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The performance of reading disabled children on tests of verbal and visual learning and memory

by

Kay Wilson ©

A dissertation submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

Counselling Psychology and School Psychology

Department of Educational Psychology

Edmonton, Alberta

Fall 2002

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Degree: Doctor of Philosophy

Year this Degree Granted: 2002

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The Performance of Reading Disabled Children on Tests of Verbal and Visual Learning and Memory submitted by Kay Wilson in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Counselling Psychology and School Psychology.

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September 23/2002

Abstract

Fifty-three children aged nine to 12 years old with a reading disability were compared to two matched control groups on five tests of learning and memory. Three verbal memory tests included the Wechsler Memory Sale-Revised (WMS-R) Logical Memory subtest (LM), the Selective Reminding Test (SRT), and the Consonant Trigrams Task (CTT). Two visual/spatial memory tests included the Wechsler Memory Scale – Revised (WMS-R) Visual Reproduction subtest (VR), and the Continuous Visual Memory Test (CVMT). Results revealed that children with a reading disability performed lower than control groups on most variables from the Selective Reminding Test and the Consonant Trigrams Task. The children with a reading disability also performed lower than controls on the delayed recall task and the saving score variable of the WMS-R Visual Reproduction subtest. There was no significant differences noted between groups on the WMS-R Logical Memory subtest and the Continuous Visual Memory Test. As a whole, the data was thought to suggest that children with a reading disability have more difficulty processing verbal than visual information and that this difficulty is reduced when the material presented is meaningful.

Acknowledgments

I would like to extend a special thank you to the Edmonton Public School System for giving permission for this project to be conducted in their schools, and I especially wish to thank all the children who took part in the study. Without their openness to participate, this project would not have been possible.

I sincerely thank all my committee members for their interest and contributions to this project. In particular, I would like to thank Dr. Chris Paniak and Dr. Moira Juliebo for the extra time and support they provided. I would also like to thank Dr. Jennifer MacDonald whose daily encouragement made the writing process much more bearable. Lastly, I wish to thank my mom for her unwavering belief in me throughout my career as a student.

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Chapter One

Introduction

Within the area of cognitive psychology, there is a large body of research exploring memory functioning in children. There is also an increasing body of research in the area of clinical evaluation. However, the growth in the research available on children is surpassed by that available on adults. Likewise, despite an increase in the number of memory tests available for use with children, it remains relatively low compared to those available for use with adults (Snow, English, & Lange, 1992). Learning and memory difficulties are a component of many clinical referral problems and thus generate a need for instruments in this area.

Learning and memory are complex cognitive processes involving structural and temporal constructs that lead to models of memory involving visual and verbal modalities, as well as immediate and long-term storage. Assessment of memory functioning is particularly relevant with learning disabled children because memory difficulties are a recognized component of learning disabilities (Cooney & Swanson, 1987; Share & Stanovich, 1995). Although there is considerable debate about the nature of the primary cognitive deficit that underlies learning disabilities, researchers consider learning disabilities as a multi-type rather than unitary disability (Miles & Stelmack, 1994). A learning disability refers to a deficit in acquiring academic skills. In its most general definition, a learning disability can be associated with, or a consequence of, a host of disabling conditions such as mental retardation, traumatic brain injury, or behavioral disturbance (Sattler, 1992). A more specific definition refers to the occurrence of academic deficits despite a lack of any other disabling condition. Three specific learning disorders are outlined in the Diagnostic and Statistical Manual of Mental Disorders (4^{th} Ed.), which include reading, mathematics, and writing (American Psychiatric Association, 1994).

The prevalence of learning disabilities in the school system is approximately five percent; however, this estimate usually ranges between 2-10% depending on the criteria used for its diagnosis. Currently most school systems independently define the criteria for learning disabilities. Those school districts with stricter criteria for selection have fewer children diagnosed as learning disabled (Lyon, 1996).

Eighty percent of learning disabilities are in the area of reading (American Psychiatric Association, 1994). The diagnosis of a reading disability is currently based on a criterion of exclusion. An individual must be reading significantly below an expected level based on age or intelligence, but this delay cannot be attributable to other causes such as severe emotional problems, sensory deficits, neurological disease, or inadequate educational opportunity (American Psychiatric Association, 1994). This diagnostic criteria is used as the basis for defining a reading disability because the phrase "reading below expected levels" identifies a distinct group of individuals.

Unfortunately, the mere discrepancy between achievement in reading and aptitude in the academic domain, based on IQ scores, does not describe the complex nature of the cognitive profiles demonstrated in individuals with reading disabilities. Researchers have found that children with reading disabilities display a variety of cognitive deficits. The area of deficit that has received a large amount of research is the phonological processing difficulties often observed in these children (see Share & Stanovich, 1995). Correspondingly, language deficits in general have been identified as the early signs of, and are predictive of, a later reading disability (Scarborough, 1990; Tallal, Allard, Miller, & Curtiss, 1997). Language deficits in general appear in both expressive and receptive areas, but receptive language deficits are likely to be the most dramatic. Expressively, these children have been found to generally produce less information and use shorter utterances (see Gaddes & Edgell, 1994). Receptively, reading disabled children have been found to exhibit poor comprehension of verbally delivered language (Hynd, Connor, & Nieves, 1987). Reading disabled children have also been found to evince temporal processing deficits (Farmer & Klein, 1995; Tallal, Allard, Miller, & Curtiss, 1997), executive functioning deficits (Helland & Asborjornsen, 2000; Lazar & Frank, 1998), and working memory deficits (Swanson & Berninger, 1995). Research has also demonstrated that reading disabled children performed lower than controls on neuropsychological tasks involving a variety of cognitive demands (O'Donell, Kurtz, & Ramaniah, 1983; Selz & Reitan, 1979).

