAML purports to be the first comprehensive measure of memory functioning for children/adolescents (Bigler & Adams, 2001). The verbal STM subtests include immediate memory for stories (Story Memory), sentences (Sentence Memory), word lists

Table 1. Participant descriptive data for the Wide Range Assessment of Memory and Learning study

Characteristic	Dyslexia, *M* (*SD*)	Controls, *M* (*SD*)
Age	11.10 (1.38)	11.36 (1.48)
Grade	4.68 (1.25)	5.25 (1.52)
SES	2.47 (.84)	2.40 (.68)
FSIQ	102.70 (12.85)	104.50 (9.86)
VIQ	101.75 (12.80)	105.95 (12.94)
PIQ	104.30 (14.35)	103.30 (13.18)
Word identification***	80.95 (11.67)	111.60 (11.91)
Spelling***	86.82 (13.23)	105.35 (10.24)
Arithmetic	94.72 (13.17)	102.65 (14.13)
Articulation rate	1.86 (.42)	1.98 (.37)
WJ-R Word Attack***	12.84 (4.99)	22.45 (4.01)

Notes: Socioeconomic status (SES) was measured on a 5-point scale according to the Hollingshead (1975) Four Factor Index of Social Status. Articulation rate was recorded in number of words spoken per second. Word Attack was measured in raw scores.
***$p < .001$.

Table 2. Partial correlations among the Wide Range Assessment of Memory and Learning Verbal Short-term Memory measures controlling articulation rate

Variables	Verbal Learning	Sentence Memory	Sound Symbol	Number/Letter Memory
Story Memory	.51***	.26	.35*	.19
Verbal Learning		.29	.46**	.18
Sentence Memory			.38*	.59***
Sound Symbol				.32*

Notes: *$p \leq .05$.
**$p < .01$.
***$p \leq .001$.

(Verbal Learning), and number/letter strings (Number/Letter Memory), along with Sound Symbol. Although Sound Symbol requires paired associate learning of nonsense sounds and symbols, researchers have suggested that it loads more heavily on verbal factors than visual ones (Burton, Mittenberg, Gold, & Drabman, 1999; Dewey, Kaplan, & Crawford, 1997). The visual STM measures include immediate memory for meaningful scenes (Picture Memory), serial recall for strings of spatial positions (Finger Windows), and STM for geometric figures (Design Memory) and spatial positions (Visual Learning). STM subtests have an *M* of 10 and an *SD* of 3. LTM is measured through savings scores, subtracting number of items recalled at long-delay from those recalled at short-delay. Hence, deficits at encoding are controlled. Measures with savings scores include Story Memory, Verbal Learning, Sound Symbol, and Visual Learning. Story Memory also has a long-delay recognition subtest.

The WRAML has been described in detail elsewhere including its reliability and validity (Bigler & Adams, 2001; Sheslow & Adams, 1990); therefore, its psychometric properties will not be discussed here. Prior research suggests verbal STM tests that require serial order recall, verbatim recall, or non-word recall necessitate greater phonetic coding than those which permit recall of words/sentences in any order (Henry, 2001; Howes et al., 2003; Swank, 1994). Thus, based on their content, the verbal STM subtests likely vary in the extent to which they support semantic coding, with Story Memory fostering the greatest semantic coding, then Verbal Learning as the words are familiar and can be recalled in any order, then Sentence Memory as verbatim repetition is required, and lastly Number/Letter. Number/Letter may require the greatest reliance on phonetic coding as the stimuli are presented orally, encouraging focus on their phonological rather than their orthographic characteristics; the stimuli are not words; and the stimuli must be recalled in serial order. This proposed ordering of subtests, from those fostering the greatest semantic coding to those fostering the greatest phonetic coding, is consistent with subtest inter-correlations (see Table 2 for inter-correlations).

