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EXAMINING VISUAL-VERBAL ASSOCIATIONS IN CHILDREN WITH AND WITHOUT READING DISORDER

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*The purpose of this study was to investigate verbal working memory processing both before and after providing semantically elaborated training sentences designed to enhance memory for symbol-word (visual-verbal) pairs. Abilities of 20 children diagnosed with Reading Disorder (RD) and 20 age-matched peers who were normally achieving in reading (NA) were compared (*M *= 10 years old). Results demonstrated RD children experienced significantly more difficulties on measures of complex auditory-verbal working memory than their NA peers. The best predictor of reading performance was word recall ability measured after students were provided with semantic training sentences. Findings have important implications for identifying young children with potential reading impairment.*

The importance of reading for learning and for functioning in the world cannot be overemphasized. For nearly 60% of children in the United States, learning to read presents some challenge. For 20–30% of these children, reading is one of the most difficult tasks they will attempt to master during their school years (Lyon, 1998). To read effectively, individuals must be able to make meaning of print. This requires coordinated orthographic and phonological skills: being able to understand a series of abstract lines and curves representing a sequence of letters with their corresponding sounds.

Researchers have identified three specific component processes of reading: (1) orthographic coding for identification of letter sequences corresponding to print; (2) phonological coding

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for manipulation of the sounds of oral language; and (3) semantic coding for deriving meaning from written language (Shaywitz et al., 1998). These component processes, which are all important to the development of efficient reading abilities, share the underlying construct of verbal working memory (VWM). For children at the early stages of reading, the ability to convert the alphabetic representations of letters to printed words and spoken language has been identified as a major factor in reading comprehension (Shankweiler et al., 1999). Difficulty with the mental representations of phonological information is the most frequently reported symptom of dyslexia (Shaywitz, 2003; Torgesen, Wagner, & Rashotte, 1999).

Given the importance that VWM plays in reading acquisition and performance, research further characterizing the relationship between VWM and reading capability is worthy of attention. To explore this relationship, children diagnosed with Reading Disorder (RD) and same-aged normally achieving (NA) readers can be compared in ability. The main purpose of the present study is to compare these groups on VWM skills both before and after providing semantically elaborated training sentences designed to enhance memory for symbol-word, or visual-verbal, pairs. This research thereby aims (1) to better understand the effects of semantic training (providing added verbal information) on children's VWM abilities and (2) to determine the best predictor of reading proficiency on a series of VWM tasks. According to Montgomery (2002), VWM is crucial to reading success. Individuals with lower VWM skill demonstrate poorer reading comprehension capabilities and tend to concentrate more of their resources upon decoding messages, thereby having fewer resources available to store information. This limited storage capacity may indicate that incoming information is not being sufficiently activated and thus may not be adequately recalled. Just and Carpenter (1992) explained the capacity constraints of comprehension, stating that limited working memory capacity affects storage, processing, accuracy, and speed.

Visual Orthographic Images and Working Memory

When individuals begin to learn to read, decoding initially requires allocation of mental resources that result in reduced reading comprehension (Kamhi & Catts, 1999). As children learn spelling patterns and gain orthographic knowledge, they store this information in memory (Ehri, 1991). Phonological awareness skills contribute to the development of visual orthographic images (VOI) in memory (Share & Stanovich, 1995). Beginning readers may require as few as four visual exposures of a word to develop a VOI (Ehri & Saltmarsh, 1995). Once the VOI is established, readers automatically access the word's mental representation rather than decoding it so that stored mental images are used for decoding new words. The ability to use a direct visual route with minimal phonological mediation to access semantic memory for word meaning is crucial for developing automatic word recognition, fluent reading, and ultimately more efficient comprehension.

Without automatic orthographic knowledge, readers would have to sound out long multisyllabic words and rely on the more inefficient and time-consuming phonological route to read (Kamhi & Catts, 2002). Therefore, although phonological knowledge is needed to map sounds to letters and learn the orthographic patterns, it is orthographic knowledge that appears necessary to make reading automatic and to help an individual become a fluent, successful reader. According to Share and Stanovich (1995), print exposure to words helps whole words to be viewed as a unit and recognized as an entity. It may not be possible to become a skilled reader by relying on sound-letter correspondence rules alone (Shaywitz, 2003).

Visual-Verbal Integration and Working Memory

Verbal working memory (VWM) is integral to assessing potential reading impairment in children. This is because reading requires working memory to recall the connections of speech sounds to printed letters, recognize those letter patterns quickly for fluent reading of words, and understand what is read. It has been documented that individuals with reading disability have difficulty with visual-verbal integration and working memory processing (Swanson & Berninger, 1995). Each person's working memory system has capacity limitations that determine how much information can be successfully processed at a given moment.

Baddeley (1992) contends that working memory is a multi-component, capacity-limited system with central executive control that regulates the flow of information. An articulatory, or phonological, loop is responsible for temporary storage of verbal information in the form of phonological input (Baddeley, Gathercole, & Papagno, 1998). Poor readers may have a normally functioning articulatory loop that is more limited in capacity (Baddeley, 1986). The ability to use a short-term storage strategy such as verbal rehearsal for phonological processing assists the listener in holding onto phonological speech representations so that utterances can be processed and comprehended. Montgomery (2002) believes that phonological working memory is essential to deciphering and encoding orthographic patterns of print to create more permanent phonological representations of language as well as for retrieving information for reading comprehension. One can imagine how difficult it would be to comprehend a sentence if the semantic representations, or word meanings under construction, are forgotten by the time the end of the statement is uttered or read.