Memory deficits among reading disabled individuals have also been demonstrated (Swanson, 1994). Disabled readers consistently perform poorly on tasks that can be coded verbally regardless of the type of stimuli used: letters, numbers, words, or sentences (see Share & Stanovich, 1995). Swanson (1996) found that the performance of reading disabled children was similar to controls on immediate visual-spatial memory tasks and lower on verbal memory tasks. However, in demanding conditions disabled readers performed lower than controls on both verbal and visual-spatial memory tasks.

Rationale

The long-term consequences of a reading disability can be dire. Individuals with a reading disability are more likely to experience school failure, drop out of school, and experience unemployment or underemployment as adults (Reynolds, Elksnin, & Brown, 1996). Information about the cognitive profiles of a reading disability are important to psychologists, educators, and families to assist in the management and planning for children who experience these difficulties. The data provided by formal assessment instruments can potentially supply important diagnostic information useful in the development of remedial and compensatory programming.

The primary purpose of this study is to examine the performance of children with a reading disability on measures of learning and memory in general, and specifically to examine the performance of these children on the five selected tests. These test were chosen not only because each is a measure of verbal or visual/spatial memory, but because each measures a different aspect of memory within its stimulus domain. Three of the tests use verbal stimuli and two use visual/spatial stimuli. The verbal tests include the Wechsler Memory Scale – Revised Logical Memory subtest, which is a measure of story recall, the Selective Reminding Test, which is a measure of word list acquisition, and the Consonant Trigrams Task, which is a measure of working memory. The visual/spatial tests used include the Wechsler Memory Scale – Revised Visual Reproduction and the Continuous Visual Memory Test. Although both of these tests address visual memory functions, they do so somewhat differently. The Visual Reproduction subtest requires the reproduction of designs from memory involving perceptual motor abilities, while the Continuous Visual Memory Test is a visual recognition test and therefore does not require the perceptual motor abilities.

All five of these tests were originally used within the adult realm. With the development of a normative database for children aged nine to 15 (Miller, Paniak, and Murphy, 1993, for norms see also Spreen & Stauss, 1998), they are now also available to be used with children. This allows research to explore whether these tests are sensitive to the deficits generally found in the performance of children with a reading disability and enables the following research questions to be addressed:

1. Do children with a reading disability demonstrate lower performance on tests of verbal and visual learning and memory?
2. If so, is there a particular pattern to the deficits demonstrated?

Based on a review of the literature, these basic research questions are further developed into five hypotheses that are presented in chapter 2, and are used to guide the presentation of the results in chapter 4 and the discussion in chapter 5.

Delimitations and Limitations

This study was delimited by the means with which participants were selected for the study. Only children between the ages of nine and 12 were included, meaning findings cannot be generalized to other age groups of children with a reading disability. Children were also excluded if they had co-occurring reading and mathematics disabilities.

The selection of children with a reading disability was not differentiated by subtypes in this study. In general, subtypes are defined based on the type of information that is seen to be the basis of the reading difficulty. Groups are defined by whether reading failure is caused by verbal processing failures or visual processing failures. Children with difficulties in the verbal domain, referred to as dysphonetic, experience difficulty phonetically decoding words and therefore have difficulties reading words that follow the direct sound to letter mapping rules; they also experience deficits in reading pseudo-words. The second group of children, referred to as dyseidetic, have been found to have fewer difficulties with pseudo-word tasks and in contrast exhibit difficulty reading irregular words that do not follow grapheme phoneme correspondence principles (Howes, Bigler, Lawson, & Burlingame, 1999). Rayner, Pollatsek, and Bilsky (1995) suggest that the proportion of children with a reading disability predominately visual in origin is quite low, ranging from 4% - 16%. Researchers have recently investigated the performance of reading disability subtypes in memory (Howes, et al., 1999; van Strien (1999). However, the issue of whether these subtypes represent definably different groups remains unresolved (Stanovich, Siegel, & Gottardo, 1997). Equivocality regarding these groupings led to the decision to delimit the study to include children with a reading disability without further reduction into subtypes.

A number of limitations are also present in the current study. Firstly, the sample contains a disproportionate number of boys than girls (34 versus 19). While reading disabilities as a whole are identified most often in boys than in girls, this may limit the generalizability of the findings to girls with a reading disability.

Secondly, although the control participants were based on a general population of school children who had not received special education services, this does not preclude the possibility of the presence of individuals with an undiagnosed reading disability. Similarly, children with Attention Deficit Disorder were excluded only if they had been hospitalized. Because children with Attention Deficit Disorder have also often been found to demonstrate comorbid academic disabilities, these could act as potential confounds.

Finally, this study is limited by the explanatory power of the findings, especially regarding whether the lower performance that is expected for the children with a reading disability is the result of a deficit or a delay. Researchers exploring this issue often include a reading level matched control group of children chronologically younger than the children with a reading disability. If performance is similar to that of a reading level matched group, but lower than an age matched group, it is assumed to be the result of a delay and associated with reading skills. However, if performance is different from both of these control groups, it is assumed to be the result of a deficit (for a review of this design see Stanovich & Siegel, 1994). Because a reading level matched control group was not included for comparison, the question regarding the existence of performance patterns that might represent a delay rather than a deficit can not be delineated.