Articulation rate was assessed as the verbal STM buffer is reported to hold as much information as an individual can say in 2 s (Baddeley, 1986). Articulation rate was measured using a modified approach from Roodenrys, Hulme, and Brown (1993). Specifically, children were presented with 40 words in 20 pairs. Each pair of words was repeated as often as necessary for the child to say the pair correctly. Once the child could repeat the word pair accurately, he/she had to say the pair 10 times as quickly as possible, and the time required to do this was recorded. The mean of these times was transformed to yield a measure of items spoken per second. Groups had comparable articulation rates [$F(1, 37) = 1.02$, $p > .10$].

Procedure

The WRAML, Word Attack, and articulation rate measures were administered on the first day of testing after parental informed consent/child informed assent were obtained. The WISC-III screener and WRAT-3 were administered to controls on a second testing day.

Results

The Wide Range Assessment of Memory and Learning

Three sets of MANOVAs were run to test for group differences in memory performance: one containing the verbal STM subtests, one containing the visual STM subtests, and one containing the LTM savings scores. For the verbal STM measures, the omnibus tests were significant [$F(5, 33) = 3.25$, $p < .05$]. At the univariate level groups differed on Sentence Memory [$F(1, 37) = 4.96$, $p < .05$] and Number/Letter Memory [$F(1, 37) = 17.05$, $p < .001$]. Group differences approached significance on Sound Symbol, $F(1, 37) = 3.63$, $p = .06$. In contrast, the groups performed comparably on Story Memory [$F(1, 37) < 1.0$, $p > .10$] and Verbal Learning [$F(1, 37) < 1.0$, $p > .10$]. The omnibus tests were not significant for the visual STM measures [$F(4, 34) < 1.0$, $p > .10$] nor the LTM savings scores [$F(5, 31) < 1.0$, $p > .10$]; furthermore, none of the univariate tests were significant. See Table 3 for WRAML descriptive data.

Table 3. WRAML performance by group

Subtests by area	Dyslexia, *M* (*SD*)	Controls, *M* (*SD*)
Verbal STM Scaled Scores		
Story Memory	9.42 (3.15)	10.40 (3.49)
Verbal Learning	9.74 (2.62)	10.50 (3.09)
Sound Symbol	9.11 (2.75)	10.90 (3.11)
Sentence Memory*	8.42 (2.27)	10.80 (2.26)
Number/Letter Memory***	6.84 (2.34)	9.70 (1.98)
Visual STM Scaled Scores		
Picture Memory	10.37 (2.11)	10.95 (2.44)
Design Memory	10.21 (2.07)	9.90 (2.22)
Visual Learning	10.68 (2.77)	11.15 (3.20)
Finger Windows	9.16 (3.05)	9.05 (2.28)
LTM Savings Scores[a]		
Story Memory	3.94 (0.66)	3.95 (0.69)
Verbal Learning	3.53 (1.01)	3.85 (1.27)
Sound Symbol	3.76 (1.35)	3.85 (1.42)
Visual Learning	3.71 (0.92)	4.25 (0.97)
Story Recognition	3.94 (0.83)	4.10 (0.97)

Note: [a]For the LTM Savings measures, scores are normed as follows: 1 is Atypical; 2 is Borderline; 3 is Low Average; 4 is Average, and 5 is Bright Average.
*$p < .05$.
***$p < .001$.

Table 4. Partial correlations between phonological/semantic STM and basic reading performance controlling Full-Scale IQ and articulation rate

Variables	Number/Letter Memory	Word Recognition	Word Attack
Story Memory	.11	.09	.23
Number/Letter Memory		.53***	.70***
Word Recognition			.76***

Note: ***$p \leq .001$.

Verbal Short-term Memory

As children with dyslexia were hypothesized to have greater difficulty with phonological STM than semantic STM, a paired *t*-test was run to compare performance on Number/Letter and Story Memory. The paired *t*-test was significant for the dyslexia group [$t(18) = 3.76$, $p = .001$], but it was not significant for the control group [$t(19) = 0.78$, $p > .10$].