Previous studies investigated the awareness of rhyme, syllables, word/sentence segmentation, and sound blending to establish links between working memory and reading (Baddeley, 1979; Bradley & Bryant, 1983; Fox & Routh, 1983). However, according to Baddeley (1986), storage and processing are required to work simultaneously if one learns to read with comprehension.

Recent research indicates that the inability to link phonology with orthography and meaning results in an inefficient pattern-recognition template (Pugh et al., 2001). Interference and limited capacity problems have been implicated in reading difficulties (Perfetti, 1999). The more phonologically and orthographically complex words are, the more the reader must rely on lower-level memory processes to decipher them (Perfetti, 1985).

The role of working memory in reading ability has been theoretically established and identifies intact phonological working memory ability as necessary for lexical acquisition and forming speech-sound associations. However, little work has been done to examine how well children who have been diagnosed with Reading Disorder perform on working memory tasks beyond the specific skill of phonological processing (Gathercole, Service, Hitch, Adams, & Martin, 1999).

Applying Verbal Working Memory Theory

The idea that children with reading difficulties may have problems developing strategies to engage working memory is not new. Carlisle (2001) found that students with reading and language-learning disabilities were at a disadvantage when free recall for stories was used to assess comprehension. In an effort to determine strategies for enhanced learning, Swanson (1989) examined verbal word recall in four groups of children (mildly mentally retarded/poor readers, average intelligence/reading disabled, average intelligence/average readers, and high intelligence/proficient readers) and found that the reading disabled group was the only group that did not show enhanced learning when provided with an elaborative encoding strategy. Bauer and Emhert (1984) investigated memory span and recency/primacy effects. Children with reading disabilities were comparable to normal readers in recalling the last words uttered in a list of ten words (recency effects) but were deficient in total list recall and primacy word recall (first words uttered from the list). Difficulties with information processing and working memory capacity limitations were implicated. When comparing memory for objects between poor readers and age-matched peers, poor readers recalled significantly fewer words and demonstrated a less developed ability for categorizing the objects (Torgesen, 1985). However, when given an association strategy using a sorting technique, the poor readers improved. In the present study, we investigate whether children diagnosed with Reading Disorder will improve in word recall when provided with semantic associations for pictured symbols. We question if such semantic training will enhance children's verbal recall or constrain their capacity.

According to Howes, Bigler, Lawson, and Burlingame (1999), studies comparing different learning and memory processes for children with reading disabilities are valuable for clinicians and educators. Wood and Algozzine (1991) recommend using a test-teach-test paradigm to help determine the effects of teaching on learning and memory. The present study used a test-teach-test model, with semantic training provided at the teaching stage to help children remember new visual-verbal pairs. Although successful encoding and thus similar performance on recognition memory tasks was anticipated, it was hypothesized that RD children would perform below their NA peers in free recall.

Research Questions

Given the capacity limitations of verbal working memory (VWM) on language-based tasks and the possibility that children diagnosed with Reading Disorder may have difficulty enacting strategies to assist memory performance, two theoretically based questions were explored through the current research project. First, can VWM efficiency for word and symbol recall be improved by providing semantic associations using training sentences? Second, which VWM variables are most related to reading performance?

Method

Participants

Twenty children diagnosed with Reading Disorder (RD) were matched by age and sex with 20 normally achieving (NA) peers. There was no significant difference between the groups in age, $t(38) = -.03$, $p = .98$: RD $M = 121.35$, $SD = 28.25$ months, *range* = 76–166 months; NA $M = 121.60$, $SD = 25.53$ months, *range* = 81–165 months. There were 19 males and 1 female in each group. All participants were Caucasian and were members of middle-class suburban or rural families living in the Eastern Shore region of Maryland. Referrals for children with Reading Disorder were obtained from the Director of a small, 60-student private elementary/middle school that services children with learning difficulties from several Maryland counties. Educational files of all students were reviewed. Of the 28 children referred over a 2-year period, 8 were excluded from the experimental group due to their pattern of cognitive deficits (i.e., generalized academic impairment; severe receptive language impairment) or questionable evidence of any reading deficits in the school records. The remaining 20 RD students had all been previously diagnosed with Reading Disorder by a licensed psychologist and met the traditional diagnostic criteria of having a significant discrepancy between intellectual and reading measures (American Psychiatric Association, 2000). Although these selection criteria made the RD group true to the traditional definition, it is debatable whether the difference score method of identifying children with learning disorders is necessary (discussed in Sternberg & Grigorenko, 2002). The 20 matched NA students were randomly selected from a larger pool of participants who were enrolled at various nearby public and private schools and who had no known developmental delays, sensory impairments, or psychiatric/learning disability diagnoses as verified through parental consent forms.