Chapter Two

Literature Review

Learning and memory are closely related constructs where memory is considered to be a permanent record of learning. Current models are multidimensional in their view of memory, and in particular, distinguish between short-term and long-term memory (Atkinson & Shiffrin, 1968). Long-term memory is seen as knowledge that is retained, while short-term memory is recall over a short period of time. The theorized components of memory have stimulated a number of labels to describe their functions. Although some of these components help create a more precise picture of the different facets that compose the general term memory, the multitude of labels referring to various aspects of memory sometimes overlap, thereby creating a confusing picture of memory (Neath, 1998). For example, short-term memory and long-term memory are also referred to as primary and secondary memory. The information one retains regarding personal history is referred to as autobiographical or episodic memory (Gathercole, 1998), and general knowledge is viewed as semantic memory (Neath, 1998). A further sectioning of memory is seen in the distinction between declarative and procedural memory, where declarative knowledge is that which is known and therefore can be declared, and procedural knowledge is knowing how to do something (Baddeley, 1999). Because this study is focused on learning and memory that is considered intentional, only those concepts referring to information processing within this framework will be used. Therefore, the concepts of short-term memory, working memory, and long-term memory are those that will be used for this discussion, especially because it is these constructs that underpin most clinical assessment of memory.

The theoretical beginnings of long-term and short-term memory are encapsulated in the model produced by Atkinson and Shiffrin (1968). With the growth of cognitism in the 1960s, a number of models were developed. However, Atkinson and Shiffrin's model is the primary example of these and is often referred to as a modal model (Neath, 1998). Their work in the area of memory is seminal because it spurred a great deal of subsequent research that sought to prove the existence of these constructs, as well as clinical research that used these constructs to explore memory functioning in various populations.

Although referred to as a dual store model, Atkinson and Shiffrin's (1968) model is actually comprised of three structures, the sensory register, short-term memory (STM), and long-term memory (LTM). The movement of information from the sensory store to STM is mediated by attention. The capacity of STM is limited and can hold approximately seven pieces of information plus or minus two. Information from STM is said to be copied into LTM through the use of rehearsal, which is required for the preservation of the information. Therefore, STM is a site of temporary storage as well as a working space for rehearsing information to be stored or retrieving information from LTM.

Earlier theories of memory assumed that both STM and LTM were extensions of a similar process. Long-term memory (LTM) was conceptualized as representing a more enduring version of STM, with the mechanisms underlying both LTM and STM seen as similar in process. Evidence from clinical cases, however, called into question the validity of this assumption. Patients with brain damage demonstrated different patterns of performance depending on the site of the damage. For example, some patients post-injury exhibited impaired short-term memory, yet retained normal long-term memory and learning ability (Shallice & Warrington, 1970). Alternatively, other individuals demonstrated the retention of short-term memory ability with disrupted long-term memory (Baddeley, 1996; Baddeley & Warrington, 1970). Evidence from these natural sources prompted the adoption of a stage view of memory where STM and LTM are recognized as discrete entities. Subsequent work with this model has led researchers to expand the functions and attributes of the STM component, which has evolved to be part of a larger system called working memory (Baddeley & Hitch, 1974). Following is an overview of the model of working memory proposed by Baddeley and Hitch (1974). A review of the development of memory in children and working memory in children with a reading disability is then presented.

Working Memory

Working memory is generally seen as a capacity limited resource that involves the holding of information while simultaneously processing information (Swanson, 2000). Conversely, short-term memory generally refers to the mere passive holding of small amounts of information (Swanson, 1993). There is a strong relationship between working memory and most cognitive tasks. Working memory is involved in arithmetic, logical reasoning, the acquisition of vocabulary, and extrapolating meaning from sentences (Gathercole, 1994). In particular, verbal working memory is significantly correlated with comprehension (Dixon, LeFevre, &

Twilley, 1988; Baddeley, Logie, Nimmio-Smith, 1985). For example, working memory tasks have been shown to differentiate children with reading disabilities from those without reading disabilities (Swanson, 1992).

Baddeley and Hitch (1974) developed a model of working memory that expanded on the concept of short-term memory presented by Atkinson and Shiffrin (1968). Baddeley and Hitch questioned whether information in short-term memory was composed only of acoustic code. Besides its place as currently the most influential model addressing immediate memory, this model has also been extended into the area of reading (Neath, 1998). Baddeley and Hitch's model of working memory is composed of three units: the central executive, visuo-spatial sketchpad, and phonological loop (cited in Baddeley & Hitch, 1994). The defining feature of working memory is its ability for the simultaneous storage and processing of information (Swanson, 1994). The primary unit is the central executive system that controls the two peripheral subsystems, the visuo-spatial sketchpad and the phonological loop. The central executive system is primarily involved with the dispersion of attention, involving planning and the control of action (Baddeley, 1996).

The visuo-spatial sketchpad processes visual and spatial material. Its actual mechanisms have not been fully explored but evidence shows it to have independent processes, so that the visual and spatial components are seen to function separately and represent distinct, although related processes. The separate visual and spatial elements are described as representing the "what" and "where" systems. That is, the visual imagery system identifies the "what" and the spatial imagery system represents the "where" (Gathercole, 1994).

The phonological loop processes verbal information. However, its size is limited and only one to two seconds of information can be held. The phonological loop is subdivided into two sub-components: the phonological short-term store and an articulatory subvocal rehearsal process (Vallar & Baddeley, 1984). The phonological store is the site where phonological representations are held. These representations soon begin to decay if they are not kept active. The articulatory subvocal rehearsal system is used to prevent the fading of phonological information by maintaining attention on the material. Because the phonological loop is only able to maintain a limited amount of material, the string of information being remembered must fit within these parameters. If the information extends this pre-set length of one to two seconds, it will begin to fade before it can be renewed, resulting in the material becoming indiscriminable.