Basic Reading Performance

Using the total sample, partial correlations were conducted between Story Memory, Number/Letter Memory, word identification and Word Attack, controlling Full-Scale IQ and articulation rate. In order to determine whether verbal STM may be directly related to basic reading ability, articulation rate was controlled given work by McDougall and colleagues (1994) which suggests slow articulation rate may mediate the relation between verbal STM and basic reading skill. FSIQ was controlled to see if verbal STM is related to reading performance beyond general intellectual ability. See Table 4. Results did not change when not controlling FSIQ: Story Memory had small correlations with word identification ($r = .12$, $p > .10$) and Word Attack ($r = .24$, $p > .10$), but Number/Letter had moderate to large correlations with word identification ($r = .55$, $p < .001$) and Word Attack ($r = .70$, $p <$ 001).

Discussion

Memory Performance

Consistent with hypotheses, children with dyslexia performed worse than controls on the phonological STM subtests. Some caution in interpretation is warranted, however, as mild ADHD was allowed in the sample and Number/Letter Memory has been shown to load on an attention factor (Burton et al., 1999). Nonetheless, presence of ADHD was comparable between both groups, and Number/Letter was highly correlated with phonological skill (WJ-Word Attack) in this sample. In contrast to phonological STM, the two groups were quite comparable in semantic STM, visual-spatial STM, and LTM for both verbal and visual material, with the dyslexia group scoring within the Average range on these measures. Moreover, the dyslexia group performed worse on phonological STM (Number/Letter) than semantic STM (Story Memory), whereas controls performed comparably on these two subtests. Hence, the memory deficit in dyslexia appears to be specific to phonological STM, with the rest of memory functioning being intact. This finding is consistent with the phonological core deficit model of dyslexia (Liberman & Shankweiler, 1991; Rack et al., 1992; Swank, 1994; Wagner et al., 1994).

Basic Reading Performance

Phonological STM was moderately to highly correlated with word identification and decoding skill in the total sample, even when controlling Full-Scale IQ and articulation rate. This finding is consistent with hypotheses and prior research (Hansen & Bowey, 1994; Snowling, 1991; Wagner et al., 1994). In contrast, correlations between semantic STM and basic reading measures were small. Therefore, semantic STM may play a limited role in basic reading performance when older children are studied. However, future research is indicated to determine whether semantic STM contributes substantially to reading comprehension, as both tasks require semantic processing. Future research also is warranted on semantic STM's relation to basic reading skill in individuals with language impairment.

Study 2

Similar to the WRAML, limited research has been conducted on individuals with dyslexia using the California Verbal Learning Test (CVLT). Only one published study was found which used the CVLT-C to study children with dyslexia (Kramer et al., 1999), and no published studies were found using the CVLT or CVLT-II in adults with dyslexia. This could be a serious shortcoming in the literature given that the CVLT variants measure semantic coding, storage and retrieval, along with intrusions and interference. Therefore, the CVLT-C has the potential to be an excellent tool to decipher the nature of the semantic STM/LTM deficit in dyslexia if there is one.

The findings on the CVLT-C by Kramer and colleagues (1999) suggest that children with dyslexia have poor encoding of word lists but intact retention and retrieval over time, along with intact interference and intrusion scores. Children with dyslexia learned fewer items in general, and they learned the items more slowly. They also had different serial position effects than controls, recalling fewer items from the middle of the list. According to the authors, these findings are consistent with poor encoding because of faulty strategy use during rehearsal. Nonetheless, given the literature reviewed in the general introduction, group differences were not expected on the CVLT-C as this measure fosters semantic coding.

Materials and Methods

Participants

Eighteen children with dyslexia and 18 controls were tested with the CVLT-C. These data were collected during an earlier study (Kibby, in press). In the dyslexia group, 61% of participants were males; in the control group 56% of participants were males. Groups were equated on age, grade level, gender, SES, and WISC-III FSIQ, similar to Study 1.