To determine that the two groups were fairly comparable in vocabulary knowledge, a gross measure of verbal intelligence was obtained through total scores on the Expressive One Word Picture Vocabulary Test (Gardner, 1990; described in Table 1). Analyses showed that there was no difference between the groups on vocabulary scores, $t(38) = -.74$, $p = .47$, with average age equivalents in both groups being higher than their corresponding chronological age averages (RD $M = 131.45$, $SD = 17.29$ months; NA $M = 135.45$, $SD = 17.11$ months). To verify that the RD and NA groups held substantially different skill sets in the area of reading, an educational reading screener (Chall, Roswell, Fletcher, & Richmond, 1998; described in Table 1) was used to show that RD children had significantly poorer scores, $t(38) = -4.24$, $p =< .001$; RD $M = 78.05$, $SD = 23.27$; NA $M = 100.80$, $SD = 5.78$.

Procedure

Participants were secured over a 2-year period, with school and parent permission being obtained for all participants. Using standardized testing procedures in accordance with test manuals, the chosen cognitive measures were individually administered by two trained psychology student evaluators under the supervision of a Ph.D. licensed psychologist. Testing took place in the school conference room or small office and lasted no longer than one hour per participant.

Initially, the evaluator gained rapport by telling the student that he or she would be doing a number of activities that would take about an hour. It was further explained that some tasks would be easy and others may be more difficult. Each student was asked to do their best and was told that they would be able to take short breaks between the activities. It was also conveyed that if they did

TABLE 1 Testing Battery

Name of Test	Author(s), Year	Purpose	Task(s)
Expressive One Word Picture Vocabulary Test	Gardner, 1990	Semantic knowledge and verbal naming abilities; considered a gross estimate of verbal intelligence	Name black and white pictures
The Screening Assessment for Reading	Chall, Roswell, Fletcher, and Richmond, 1998	Gross measure of children's reading ability	Read lists of words of increasing difficulty, name capital and lower case letters, produce consonant sounds, and read words with short and long vowel sounds
Phonological Processing subtest from the NEPSY: A Developmental Neuropsychological Assessment	Korkman, Kirk, and Kemp, 1998	Phonological processing from a developmental neuropsychological perspective	(1) Choose one of a series of three pictures corresponding to a syllable within the pictured word, and (2) Create a new word by omitting a syllable or phoneme or substituting one phoneme in a word for another
Digit Span Forward and Backward from the WISC-III Test (Wechsler Intelligence Scale for Children)	Wechsler, 1991	Auditory-verbal short-term memory ability measuring rote verbal capacity (forward) and complex working memory (backward)	(1) Repeat an increasing series of numbers in same order, and (2) Reverse the order of the sequence heard and say the numbers backwards
Word Associations subtest from the Clinical Evaluation of Language Fundamentals—3	Semel, Wiig, and Secord, 1995	Verbal fluency relating to semantic knowledge	Say as many words as possible that fit into a given category within one minute
Association Memory Test	Klein and Littlefield, 2000	Symbol-word learning and verbal working memory	Recall words associated with drawings and name drawings before and after semantic training sentences

not like doing the activities, they could stop. No students requested this option.

Test order was random with the exception of the Association Memory Test (AM Test; Klein & Littlefield, 2000) being administered first in the battery and the Phonological Processing subtest of the NEPSY (Korkman, Kirk, & Kemp, 1998) being administered last. The AM Test was given first because it requires new memory formations with which other measures could potentially interfere. Phonological Processing was given last because it was expected that children with Reading Disorder may find this task especially challenging. Thus, the potential of the Phonological Processing task to frustrate and possibly hamper additional test performance was considered.

Tests Administered

Table 1 organizes the battery of tests administered by listing the name of each measure, its source, its purpose, and a brief description of the task required by examinees. Aside from the AM Test, all measures within the standardized testing battery are nationally marketed and published by large educational and psychological companies. Formal manuals were available and indicated acceptable reliability and validity quotients.

The Appendix provides the AM Test protocol (Klein & Littlefield, 2000). Briefly, the AM Test procedure involves presentation of 15 black and white line drawings while being told the word for each one. After a free recall phase, the same symbol-word pairings are presented along with a semantically elaborated sentence designed to assist in forming visual-verbal associations. A second free recall phase follows. The AM Test, piloted on 125 kindergarten and first grade children and 24 second to fourth grade children, demonstrated adequate reliability and strong validity (Klein & Littlefield, 2000). The measure is experimental for the age range used in the present study.