The phonological loop and the working memory model as a whole was designed to account for four basic phenomena, including the phonological similarity effect, effects of articulatory suppression, the irrelevant speech effect, and the word-length effect (cited in Neath, 1998). The phonological similarity effect relates to the discovery that items or sounds that are similar are more difficult to retain than items with dissimilar sound (Baddeley, 1996). For example, X, M, and K are more easily retrieved than B, D, and P, because the latter group of letters possesses a similar phonological structure. When information in short-term storage begins to decay, the representations of items with similar phonological structures become increasingly similar and therefore more difficult to discriminate (Gathercole, 1994). This phenomenon is also true when items are presented visually. However, if the phonological store is kept busy with a verbal task such as repeating a simple word, i.e. *the*, this articulatory suppression eliminates the phonologically similarity effect for visual material. Therefore, the information is being processed wholly by the visual system. The irrelevant speech effect refers to the finding that when recalling consonants presented visually, irrelevant speech played at the same time reduced recall. Lastly, the word-length effect refers to the finding that longer words are not recalled as easily as shorter words. The working memory model accounts for this effect in terms of time taken to subvocally rehearse. The longer the word, the longer the process will take to refresh the information in the phonological store, which increases the vulnerability of the information to decay (Neath, 1998).

The Development of Working Memory. In terms of the development of working memory in children, it has been found that children's memory span increases from two to three items at four years old, and to six items at 12 years old. This development is seen as reflecting the growth of strategy use. Young children have been shown to not actively rehearse until the age of approximately seven. This was demonstrated in a frequently cited study by Flavell, Beach, and Chinsky (1966). Without being refreshed through rehearsal the information begins to decay, rendering it irretrievable. Evidence that young children do not rehearse was found when items were presented visually. Younger children did not show the word length or phonological similarity effect and so were not impaired when the labels for these items were long or were phonologically similar, supporting the conclusion that the children were likely encoding the information via visual characteristics (Hitch, Halliday, Schaafstal, & Schraagen, 1988). When taught to use a rehearsal strategy, the performance of young children improves. Nevertheless even when using rehearsal, their performance does not reach the level of older children (Siegler, 1991). This was thought to be possibly due to the fact that young children rehearse more slowly, so they are unable to retain the same level of information as older children (Gathercole, 1998). In fact, research has supported the idea that the articulation rate in children increases through middle childhood and is correlated with an increase in word span (Hitch, Halliday, & Littler, 1993).

Another account of change in working memory has been posited by Case (1995) whose theory is most closely related to the central executive. Case proposes a trade off between the storage and processing mechanism, whereby the basic capacity or total processing space remains relatively constant throughout development, while efficiency and speed of processing changes with development and is presumed to be related to maturation and general experiential factors (Case, 1995).

Working memory in children with a reading disability. The phonological loop has been shown to be an important processing system in the development of language. Baddeley and Hitch (1994) argue that the importance of the phonological loop is demonstrated through evidence that nonword repetition is predictive of vocabulary acquisition in normal four year olds. However, it has also been found that the processing of phonological information itself is most important in learning to read, and that phonological ability is the most reliable predictor of young children's later reading ability (Bryant, Maclean, Bradley & Crossland, 1990).

Because the level of a child's phonological ability is related to reading, it follows that poor readers who do not perform well on measures of phonological awareness will also perform poorly on tasks that measure verbal immediate memory, likely because both tasks are composed of verbal information (McDougall, Hulme, Ellis, and Monk, 1994). Word decoding and comprehension are dependent on the functions of working memory to retain the letters to be combined into words and similarly to retain consecutive words so that their meaning can be extracted (Baddeley, 1982). McCutchen & Crain-Thoreson (1994) support the view that children have processing difficulty at the site of working memory when reading consecutive words. Words with similar phonemic codings become entangled in the memory buffer, and need extra processing to be differentiated. The results of this study illustrate that when confronted with sentences containing phonologically similar words (i.e., tongue twisters), children require more time to comprehend than they do with control sentences containing words that are phonologically dissimilar. It can be hypothesized that phoneme confusability is likely more pronounced for those children with a reading disability because of their limited proficiency in manipulating phonological information in working memory (McCutchen & Crain-Thoreson, 1994).

It might then be expected that readers with limited working memories will have more difficulty processing connected text, including reading and comprehending related sentences. Wagner, Torgesen, Laughon, Simmons, and Rashotte (1993) speculate that the relationship between working memory and reading has less to do with the size of working memory and more to do with the inability of poor readers to sustain phonological codes long enough to manipulate them. Therefore, reading requires the efficient encoding of phonological units in working memory; poor encoding will lead to phonological representations that are prone to degradation despite adequate working memory size. Wagner et al. (1993), emphasize that a lack of facility with encoding is the fundamental problem of poor readers. Moreover, this hypothesis implicates the importance of encoding strategies for remediation. Young children who have difficulty with processing and retrieval because they do not initially encode information efficiently are often unable to identify important features that can be used in the encoding process (Wagner et al., 1993). In ordinary processing, information that is not attended to will be lost within a relatively short period. Therefore, if encoding has not adequately taken place, information will be lost considerably faster. Attending strategies, such as rehearsal, keep the material active so that it can be maintained for a longer period of time circumventing short term memory failure and facilitating the process of reading (Siegler, 1991).

Hurford and Sanders (1993) provided disabled readers with a matching task where the readers were to decide if a pair of syllables were the same as a comparison pair. By changing the task requirements so that the interval time between the standard pair of syllables and the comparison pair was manipulated, the performance of disabled readers changed. They concluded that there is an interaction between phonological processing and memory. Phonological processing deficits become more evident as increasing demand is placed on the processing system. Similarly, McDougall, Hulme, Ellis, & Monk (1994) propose that children do not have working memory problems because of their inefficient phonological skills. Rather, they argue that both memory and phonological skills contribute independently to reading difficulties. They further hypothesize that speech rate may be a more important measure of reading potential because it is an index of the speed at which phonological codes are activated and enlisted into use. Children with slower speech rates may be demonstrating difficulties in matching phonological sounds to orthographic information.