Children with dyslexia and controls were recruited and defined according to the same criteria and procedures used in Study 1, although children with a history of ADHD or suspected ADHD were excluded from this study. Presence of ADHD was determined on the basis of parental report and review of school records. The mean IQ/word identification discrepancy for the dyslexia group was 21.94 (range: 15–44); the mean prorated Full-Scale IQ/WRAT-3 Reading discrepancy for the control group was −7.17 (range: −29 to +5).

The two groups were comparable in age, grade level, gender, SES, FSIQ, and PIQ. They differed in VIQ [$F(1, 34) = 9.77$, $p < .01$], word identification [$F(1, 34) = 55.61$, $p < .001$], WJ-R Word Attack [$F(1, 33) = 41.34$, $p < .001$], spelling [$F(1, 34) = 21.08$, $p < .001$], and arithmetic [$F(1, 34) = 9.15$, $p < .01$], with controls scoring higher (see Table 5 for descriptive data).

Table 5. Participant descriptive data for the CVLT-C study

Characteristic	Dyslexia, *M* (*SD*)	Controls, *M* (*SD*)
Age	12.27 (1.11)	11.97 (1.87)
Grade	5.61 (1.14)	5.72 (1.99)
SES	2.33 (1.08)	2.11 (.68)
FSIQ	101.11 (8.55)	104.72 (9.95)
VIQ**	98.50 (9.94)	108.50 (9.24)
PIQ	104.67 (10.87)	101.61 (15.02)
Word identification***	84.00 (8.75)	111.89 (13.23)
Spelling***	84.61 (11.90)	105.44 (15.13)
Arithmetic**	91.50 (12.56)	105.67 (15.40)
WJ-R Word Attack***	13.41 (5.27)	23.06 (3.47)
Articulation rate	2.27 (.51)	2.68 (.46)

Notes: SES was measured on a 5-point scale using the Hollingshead (1975) Four Factor Index of Social Status. Word Attack was measured in raw scores. Articulation rate was recorded in number of words spoken per second.
**$p < .01$.
***$p < .001$.

Measures

The CVLT-C is a word list test that fosters semantic coding of material. Similar to other memory tasks, it includes measures of STM and LTM. However, the CVLT-C only measures verbal learning and memory. As the CVLT-C has been described in detail elsewhere (Bigler & Adams, 2001; Delis et al., 1994), only a brief description of the test is provided here. The child is presented with a list of 15 familiar words that can be grouped into three categories (List A). The test measures immediate recall of List A over five learning trials, free and cued short-term recall of List A after a distracter list (List B), and free and cued long-term recall of List A. After long-term cued recall of the list, recognition testing of List A is performed (Discriminability Index). The recognition task includes the words from Lists A and B, as well as other words that are semantically related to List A, phonetically similar to it, and unrelated to it.

The CVLT-C yields several scores. These include two measures of strategy use: semantic clustering (spontaneously grouping the words by category) and serial clustering (recalling the words in serial order). Semantic clustering is purported to be the more active learning strategy and may be associated with better learning and retention (Delis et al., 1994). The CVLT-C computerized scoring program was used to generate the scores. Articulation rate was assessed with a task similar to that used in Study 1, modified from Hulme, Maughan, and Brown (1991). When controlling VIQ, children with dyslexia and controls were comparable in articulation rate.

Results

Immediate Memory, Short-term Memory, and Long-term Memory

WISC-III VIQ was used as a covariate due to group differences on this measure. Given low power, analyses also were re-run without a covariate.