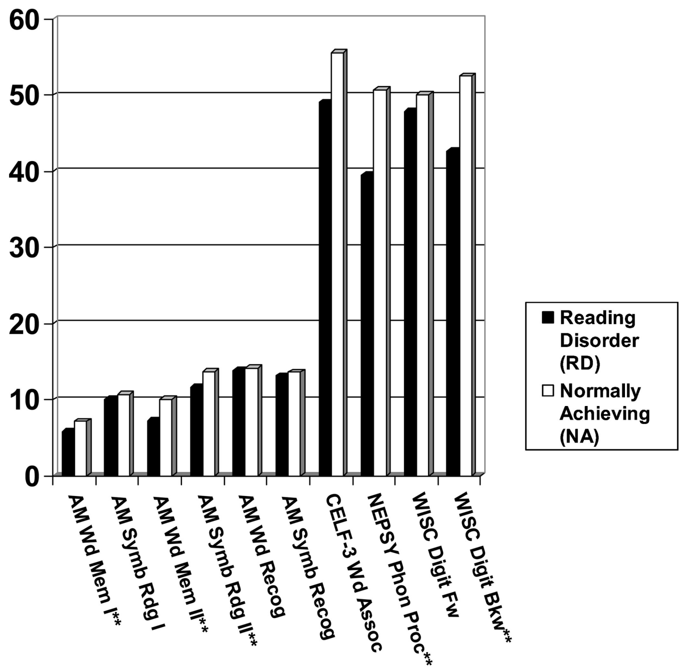
Results

A strict probability cut-off of .01 was established for group comparisons due to the small sample sizes. Students diagnosed with Reading Disorder (RD) performed significantly poorer on Word

TABLE 2 Descriptive Statistics and Group Comparisons on the Testing Battery

Test/Cognitive Construct	Reading Disorder Group $n = 20$ *Means (SDs)*	Normally Achieving Children $n = 20$ *Means (SDs)*	Corrected Probability Level	R^2
AM Test Word Memory I Raw score out of 15	5.80 (2.14)	7.20 (2.12)	<.01	.30
AM Test Symbol Reading I Raw score out of 15	10.10 (3.34)	10.75 (3.18)	.13	.06
AM Test Word Memory II Raw score out of 15	7.25 (2.94)	10.10 (2.29)	<.01	.42
AM Test Symbol Reading II Raw score out of 15	11.65 (2.94)	13.75 (1.52)	<.01	.27
AM Test Word Recognition Raw score out of 15	13.85 (1.27)	14.20 (1.06)	.45	−.01
AM Test Symbol Recognition Raw score out of 15	13.15 (1.63)	13.65 (1.42)	.02	.15
CELF-3 Word Association T-score	49.05 (8.37)	55.53 (12.15)	.03	.13
NEPSY Phonological Processing T-score	39.48 (7.65)	50.70 (8.88)	<.01	.33
WISC-III Digits Forward T-score	47.83 (9.73)	50.10 (12.09)	.73	−.04
WISC-III Digits Backward T-score	42.65 (7.32)	52.48 (10.64)	<.01	.19

Memory I, Word Memory II, and Symbol Reading II than did their normally achieving peers (NA) on the Association Memory Test (AM Test; Klein & Littlefield, 2000). Table 2 provides descriptive statistics and corrected probability levels resulting from covariate interaction analysis, with age being covaried due to the 7 year age range (from 6 to 13 years old) in the overall sample. Word Memory performance, both before and after semantically elaborated training sentences, was consistent across the age range. In other words, regardless of age, RD students generally performed more poorly than NA students in freely recalling words that represented



** indicates $p < .01$ for RD and NA group differences

FIGURE 1 Group comparisons on the testing battery detailed in Table 2.

symbols in new symbol-word pairs. As expected, there was no significant group difference found in recognition of words used in the AM Test (Word Recognition). Group differences are displayed pictorially in Figure 1.

Can Verbal Working Memory (VWM) Efficiency for Word and Symbol Recall be Improved by Providing Semantic Associations Using Training Sentences?

In order to determine whether the AM Test training sentences supported improvement in Word Memory II (free verbal recall for the 15 words after the training sentences) and Symbol Reading II (naming the 15 symbols after the training sentences), the groups were initially scored on word and symbol recall prior to presentation of the 15 training sentences. Using repeated measure ANOVAs, both groups significantly improved from Word Memory I

TABLE 3 Descriptive Statistics for AM Test Learning: Comparing Raw Scores from Before to After Semantically Elaborated Training Sentences

	Descriptives	RD Group Scores	NA Group Scores
Word Memory gains	*Mean*	1.45	2.90
	Median	1.5	3
	Mode	1	2, 3
	Range	−4 to 5	0 to 9
Symbol Reading gains	*Mean*	1.55	3.00
	Median	1.5	3
	Mode	0	3
	Range	−1 to 4	0 to 8

to Word Memory II and from Symbol Reading I to Symbol Reading II (all *p*s < .01; descriptive statistics presented in Table 3).

The NA group made more pronounced intra-individual gains than did the RD group with an average gain of 3.0 new visual-verbal pairings freely recalled by the NA group after the training sentences as compared to 1.5 new pairings recalled by the RD group. In 4 NA participants, no gains were made as they recalled most of the words prior to being presented with the training sentences. A similar near-ceiling effect was achieved in 5 RD participants. However, an additional 4 RD children reported fewer than half of the symbol-word pairs at pre-training and subsequently did not demonstrate gains post-training. Two RD children reported fewer words after the training sentences were given. Thus, all NA children either showed a near-ceiling effect upon first presentation of symbol-word pairs or demonstrated learning as a result of the training sentences. Overall, 6 of the 20 RD children had difficulty with free recall of the 15 words despite fairly good recognition scores.

Which Verbal Working Memory (VWM) Variables are Most Related to Reading Performance?