Swanson (1993) looked at individual differences in working memory and found evidence to support the notion that there is an independence between working memory and reading skills for poor readers. The evidence shows that poor readers have less working memory capacity available to actually process information, whether it be reading related or not. However, he further suggested that as readers become more skilled there is corresponding growth in the interdependence of working memory and reading skills. This is consistent with the model of a storage and processing trade off (Case, 1995). Because the system is of limited capacity, if it is burdened in some way, there will be a resulting trade-off between storage and processing capacities. For readers with a disability there is a slowing of their processing of phonological information, leaving fewer resources available for higher level functions such as integrating new information with that already stored in long term memory. This is similar to the view of automatic information processing advanced by Samuels (1993).

Through this model, Samuels outlines the cognitive mechanisms responsible for the process of reading. When an action is automatic, it requires little cognitive attention, therefore little cognitive energy is used in the processing of automatic information. Because the capacity of memory or attention is limited, tasks that are novel or require a large amount of attention usually have to be performed in isolation. Therefore, to read, children must perform two highly attention intensive activities:

first they must decode the words on a page, and then they must comprehend their meaning. Because both activities require significant attentional capacity, they are difficult to perform simultaneously. The young reader must first decode the individual words, and then integrate the words to comprehend their meaning. Under normal circumstances with sufficient practice, the beginner becomes a proficient decoder and is able to execute this skill with relatively little attention, thereby leaving attentional capacities open for the task of comprehension.

Samuels' model involves a number of memory processing mechanisms. Visual memory analyzes the incoming graphic information, the phonological processor is used to analyze auditory information, and semantic memory is accessed because it contains all known word meanings. The visual memory analyzer and phonological processor appear to have similar characteristics to the phonological loop and the visuo-spatial sketch pad. A reading disability, which is associated with difficulty decoding new or complex words, places pressure on the memory system. With a large portion of immediate memory consumed with the task of decoding, very little space remains for comprehension. Because working memory has a limited capacity when one part of the memory system is stressed, the central executive system will have fewer resources to allocate elsewhere (Baddeley, 1982).

Although the visual system is generally considered not deficient in children with a reading disability, this system can be essentially depressed when the entire system is overburdened (Palmer, 1999; Swanson, 2000). This finding is thought to be related to the limited resources available to the executive system. Therefore, it is not merely a deficit in verbal processing that interferes with working memory but a domain-general deficit (Swanson, 2000).

Although the search for the specific processing mechanisms that impair the disabled reader continues, these efforts are built on theories and models that present constructs that cannot be directly measured. Researchers on a different front are attempting to look for directly measurable differences that can account for the difficulties experienced by children with a reading disability. With the advent of technology, there has been an increase in brain based research.

Neurobiological Evidence of Impairment in Children with a Reading Disability

Memory is widely distributed in the brain and not "located" in one specific area. Many different parts of the brain can be responsible for representations of a single episode, but the site of the memory store is likely to be in the area that was activated when the material was initially learned (Neath, 1998). Material held in memory will likely be housed within those structures related to the production, organization, and understanding of the particular information type.

Using a number of techniques, researchers have attempted to increase the precision with which a diagnosis is made, as well as to increase general knowledge regarding the neurobiology of a reading disability. The first studies conducted in the 1970s used computerized tomography (CT) (see Bigler, Lajiness-I'Neill, & Howes, 1998). These studies searched for evidence of structural irregularities in the brains of individuals with a reading disability. Although there were some findings regarding altered asymmetries of the parieto-occipital areas, (which were different from the left larger than right asymmetry usually evident in the general population) individuals with low verbal IQs or language delays often associated with a reading disability displayed a reduction or reversal of this pattern. However, there were inconsistencies in studies. This may have been related to differences in the criteria used in the definition of an asymmetry, or possibly to intrasubject differences, as in a lack of control of the placement of a subject's head during the scanning procedure (for a review see Rumsey, 1996).

Magnetic resonance imaging (MRI) allows for images with increased resolution. An additional benefit of the MRI is that it does not require subjects to be exposed to the radiation required in the CT scanning (Rumsey, 1996). Using magnetic resonance images (MRI), Flowers (1993) found that a dyslexic group had a significantly larger surface area in the right hemisphere, rather than a decrease in tissue in the left planum temporale region. Usually the planum temporale is larger in the left hemisphere than in the right. The planum temporale is a structure located in the Sylvian fissure on the superior surface of the temporal lobe, an area affiliated with auditory association (Bigler et al., 1998). Flowers (1993) found that the existence of a larger surface area in the planum temporale of the right hemisphere was correlated with poorer performance on rapid serial naming and rote verbal memory. Although there has been evidence pointing to the relationship of symmetry of the planum temporale with symptoms of dyslexia, particularly phonological deficits, symmetry of this structure has also been found in other individuals, such as those who are left handed. Therefore, this structure may or may not be related to a reading disability (see Bigler et al., 1998; Eckert & Leonard, 2000).

Positron Emission Tomography (PET) technology has provided specific neurological information on the connection between reading and oral language. The PET scan measures the energy dispensed by nerve cells in the brain. Brain activity is shown through activity images that provide reliable interpretations of brain function. Unfortunately, this technique is extremely invasive because it requires the injection of radioactive tracers, thereby making it inappropriate in studies with children (Flowers, 1993). As a result, the information received from these studies is based on adult samples. Because adults may rely on different processing mechanisms than children do, results of these studies cannot be generalized to interpreting neurological processes in children. Nevertheless, these results provide valuable information on cognitive processing and its biological associations in general.