For immediate memory, total number of words recalled and rate of acquisition over the five learning trials were analyzed through repeated measures analysis of covariance (ANCOVA). Diagnosis was the between-subject variable (dyslexia versus control), and Trial was the within-subject variable (raw scores on Trials 1–5). Diagnosis [$F(1, 33) = 1.89$, $p > .10$] and the Diagnosis X Trial interaction [$F(4, 132) < 1.0$, $p > .10$] were not significant. When VIQ was not used as a covariate, Diagnosis was significant [$F(1, 34) = 6.16$, $p < .05$], but the interaction was not. A repeated measures ANCOVA was used to assess retention over time. The within-subject variable was Recall (Trial 5, Short-delay, and Long-delay Free Recall raw scores). Diagnosis and the Diagnosis X Recall interaction were not significant (F's < 1.0, p's $> .10$). Moreover, groups did not differ in delayed recognition when using ANCOVA [$F(1, 33) < 1.0$, $p > .10$]. Results for short- and long-delayed recall and recognition did not change when using ANOVA (see Table 6 for CVLT-C descriptive data).

Serial position effects were assessed using repeated measures ANCOVA. Position (number of words immediately recalled from the primacy, middle, and recency portions of the list) was the within-subject variable. Diagnosis was not significant [$F(1, 33) = 1.72$, $p > .10$], nor was the Diagnosis X Position interaction [$F(2, 66) < 1.0$, $p > .10$]. Results did not change when using repeated measures ANOVA. Strategy use was assessed using the clustering scores from List A Trials 1–5. Using

Table 6. CVLT-C performance by group

Subtests by area	Dyslexia, *M* (*SD*)	Controls, *M* (*SD*)
Immediate Memory		
List A Total Trials 1–5	47.61 (13.08)	57.28 (9.48)
List A Trial 1	6.00 (1.53)	6.94 (1.43)
List A Trial 5	11.33 (2.89)	12.72 (1.84)
List A Semantic Clustering	1.55 (0.62)	1.57 (0.36)
List A Serial Clustering	2.35 (2.34)	2.26 (1.79)
List A Primacy Region	29.52 (6.73)	28.63 (3.89)
List A Middle Region	42.75 (6.20)	42.51 (3.13)
List A Recency Region	27.73 (6.66)	27.75 (8.05)
List B	5.89 (1.78)	6.67 (1.85)
STM		
List A Short-Delay Free Recall	10.22 (3.49)	11.78 (2.53)
LTM		
List A Long-Delay Free Recall	10.67 (3.18)	11.83 (1.86)
Discriminability Index	94.94 (6.89)	96.17 (4.69)
False-Positives	0.89 (1.37)	0.94 (1.76)

Notes: The Discriminability Index is in standard scores, and List A Total Trials 1–5 is a T-score. The Clustering scores are measured in observed/expected, and the Region scores are in percentages. The rest are raw scores. There are no group differences when controlling Verbal IQ.

ANCOVA, groups were highly comparable in semantic clustering [$F(1, 33) < 1.0$, $p > .10$] and serial clustering [$F(1, 33) < 1.0$, $p > .10$]. Results did not differ when ANOVA was used.

Basic Reading Performance

Using the total sample, partial correlations were conducted between List A Trials 1–5, word identification, and Word Attack, controlling FSIQ and articulation rate, following the procedure used in Study 1. Consistent with Study 1, partial correlations between List A Trials 1–5 and the basic reading measures were small ($r = .24$ with word identification and $r = .25$ with Word Attack, p's $> .10$). Pearson correlations between List A Trials 1–5 and the basic reading measures were not significant ($r = .30$ with word identification and $r = .30$ with Word Attack, p's $> .05$) when not controlling FSIQ.

Discussion

Memory Performance

When VIQ was statistically controlled, performance on the CVLT-C was highly comparable between the two groups as hypothesized. This was true for immediate, STM, and LTM, as well as semantic clustering. When VIQ was not controlled, groups only differed in immediate recall. However, this difference in performance likely was because of the high proportion of controls with above average VIQ (72% of controls vs. 11% of the dyslexia group, $\chi^2(1) = 13.83$, $p < .001$), as those with high VIQ performed better than the rest of the sample on List A Trials 1–5 [$F(1, 34) = 4.45$, $p < .05$]. Furthermore, the mean T-score from List A Trials 1–5 was Average for the dyslexia group despite it being better for the control group. In general, children with dyslexia scored in the Average range on all CVLT-C measures when using z-scores, suggesting that their semantic STM and LTM are intact.