In addition to group differences on AM Test variables, it was hypothesized that the RD group would perform more poorly than the NA group on Phonological Processing, Digits Backward, and Word Association. Despite the small samples that would be expected to keep effect sizes low, effect sizes for statistically significant verbal working memory variables were moderate (adjusted R^2 values are shown in Table 2). Because Word Association scores from the CELF-3 (Semel, Wiig, & Secord, 1995) did not show a compelling difference between the groups ($p > .01$), this variable was eliminated from further analyses. Additionally, due to the high correlation and sameness in tasks between Word Memory I and Word Memory II, the former was not included as a regression equation predictor because the latter was able to better delineate group differences.

Regression analyses were conducted in order to explore which combination of the VWM variables best predicted reading raw scores (Chall, Roswell, Fletcher, & Richmond, 1998). Because RD and NA groups could potentially use different cognitive processes to support reading skills, separate regressions were performed for each group. Specifically, Backward Digit Span T-score, Phonological Processing T-score, AM Test Word Memory II raw score (freely recalling words after semantically elaborated sentences were presented verbally), and AM Test Symbol Reading II raw score (recalling words for symbols after semantically elaborated sentences were presented verbally) were identified as potential predictors in the two separate enter regressions. For the NA group, the overall regression was significant ($p < .001$; $R^2 = .802$), with all variables except for Phonological Processing T-score being significant predictors of reading ability (Tables 4 and 5). Although the proportion of variance accounted for in the RD group analysis was lower ($p = .025$; $R^2 = .503$), the only variable shown to predict reading raw score was Word Memory II (Tables 6 and 7).

TABLE 4 Regression Analysis Summary for Verbal Working Memory Variables Predicting Reading Scores in Normally Achieving Readers

Variable	**B**	**SEB**	β
Word Memory II	1.25	.33	.50**
Symbol Reading II	1.48	.52	.39**
Phonological Processing T-score	.03	.08	.05
Backward Digit Span T-score	.18	.07	.34*

Note. $R^2 = .80$ ($N = 20$, $p < .01$). $^{*}p < .05$; $^{**}p < .01$.

TABLE 5 Intercorrelations for Reading Score and Verbal Working Memory Variables in Normally Achieving Readers

Measure	1	2	3	4	5
1. Chall Reading Raw Score	—				
2. Backward Digit Span T-score	.49*	—			
3. Phonological Processing T-score	.26	.29	—		
4. Word Memory II	.73**	.17	−.01	—	
5. Symbol Reading II	.67**	.14	.29	.45*	—

* $p < .05$; ** $p < .01$.

Discussion

On the chosen test battery, the most pronounced differences between the groups indicated that students diagnosed with Reading Disorder (RD) struggled with: free recall of words after one presentation of novel visual-verbal pairings; free recall of symbols and words after the provision of semantically elaborated training sentences; phonological processing; and reporting digits backwards. Each of these tasks requires complex auditory-verbal memory processing for successful performance. This finding is particularly important because phonological processing skills are often thought to be at the root of reading difficulties, yet it appears that the development of phonological processing skills is ultimately made possible through intact auditory-verbal memory processing abilities. To support the notion that phonological processing skills are dependent on verbal working memory, the current results showed that being able to freely recall words following semantically elaborated sentences was the best predictor of word reading capability

TABLE 6 Regression Analysis Summary for Verbal Working Memory Variables Predicting Reading Scores in Reading Disorder Group

Variable	**B**	**SEB**	β
Word Memory II	6.75	2.52	.85*
Symbol Reading II	−2.01	2.61	−.26
Phonological Processing T-score	−.84	.63	−.28
Backward Digit Span T-score	.35	.62	.11

Note. $R^2 = .50$ ($N = 20$, $p < .05$). * $p < .05$.

TABLE 7 Intercorrelations for Reading Score and Verbal Working Memory Variables in Reading Disorder Group

Measure	1	2	3	4	5
1. Chall Reading Raw Score	—				
2. Backward Digit Span T-score	.29	—			
3. Phonological Processing T-score	−.13	.16	—		
4. Word Memory II	.61**	.33	.29	—	
5. Symbol Reading II	.32	.20	.45*	.80**	—

* $p < .05$;** $p < .01$.

for both RD and normally achieving (NA) children. This finding is similar to that found with 2nd–4th grade students in a pilot study of the AM Test that revealed significant paired correlations between 2nd graders' recall of words and their basal text reading ability in 4th grade (Klein & Littlefield, 2000).

When semantic elaborations were provided in the form of training sentences (Appendix), both the RD and NA groups performed at higher levels than they did after the first presentation of visual-verbal pairs. Although semantic elaborations appear to have a generally facilitative effect, the RD group evidenced fewer gains on average. Thus, RD children may benefit from repeated exposures to information, but as a group, they make gains at a slower rate than their same-aged peers with normal reading ability.

Not only was the total number of words produced by the RD group on the AM Test lower than the NA group but the RD group also appeared to commit a greater number of memory precision errors during recall. When recalling visual-verbal pairs after training sentences, errors were predominantly semantic in nature: saying "smile" or "happy" for the stimulus word "laugh"; saying "blocks" or "bricks" for the stimulus word "build." This may indicate less precise encoding and/or retrieval mechanisms. Informed by the findings of Kramer, Knee, and Delis (1999), it appears that RD populations may experience difficulty with semantic information. Semantic elaboration may inadvertently cause confusion for the RD student when presented as a memory enhancer.