Adult PET studies with individuals who have a reading disability have found underactivity in the left temporo-parietal region (Flowers, 1993). Price, Wise, Watson, Patterson, Howard, & Frackowiak (1994) also used PET technology to examine phonological processing of normal adults during three tasks: reading aloud, reading silently, and lexical decision-making with visually presented real and pseudowords (a word that follows the rules of English but is not a real word). In the lexical decision-making task, individuals decided whether the word presented was a real word by indicating "present" or a pseudoword by indicating "absent." Results suggested that both right and left hemispheres are involved in the processing of visual material in both reading conditions. However, the results also showed brain activity in other areas of the brain during lexical decision-making. These areas included the left premotor cortex, left dorsolateral prefrontal cortex, and the left supplementary motor cortex area. Activity in these regions is suggestive of a phonological strategy. Specifically, activation in the supplementary motor area is strongly indicated in inner speech, implicating phonological processors. During the lexical decision-making task, it was speculated that the words were silently "sounded out" suggesting that decisions were based on phonological versus orthographic characteristics (Price et al., 1994).

The development of new techniques now provide researches with additional tools for viewing the brains of children. The invasive nature of PET scanning precluded its use with children in research. However, similar information that is garnered in PET scanning about brain activity can also be achieved with functional magnetic resonance imaging (fMRI). These images are possible because of the make-up of hemoglobin particularly its paramagnetic properties. Both of the imaging technologies are based on increased blood flow to areas of the brain that are engaged in activity (Joseph, Noble, & Eden, 2001). Although, this technology is promising for use with children, there are currently no available studies specific to children and reading skills. However, this is predicted to be an area of great growth in the near future (Joseph et al., 2001).

In summary, technology has provided useful techniques in exploring the brains of individuals with a reading disability. Although unable to pinpoint the specific location where memory is located, these studies have produced interesting results regarding the location where particular types of information are processed. Thus far these studies have added little in terms of the diagnosis of reading disability. With increasing advancement, however, these technologies may yet prove to be useful in the elucidation of a reading disorder and the type of difficulties individuals with a reading disability experience, particularly when processing information to be remembered.

Clearly, phonological processes are necessary for the acquisition and maintenance of reading. Researchers have demonstrated that facility in using phonological information is intricately connected with the reading development of young children (Bryant, Maclean, Bradley, and Crossland, 1990). Reading disabilities are undoubtedly multidimensional in nature and difficulties in any one area of processing will lead to difficulties in others. For example, problems in phonological processing will impair mappings to orthographic features, which may in turn impair the retention of these features in working memory. Despite the breadth of research conducted, the exact relationship between reading and memory functioning remains elusive. In the next section an overview of clinical studies is presented. These studies present data that is useful within the clinical realm to more clearly differentiate where learning is disrupted.

The clinical assessment of learning and memory provides valuable information regarding the cognitive functioning of an individual compared to what would be generally expected. This type of information is useful for diagnosis or in predicting the functional capabilities of a person given their measured deficits. In the case of a child, this information is useful within the educational setting so that a child's abilities are well understood by his or her teachers and appropriate remedial or compensatory program plans can be developed.

The Performance of Children with a Reading Disability on Tests of Learning and Memory

A large focus of the learning and memory research in the clinical domain with children diagnosed with a reading disability has been in locating the area of difficulty within the learning process. Relating to cognitive processing models, the search has striven to identify differences between individuals with a reading disability and individuals without a disability in terms of the constructs that define information processing. Buschke & Fuld (1974) used the terms "initial storage, retention, and, retrieval" to describe these functions (p 1019). However, the terms encoding, storage, and retrieval appear to be used most recently (for an example of use see Kramer, Knee, & Delis, 2000)

Using the Selective Reminding Procedure (Buschke, 1973) in a comparison study between children with learning disabilities, Fletcher (1985) found that reading disabled children performed significantly lower on the retrieval of verbal information. The Selective Reminding Procedure is a list learning task where on subsequent trials the child is reminded of only those items that were not remembered on the previous trial. Fletcher used both a verbal and nonverbal version of the Selective Reminding Procedure. For the verbal task, the items were composed of animal names, and for the nonverbal tasks, the children remembered the placement of dots. Fletcher looked at children with a disability in reading, spelling, and arithmetic. He found that children with a disability in reading differed from controls in their retrieval on the verbal task, and children who had a disability in the areas of arithmetic, spelling, and reading scored lower in retrieval scores on the verbal tasks and storage and retrieval of the nonverbal tasks. It was hypothesized that because the stimuli used in the verbal task consisted of animal names, which are semantically related, the reading disabled children may have had less difficulty with storage than they would if stimuli were unrelated or phonetically confusable, requiring increased phonemic processing.

In a later study also using the Selective Reminding Procedure, but using different stimuli, Snow, English, & Lange (1992) compared the performance of children with learning disabilities (LD), seizure disorder (SD) and normal controls. The LD group was a heterogeneous group composed of reading, mathematics, and combined reading and mathematics disabilities. Results showed that both the LD and SD groups performed lower than the control group. The two measures that were the strongest discriminators between the three groups were the recall index (Total Recall) involving basic memory and encoding skills, and the consistent long-term retrieval index (CLTR) involving memory retrieval abilities. For the recall index, the LD group performed significantly higher than the SD group, but no differences were noted between these two groups for consistent long term retrieval. This finding means that the LD group recalled more words overall, but the number of words recalled consistently across trials was similar to the SD group. Discriminant analysis showed the Selective Reminding Test was able to correctly classify 60% of LD participants and 73.33% of the control participants. However, it was not able to reliably separate participants with a seizure disorder from the LD participants and normal controls. Only 46.67% of the participants with a seizure disorder were correctly classified as belonging to the seizure disorder group. Snow et al. (1992) suggest that performance patterns on the Selective Reminding Test provide information useful in diagnosis. Besides the information achieved from the short-term and long-term indices, these authors suggest that executive functioning can also be assessed through the consistent long-term retrieval because this index also involves the organization of information allowing it to be consistently retrieved.