Basic Reading Ability

Similar to Study 1, there were small correlations between immediate semantic memory and measures of basic reading performance when FSIQ and articulation rate were controlled, and there were non-significant correlations between immediate semantic memory and basic reading when not controlling FSIQ. Hence, semantic STM may not contribute substantially to word identification and decoding skill in older children, unlike phonological STM. However, further research is needed on the relation between semantic STM and reading comprehension and on individuals with language impairment, as noted in Study 1.

General Discussion

Taken together, results suggest the primary memory deficit in children with dyslexia is poor phonological STM, with the rest of memory functioning being spared. More specifically, in Study 1 all aspects of visual STM were intact in dyslexia at the group level despite some prior research finding visual STM impairment in this population (Henry, 2001; Howes et al., 1999, 2003; Kaplan et al., 1998). Study 1's findings of Average visual STM in dyslexia is consistent with other work in this area, however (Kibby & Cohen, 2008; Kibby, Marks, et al., 2004; McDougall et al., 1994). LTM also appears to be spared in dyslexia, as LTM was comparable to controls across the two studies regardless of whether material was verbal or visual in nature. Similar results were found by Kibby and Cohen (2008). Given the limited research conducted on LTM in dyslexia to date, this is an important contribution to the literature.

In terms of verbal STM, semantic STM was intact in both studies despite their using different samples and measures. Intact semantic STM in dyslexia also has been found by Kibby and Cohen (2008) and Lee and Obrzut (1994). In contrast, phonological STM was impaired in dyslexia in Study 1, consistent with prior research (Kibby, in press; Kibby & Cohen, 2008; Rack et al., 1992; Wagner et al., 1994). As it has been suggested that there are at least two verbal short-term stores, one for phonetically coded material and another for semantically coded material (Martin, Shelton, & Yaffee, 1994), the store which holds material coded phonetically likely is affected in dyslexia, whereas the store(s) which holds material coded semantically may be intact. The phonological store may be located within/around the supramarginal gyrus (Kibby et al., 2004; Jonides et al., 1998), and the posterior peryisylvian region is frequently implicated in dyslexia (for a review see Kibby & Hynd, 2001). In contrast, semantic processing is wide-spread throughout the brain, including both hemispheres (Kolb & Wishaw, 2003). Such wide-spread networks may provide sparing of semantic coding/STM in dyslexia as other brain regions may be able to help compensate for left posterior perisylvian dysfunction.

Limitations to this research with corresponding future directions are as follows. First, sample sizes were small, and overall severity of dyslexia was mild for both studies. Hence, this study should be replicated with a larger sample of children with more severe dyslexia to determine whether deficits are still limited to phonological STM. Second, mild ADHD was allowed in the first study, but the small number of participants with ADHD made further analysis of its effects problematic. Furthermore, presence of ADHD was assessed through review of school records and parent report for both studies. Consequently, future research on memory functioning in dyslexia should formally assess for the presence and severity of ADHD. Nonetheless, the memory deficits found in Studies 1 and 2 are consistent with dyslexia, as ADHD tends to be associated with poor visual–spatial STM functioning (Kibby & Cohen, 2008) and visual–spatial STM was intact in Study 1. Third, an abbreviated WISC-III and the WRAT-3 were used with controls to minimize testing time, but the full WISC-III and various achievement batteries were used to assess children with dyslexia. Given the two groups had different IQ measures, this may have affected analyses where IQ was controlled in some fashion (partial correlations, ANCOVA). Thus, future studies should use the same IQ and achievement battery for all participants. Nonetheless, the IQ screening version used with controls has a high correlation with the full WISC, and results did not differ substantially when IQ was not controlled. Fifth, this project utilized a large age range. Therefore, future research should utilize a tighter age range. Sixth, working memory/central executive (CE) functioning was not assessed in this study, as neither the WRAML nor the CVLT-C have measures of CE functioning. Finally, neither study had a measure of reading comprehension. As a result, future research on STM's relation to reading comprehension is necessary.