It is speculated that memory imprecision in the form of semantic confusion is at least a partial contributor to the obtained results, but further work must be performed to confirm this hypothesis. A plausible explanation for the RD group exhibiting poorer free recall scores after training sentences than the NA group is that the sentences may be perceived as interference rather than memory facilitation. This has importance in teaching practices because educators often provide additional verbal information to get the point across to students. For example, when teaching sound-symbol correspondence by pairing a letter with the initial sound in a word (e.g., “a is for apple” or “b is for boat”), children may become confused as they try to attend to the verbal information while attempting to understand the semantic features of the word itself. The meaning of “apple” brings to mind a red or green fruit that is generally round and hard. This process of providing additional verbal cues may impede encoding in some RD children, perhaps due to VWM deficits.

On a theoretical level, it is believed that the RD group experienced difficulty holding information in memory while simultaneously manipulating it to select and freely recall the proper response; this difficulty is seated in the functioning of the central executive component of working memory (Baddeley, 1992). The hypothesis that the central executive component of working memory is playing a role for poor readers is consistent with the NEPSY Phonological Processing and WISC-III Digit Span Backwards findings. Both tasks appear to require use of the phonological loop and the central executive components of working memory. Retention is influenced by the ability to recall verbal information and simultaneously process added information without overloading the central executive component.

Deficits in memory seem to contribute to problems with phonological awareness, decoding, and reading comprehension (Brady & Fowler, 1988). To comprehend what is read, information must be kept active in working memory. According to Howes, Bigler, Lawson, and Burlingame (1999), students with reading disabilities tend to have less developed sequential verbal memory skills while good readers typically have more developed sequential visual and verbal memory skills. Other research has shown difficulties with phonetic coding in impaired readers who have poor verbal memory skills (Brady & Fowler, 1988). This may, in part, explain why the Phonological Processing T-score in this study was not significantly correlated with Symbol Reading II for the NA readers (see Table 5) but was significantly correlated with Symbol Reading II for the RD group of children (see Table 7). As reading becomes more proficient, phonological processing is less relied on during fluent reading. This further lends credence to the concept that VWM is associated with recall for symbols.

Individuals who have trouble holding information in working memory will also likely encounter comprehension difficulties. Swanson, Howell Ashbaker, and Lee (1996) further determined that poorer working memory capacity is associated with reading disorders. Swanson (1993) supports the notion that both visual and verbal working memory deficits are equally present in children diagnosed with math and reading disabilities, thus implying that working memory deficits are not specific to reading problems.

Study Limitations and Directions for Future Work

A limitation of the current project was the relatively small sample size that did not allow for more sophisticated statistical analyses. For instance, regression findings are in need of replication due to possible predictor variation. Although the Caucasian, predominantly male participants were matched by sex and age, a number of other variables were not controlled, although they were considered as criteria for selection in the study (e.g., academic testing scores, intelligence quotients, private vs. public school performance). However, regression effects from uncontrolled variables may have obscured some findings.

Because the mechanism underlying group differences remains controversial, future work should continue to systematically explore the relationship between Baddeley's phonological loop, visuospatial sketchpad, and central executive components of working memory in reading skills. The work of Swanson and colleagues is an important foundation in this direction (Swanson & Howell Ashbaker, 2000; Swanson & Howell, 2001). Although Reading Disorder is thought of as a verbal or language-processing disorder tapping into phonological loop processing, studies including the use of both the phonological loop and the visuospatial sketchpad may more effectively parse out the contributions these working memory modules play in reading ability. Perhaps such work could lead to further strides in guiding effective, individually tailored treatment protocols.

Clinical Application

Visual-verbal learning measures like the Association Memory Test (AM Test; Klein & Littlefield, 2000) can be useful in assessing potential reading deficits because learning to read fluently requires a similar type of task: deciphering or recalling a word given a series of visualized line-drawn symbols. The present research shows that complex auditory-verbal memory processing measures may yield better understanding of young children with reading difficulties by analyzing verbal working memory capabilities. Earlier identification allows therapists and teachers to intervene appropriately, thus curtailing further developmental lags.

Cutting and Denkla (2001) suggested that it is the quick access of visual-verbal associations that makes rapid automatic naming tasks most similar to the cognitive processing needed for reading. Research indicates that the more quickly a child can name a series of letters or numbers, the better a reader the child is likely to become (Shaywitz, 2003). Although the rapid automatic naming literature is promising on a theoretical level, it may present a concern when attempting to measure the capabilities of young children who do not yet know the names of letters, numbers, or colors. Van den Bos, Zijlstra, and Lutje Spelbert (2002) asserted that the development of number and letter naming is influenced by practice with arithmetic and reading tasks. Using the novel stimuli in the AM Test may be promising. It has been successfully administered to preschool-aged children ($M = 4.8$ years; $SD = 5.7$ months) regardless of their working knowledge of alphabet letters, colors, or numbers (Klein, Soule & Wertz, 2003).