Results similar to those of Snow et al. have also been found in other list learning tasks. Using the Rey Auditory-Verbal Learning Test, van Strien (1999) found that reading disabled boys recalled fewer words over the five trials than a nondisabled control group. Although the boys with a reading disability performed lower following a 20 minute delay, as well as on a recognition trial, they demonstrated a similar retention to the normal controls. Retention was interpreted to have taken place because, following a 20 minute delay, the reading disabled group was able to recognize the words they had recalled during the last learning trial. Likewise, Kramer, Knee, and Delis (2000), using the California Verbal Learning Test (CVLT-C), found that children with a reading disability were slower at learning a word list than a group of normal controls. They also recalled fewer words on the last trial, as well as on the delayed trial and recognition trial. Nevertheless, the children with a reading disability did not show a difference from controls in terms of the rate at which they forgot the list, indicating that after learning had taken place, the children with a reading disability showed normal retention. Kramer et al. concluded that the children with a reading disability showed poor encoding and normal storage and retrieval. They also speculated that the children with a reading disability used less efficient rehearsal strategies, which has also been found in previous studies (Cermak, 1983).

There are few studies that evaluate the performance of children with a reading disability on visual measures of learning and memory. Fletcher (1985) included both a visual and verbal selective reminding procedure and generally found that children with a reading disability did not differ from controls on the visual memory task.

With the advent of large memory batteries for children, such as the Wide Range Assessment of Memory and Learning (WRAML) (Sheslow & Adams, 1990) and the Test of Memory and Learning (TOMAL) (Reynolds & Bigler, 1994), researchers have investigated whether specific memory profiles exist for children with a learning disability. Howes, Bigler, Lawson, and Burlingame (1999) found that reading disabled children performed lower than controls on the composite memory index that included both verbal and nonverbal memory tests. Although the reading disabled children performed lower than controls on individual subtests, their performance was considered to be impaired on only two subtests, Digits Forward and Letters Forward. When examining the profiles achieved by the reading disabled and control groups, Howes, et al. found that the children with a reading disability achieved lower acquisition scores than did the control participants. Although the children with a reading disability performed lower on delayed recall, their performance scores were similar to those earned during the acquisition phase across four subtests, including Memory for Stories, Word Selective Reminding, Facial Memory, and Visual Selective Reminding. Overall, they concluded that the reading disabled group showed deficits at the early processing stage rather than at the later retrieval stage. Using the WRAML, Patrice, Cassisi, and Hoeppner (1999) found verbal memory deficits for children classified as reading disabled. However, they did not find deficits for these children on nonverbal indices.

Generally, the most consistent finding of research thus far is that children with a reading disability perform lower than children who do not have a reading disability on tests of verbal learning and memory. There also appears to be growing evidence that this lower performance rests in the initial stages of learning. Research on the performance of children with a reading disability on visual measures is sparse. Nevertheless, much of the available work does not find visual memory to be a consistent area of deficit for this population.

Much research appears to focus on the verbal modality. This direction may have been guided or at least influenced by studies exploring the cognitive processes underlying a reading disability. There is a growing body of research that implicates verbal working memory as being particularly problematic in children with a reading disability. This is consistent with the findings from clinical studies that these children experience difficulty with encoding.

Summary

Research from various areas points to the general finding that children with a reading disability evince deficits in the processing of information in the verbal domain. Clinical studies have evaluated the performance of children with a reading disability on tests of learning and memory. However, much of this research has been conducted with verbal list learning tasks, with less information available on the performance of children with a reading disability on other verbal memory tests, such as memory for stories. There is also a paucity of research in the area of visual/spatial memory. Other research has explored more specifically the performance of children with a reading disability on tasks tapping working memory.

The purpose of the current study is to add to the available literature on the performance of children with a reading disability on tests of learning and memory. Specifically, the current study evaluates the performance of a group of children with a reading disability on a number of tests not widely used with children. With the availability of normative data for children collected by Miller, Paniak, and Murphy (1993) on tests of memory previously used with adults, this allows the usefulness of these tests to be explored with children with a reading disability. Five tests were chosen for use in this study, two of which are measures of visual/spatial memory. Measures assessing verbal learning and memory include a list learning task and a measure of story memory. There is very little previous research available on this latter task type. Also included is a measure of working memory that assesses a child's ability to retain verbal information while simultaneously performing a verbal distractor task.

Based on the preceding literature review, hypotheses have been generated about the findings of the current study. Generally, it is anticipated that the children with a reading disability will differ from controls on the verbal memory tests but not on the visual memory tests. These assumed findings are presented in the form of five hypotheses.

Hypothesis one. Correlation analysis will be conducted, with the Miller et al. (1993) normative database between scores from the WISC-III Vocabulary, which is a measure of verbal ability and the tests of learning and memory. It is hypothesized that there will be a high correlation between WISC-III Vocabulary scores and verbal memory measures. It is also expected that there will be significant correlations within instruments measuring the same memory modality. For example, verbal measures of memory will likely correlate more highly with other verbal measures than with visual/spatial measures. It is also expected that there will be significant correlations between immediate and delay measures of each.

Hypothesis two. When compared with normal controls, it is anticipated that the children with a reading disability will perform lower on the verbal measures of learning and memory. It is also expected that the children with a reading disability will perform lower on both the immediate recall and 30 minute delay portions of these tests, and that an analysis of the saving scores will show that the difficulties these children encounter rest in the encoding of information rather than its storage and retrieval.

Hypothesis three. It is expected that because the Consonant Trigrams Task relies on working memory, and particularly because reading disabled children have been shown to have difficulty maintaining phonological representations in memory, performance will be lower on this task for the children with a reading disability. Similarly, it is also expected that as the difficulty level of the task increases with the inclusion of longer delay periods, the reading disabled children will show increasingly poor performance.