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Conflict of interest:

None declared.

References

Baddeley, A. (1986). *Working memory*. New York, NY: Oxford University Press.

Baddeley, A. D., & Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropsychology*, *8*, 485–493.

Bigler, E. D., & Adams, W. V. (2001). Clinical neuropsychological assessment of child and adolescent memory with the WRAML, TOMAL, and CVLT-C. In A. Kaufman, & N. Kaufman (Eds.), *Specific learning disabilities and difficulties in children and adolescents: Psychological assessment and evaluation* (pp. 387–429). New York, NY: Cambridge University Press.

Bishop, D. V. M., & Snowling, M. J. (2004). Developmental dyslexia and specific language impairment: Same or different? *Psychological Bulletin*, *130*, 858–886.

Burton, D. B., Mittenberg, W., Gold, S., & Drabman, R. (1999). A structural equation analysis of the Wide Range Assessment of Memory and Learning in a clinical sample. *Child Neuropsychology*, *5*, 34–40.

Cormier, P., & Dea, S. (1997). Distinctive patterns of relationship of phonological awareness and working memory with reading development. *Reading and Writing*, *9*, 193–206.

Delis, D. C., Kramer, J. H., Kaplan, E., & Ober, B. A. (1994). *California Verbal Learning Test–Children's Version*. San Antonio, TX: Psychological Corporation.

Dewey, D., Kaplan, B. J., & Crawford, S. G. (1997). Factor structure of the WRAML in children with ADHD or reading disabilities: Further evidence of an attention/concentration factor. *Developmental Neuropsychology*, *13*, 501–506.

Hansen, J., & Bowey, J. A. (1994). Phonological analysis skills, verbal working memory, and reading ability in second-grade children. *Child Development*, *65*, 938–950.

Henry, L. A. (2001). How does the severity of a learning disability affect working memory performance? *Memory*, *9*, 233–247.

Holborow, P. L., & Berry, P. S. (1986). Hyperactivity and learning difficulties. *Journal of Learning Disabilities*, *19*, 426–431.

Howes, N. L., Bigler, E. D., Burlingame, G. M., & Lawson, J. S. (2003). Memory performance of children with dyslexia: A comparative analysis of theoretical perspectives. *Journal of Learning Disabilities*, *36*, 230–246.

Howes, N. L., Bigler, E. D., Lawson, J. S., & Burlingame, G. M. (1999). Reading disability subtypes and the test of memory and learning. *Archives of Clinical Neuropsychology*, *14*, 317–339.

Hulme, C., Maughan, S., & Brown, G. D. (1991). Memory for familiar and unfamiliar words: Evidence for a long-term memory contribution to short-term memory span. *Journal of Memory and Language*, (30), 685–701.

Jeffries, S., & Everatt, J. (2004). Working memory: Its role in dyslexia and other specific learning difficulties. *Dyslexia*, *10*, 196–214.

Jonides, J., Schumacher, E. H., Smith, E. E., Koeppe, R. A., Awh, E., & Reuter-Lorenz, P. A.et al. (1998). The role of parietal cortex in verbal working memory. *Journal of Neuroscience*, *18*, 5026–5034.

Jorm, A. F. (1983). Specific reading retardation and working memory: A review. *British Journal of Psychology*, *74*, 311–342.

Kaplan, B. J., Dewey, D., Crawford, S. G., & Fisher, G. C. (1998). Deficits in long-term memory are not characteristic of ADHD. *Journal of Clinical and Experimental Neuropsychology*, *20*, 518–528.

Kibby, M. Y. (in press). There are multiple contributors to the verbal short-term memory deficit in children with developmental reading disabilities. *Child Neuropsychology*. Doi: 10.1080/09297040902748218.