Because reading is a language-based process requiring the ability to automatically convert a visually presented word into its semantic counterpart, the formation of precise associations for making meaning of print is crucial to reading. However, providing RD children with added verbal information and cues to enhance learning, as was done using semantically elaborated sentences described in this study, may be an inefficient use of valuable time in a proportion of cases. In light of this research and that of Baddeley (1986), it appears that reducing memory load and minimizing demands on verbal information storage are worthwhile considerations in helping some children at risk for reading difficulties.

References

American Psychiatric Association (2000). *Diagnostic and statistical manual of mental disorders TR* (4th ed. text revision). Washington, DC: Author.

Baddeley, A. D. (1979). Working memory and reading. In P. A. Kolers, M. E. Wrolstad, & H. Bouma (Eds.), *Processing of visible language* (pp. 355–370). New York: Plenum Publishing.

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

Baddeley, A. D. (1992). Working memory: The interface between memory and cognition. *Journal of Cognitive Neuroscience, 4,* 281–288.

Baddeley, A. D., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105,* 158–173.

Bauer, R. H., & Emhert, J. (1984). Information processing in reading-disabled and non-disabled children. *Journal of Experimental Child Psychology, 37,* 271–281.

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read: A causal connection. *Nature, 301,* 419–421.

Brady, S. A., & Fowler, A. E. (1988). Phonological precursors to reading acquisition. In R. I. Masland & R.W. Masland (Eds.), *Preschool prevention of reading failure* pp. (204–215). Parkton, MD: York Press.

Carlisle, J. F. (2001). Using free recall to assess and improve reading comprehension. *Perspective 27*(2), 10–13.

Chall, J., S. Roswell, F. G., Fletcher, M. B., & Richmond, D. (1998). *Teaching children to read.* Elizabethtown, PA: Continental Press.

Cutting, L. E., & Denkla, M. B. (2001). The relationship of serial rapid naming and word reading in normally developing readers: An exploratory model. *Reading and Writing: An Interdisciplinary Journal, 14,* 673–705.

Ehri, L. (1991). Development of the ability to read words. In R. Barr, M. Kamil, P. Mosenthal, & P. Pearson (Eds.), *Handbook of reading research* (Vol. 2, pp. 383–417). New York: Longman.

Ehri, L. C., & Saltmarsh, J. (1995). Beginning readers outperform older disabled readers in learning to read words by sight. *Reading and Writing: An Interdisciplinary Journal, 7,* 295–326.

Fox, B., & Routh, D. A. (1983). Reading disability, phonemic analysis, and a disphonetic spelling: A follow-up study. *Journal of Clinical and Child Psychology, 12,* 28–32.

Gardner, M. F. (1990). *Expressive One Word Picture Vocabulary Test—Revised.* Novato, CA: Academic Therapy Publications.

Gathercole, S., Service, E., Hitch, G., Adams, A., & Martin, A. (1999). Phonological short-term memory and vocabulary development: Further evidence on the nature of the relationship. *Applied Cognitive Psychology, 13,* 65–77.

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.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99,* 122–149.

Kamhi, A. G., & Catts, H. W. (1999). Reading development. In H. W. Catts and A. G. Kamhi (Eds.), *Language and reading disabilities* (pp. 15–59). Needham Heights, MA: Allyn & Bacon.

Kamhi, A. G., & Catts, H. W. (2002). The language basis of reading: Implications for classification and treatment of children with reading disabilities. In K. G. Butler and E. R. Silliman (Eds.), *Speaking, reading and writing in children with language learning disabilities* (pp. 45–72). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Klein, E. R., & Littlefield, L. M. (2000). *The association memory test.* Unpublished manuscript. Philadelphia, PA: LaSalle University.

Klein, E. R., Soule, K. V., & Wertz, J. A. (2003). Acquisition of logographics and the relationship to learning sounds of letters. Presented at *American Speech, Language, Hearing Association.* Chicago, IL. November 14, 2003.

Korkman, M., Kirk, U., & Kemp, S. (1998). *NEPSY: A Developmental Neuropsychological Assessment.* San Antonio, TX: Psychological Corporation.

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

Lyon, G. R. (1998). Overview of reading and literacy initiatives. *National Institute of Child Health and Human Development.* Washington, DC: Speech to the Committee on Labor and Human Resources.

Montgomery, J. (2002). Understanding the language difficulties of children with specific language impairment: Does verbal working memory matter? *American Journal of Speech-Language Pathology, 11,* 77–91.

Perfetti, C. A. (1985). *Reading ability.* New York: Oxford University Press.

Perfetti, C. A. (1999). Comprehending written language: A blueprint of the reader. In C. M. Brown & P. Hagoort (Eds.), *The neurocognition of language* (pp. 167–208). New York: Oxford University Press.

Pugh, K. R., Mencl, W. E., Jenner, A. R., Lee, J. R., Katz, L., Frost, S. J., et al. (2001). Neuroimaging studies of reading development and reading disability. *Learning Disabilities Research & Practice, 16*(4), 240–249.

Semel, E., Wiig, E. H., & Secord, W. A. (1995). *Clinical evaluation of language Fundamentals–Third Edition.* San Antonio: Psychological Corporation.

Shankweiler, D., Lundquist, E., Katz, L. Stuebing, K. K., Fletcher, J. M., Brady, S. A., et al. (1999). Comprehension and decoding patterns of association in children with reading difficulties. *Scientific Studies of Reading, 3,* 69–94.

Share, D., & Stanovich, K. (1995). Cognitive processes in early reading development: Accommodating individual differences into a model of acquisition. *Issues in Education, 1,* 1–57.

Shaywitz, S. E. (2003). *Overcoming dyslexia.* New York: Alfred A. Knopf.

Shaywitz, S. E., Shaywitz, B. A., Pugh, K. R., Fulbright, R. K., Constable, R. T., Mencl, W. E., et al. (1998). Functional disruption in the organization of the brain for reading in dyslexia. *Proceedings of the National Academy of Sciences, 95,* 2636–2641.

Sternberg, R. J., & Grigorenko, E. L. (2002). Difference scores in the identification of children with learning disabilities: It's time to use a different method. *Journal of School Psychology, 40,* 65–83.

Swanson, H. L. (1989). The effects of central processing strategies on learning disabled, mildly retarded, average, and gifted children's elaborative encoding abilities. *Journal of Experimental Child Psychology, 47*, 370–397.

Swanson, H. L. (1993). Working memory in learning disability subgroups. *Journal of Experimental Child Psychology, 56*, 87–114.

Swanson, H. L., & Berninger, V. (1995). The role of working memory in skilled and less skilled reader's comprehension. *Intelligence, 21*, 83–108.

Swanson, H. L., Howell Ashbaker, M., & Lee, C. (1996). Learning-disabled readers' working memory as a function of processing demands. *Journal of Experimental Child Psychology, 61*, 242–275.

Swanson, H. L., & Howell Ashbaker, M. (2000). Working memory, short-term memory, speech rate, word recognition and reading comprehension in learning disabled readers: Does the executive system have a role? *Intelligence, 28*, 1–30.

Swanson, H. L., & Howell, M. (2001). Working memory, short-term memory, and speech rate as predictors of children's reading performance at different ages. *Journal of Educational Psychology, 93*, 720–734.

Torgesen, J. K. (1985). Memory processes in reading disabled children. *Journal of Learning Disabilities, 18*, 350–357.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. (1999). *Test of word reading efficiency.* Austin, TX: PRO-ED.

Van den Bos, K. P., Zijlstra, B. J. H., & Lutje Spelbert, H. C. (2002). Life-span data on continuous-naming speeds of numbers, letters, colors, and pictured objects, and word reading speed. *Scientific Studies of Reading, 6*, 25–49.

Wechsler, D. (1991). *Wechsler intelligence scale for children—3rd Edition.* San Antonio, TX: Psychological Corporation.

Wood, K. D., & Algozzine, B. (1991). Using content-free assessment to improve reading instruction. *Diagnostique, 16*, 254–261.

Appendix

Association Memory Test Format (Klein & Littlefield, 2000)

Initial presentation involved viewing 15 black/white line drawings while being told the name for each one. *"Listen carefully. Don't say anything yet. Just look. When I am finished showing you all of the drawings, I will ask you to tell me as many of the words as you can remember."*

Word Memory I—Recall the words verbally from memory.

Symbol Reading I—Recall the words verbally from looking at each drawing.

The second presentation included viewing the 15 black/white line drawings again in the same order while being told a semantically associated sentence to go with each one. (The training sentences and corresponding black/white line drawings are listed in what follows.) *"I am going to tell you some sentences that may help you remember more of the words and drawings. Listen and look as I name each drawing."*

Baby. The baby likes her rattle. Baby.

Build. You can build with blocks. Build.

Break. Break the stick in half. Break.

Walk. Put your boot on and walk. Walk.

Wild. Wow, that picture is wild. Wild.

Fight. He used his fist to fight. Fight.

Big. One of the lines is big. Big.

Fan. The turning fan makes you cooler. Fan.

Beautiful. The diamond is so beautiful. Beautiful.

Green. Dollar bills are green rectangles. Green.

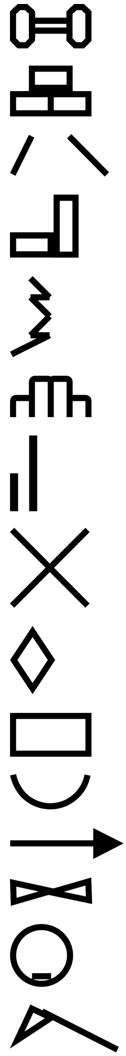
Laugh. He smiled and started to laugh. Laugh.

Indian. The Indian saw the arrow. Indian.

Moth. The moth has wings to fly. Moth.

Angry. Her mouth looked angry to me. Angry.

Horse. Sit on the horse and ride. Horse.



Following the training sentences, recall ability was measured to determine if there was a change in performance.

Word Memory II—Recall the words verbally from memory.

Symbol Reading II—Recall the words verbally from looking at each drawing.

Next, Word Recognition required the students to listen to a series of 45 words and say yes or no to indicate if each word was the name of one of the drawings.

Finally, Symbol Recognition required the students to look at a multiple-choice format of 4 different symbols representing each of the 15 drawings and point to the 1 that matched the drawing of the 1 named.