Kibby, M. Y., & Cohen, M. J. (2008). 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. *Child Neuropsychology*, *14*, 525–546.

Kibby, M. Y., & Hynd, G. W. (2001). Neurobiological basis of learning disabilities. In D. Hallahan (Ed.), *Research and global perspectives in learning disabilities* (pp. 25–42). Mahwah, NJ: Erlbaum.

Kibby, M. Y., Kroese, J. M., Morgan, A. E., Hiemenz, J. R., Cohen, M. J., & Hynd, G. W. (2004). The relationship between perisylvian morphology and verbal short-term memory functioning in children with neurodevelopmental disorders. *Brain and Language*, *89*, 122–135.

Kibby, M. Y., Marks, W., Morgan, S., & Long, C. J. (2004). Specific impairment in developmental reading disabilities: A working memory approach. *Journal of Learning Disabilities*, *37*, 349–363.

Kolb, B., & Whishaw, I. Q. (2003). *Fundamentals of human neuropsychology* (5th ed.). New York, NY: Worth Publishers.

Kramer, J. H., Knee, K., & Delis, D. C. (1999). Verbal memory impairments in dyslexia. *Archives of Clinical Neuropsychology*, *15*, 83–93.

Lee, C. P., & Obrzut, J. E. (1994). Taxonomic clustering and frequency associations as features of semantic memory development in children with learning disabilities. *Journal of Learning Disabilities*, *27*, 454–462.

Liberman, I. Y., & Shankweiler, D. (1991). Phonology and beginning reading: A tutorial. In L. P. Rieben, & A. Charles (Eds.), *Learning to read: Basic research and its implications* (pp. 3–17). Hillsdale, NJ: Erlbaum.

Lyon, G. R., Fletcher, J. M., & Barnes, M. C. (2003). Learning disabilities. In E. J. Mash, & R. A. Barkley (Eds.), *Child Psychopathology* (pp. 520–586). New York, NY: Guilford Press.

Martin, R. C., Shelton, J. R., & Yaffee, L. S. (1994). Language processing and working memory: Neuropsychological evidence for separate phonological and semantic capacities. *Journal of Memory and Language*, *33*, 83–111.

McDougall, S., & Hulme, C. (1994). Short-term memory, speech rate and phonological awareness as predictors of learning to read. In C. Hulme, & M. Snowling (Eds.), *Reading development and dyslexia*. Chichester, UK: Wiley.

McDougall, S., Hulme, C., Ellis, A., & Monk, A. (1994). Learning to read: the role of short-term memory and phonological skills. *Journal of Experimental Child Psychology*, *58*, 112.

Rack, J. P., Snowling, M. J., & Olson, R. K. (1992). The nonword reading deficit in developmental dyslexia: A review. *Reading Research Quarterly*, *27*, 28–53.

Roodenrys, S., Hulme, C., & Brown, G. D. A. (1993). The development of short-term memory span: Separable effects of speech rate and long-term memory. *Journal of Experimental Child Psychology*, *56*, 431–442.

Sattler, J. M. (1992). *Assessment of Children*. (3rd ed.). San Diego, CA: Sattler.

Shaywitz, S. E., Fletcher, J. M., & Shaywitz, B. A. (1994). Issues in the definition and classification of attention deficit disorder. *Topics in Language Disorders*, *14*, 1–25.

Sheslow, D., & Adams, W. (1990). *Wide Range Assessment of Memory and Learning*. Wilmington, DE: JASTAK.

Snowling, M. J. (1991). Developmental reading disorders. *Journal of Child Psychology and Psychiatry*, *32*, 49–77.

Stanovich, K. E. (1988). Explaining the differences between the dyslexic and the garden-variety poor reader: The phonological-core variable-difference model. *Journal of Learning Disabilities*, *21*, 590–604.

Swank, L. K. (1994). Phonological coding abilities: Identification of impairments related to phonologically based reading problems. *Topics in Language Disorders*, *14*, 56–71.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psychology*, *30*, 73–87.