Hypothesis four. It is anticipated that the results will show no difference in the performance of the children with a reading disability and controls on the visual/spatial measures of learning and memory.

Hypothesis five. Because overall it is expected that the children with a reading disability will perform lower on verbal memory measures, it is expected that verbal memory variables will better discriminate between participants with a reading disability and participants designated as controls than will visual memory variables. Specifically, previous research has found that the total recall and consistent long term retrieval variables of the Selective Reminding Test were good discriminators between children with learning disabilities, seizure disorders, and controls (Snow, English, & Lange, 1992). Therefore, similar results are expected here.

Chapter Three

Method

This study follows up previous work conducted by Miller, et al. (1993) who prepared a normative database for Edmonton children using popular memory instruments. This chapter outlines the selection criteria for participants in the current study as well as the section criteria for participants in the normative study. A brief overview of each of the instruments used is provided, along with the administration procedures of each. The last section reviews the procedure employed in data collection for the current study.

Participants

Children with a reading disability (RD). Elementary school students between the ages of nine and 12 were nominated for this study by their teachers. These students were selected from six elementary schools in the Edmonton Public School system. All of the children had been identified as having a learning disability in the area of reading and were receiving an educational program to ameliorate the effects of their disability.

Criteria used for a learning disabled designation in the Edmonton Public School system includes that the students be fluent in English and their academic delay not be a result of a lack of English fluency. The child's Full Scale IQ score is required to be above 100 on an individual intelligence measure, which is based on a mean of 100 and a standard deviation of 15. Academic achievement in two of the following areas is required to be below the 10th percentile: reading comprehension, reading decoding, spelling, written language, and mathematics. Criteria also mandates that academic delays are not a result of aggressive behaviors. Participation in the study was based on the child's disability being in the area of reading. Teachers were also asked not to nominate students who also had comorbid reading and arithmetic disability or Attention Deficit Hyperactivity Disorder. However, there was not formal test was used to systematically screen for children with these disorders. Additionally, each child's current word reading performance was assessed using the reading subtest from the Wide Range Achievement Test - Third Edition (WRAT-3). As indicated, the children had previously been diagnosed with a reading disability based on the traditional discrepancy definition. However, because the children had been instructed in a remedial program for at least one school year, the WRAT3 Reading subtest was merely used to confirm that these children continued to be poor readers.

Children with a reading score below the 25th percentile were included for participation. Lyon (1996) suggests that, because of the difficulties with current criteria for defining a reading disability, performance below the 25th percentile on a standardized reading test actually captures most of the children who would meet current criteria. Moreover, a cut off score at the 25th percentile is commonly used to define reading disabled samples in research (Siegel & Ryan 1989; Stanovich & Siegel, 1994; Swanson, 1999).

Seventy-nine children were nominated for the study by their teachers and all received parental permission. Of these children, 53 had reading scores within the parameters established for this study. The mean WRAT3 reading standard score was 77.8 (standard deviation of 7.9) or a percentile score of 7. Scores ranged between the 0.9th percentile and the 23rd percentile.

Normative participants. A normative database of 716 Edmonton children aged nine to 15 years has been compiled by Miller, Paniak, and Murphy (1993). The data resulting from the Miller et al. study was used to compare the performance of the children with a reading disability who were the focus of the current investigation.

Data collection for the normative study was conducted using the following procedure. All of these children attended school within the Edmonton Public School District. After permission was received from the children's parents, a research assistant tested them in their schools on measures described below. The criteria for participation included parental consent, and that the primary language spoken was English. Children were excluded who received special education services, who had a documented brain injury, or were diagnosed with a major psychiatric disorder. Children with diagnosed Attention Deficit Hyperactivity disorder were only excluded from the study if they had been hospitalized for treatment.

From the normative database, 477 children were identified between the ages of nine and 12. Two control groups were selected from this sample. The first control group was matched to the reading disabled group on age, gender, and WISC-III Vocabulary score. The second control group was matched with the RD group on age and gender (see table 1). Two control groups were used to explore the influence that verbal ability may have on performance on tests of verbal and visual learning and memory. For example if differences in performance on the tests of memory were due to verbal ability then once verbal ability is controlled, these differences would be expected to disappear. A one-way ANOVA computed on the WISC-III Vocabulary raw score revealed a significant difference between the groups $F(2, 156) = 4.867$, $p = .009$. Post hoc Bonferroni comparisons showed significant differences ($p < .05$) on Vocabulary raw scores between the reading disability group and the second control group matched only on age and gender, with the latter group performing better. Likewise, there was a significant difference noted between the two control groups ($p<.05$).

Insert table 1 about here

Instrumentation

The four instruments selected for this study are common measures of memory and learning used with adults: The Wechsler Memory Scale-Revised (Logical Memory I & II and Visual Reproduction I & II), the Continuous Visual Memory Test, the Selective Reminding Test (SRT), and the Consonant Trigrams Test (CTT). In this section each instrument is briefly introduced, addressing the areas it measures, and administration procedures.

Wechsler Memory Scale-Revised (WMS-R). Two subtests were chosen from the Wechsler Memory Scale-Revised (Wechsler, 1987), which included the Logical Memory subtest (immediate and delayed recall) and the Visual Reproduction subtest (immediate and delayed recall). The Logical Memory (LM) subtest is essentially a measure of memory for stories and as such is a verbally based subtest. It is composed of two short stories that are read aloud by the examiner. Following the reading of

Table 1
Demographic Variables of Reading Disabled and Control Groups

Variable	RD		Control Group 1		Control Group 2	
Gender	M	34	M	34	M	34
	F	19	F	19	F	19
Age in years						
9 yr. olds		8		8		8
10 yr. olds		20		20		20
11 yr. olds		17		17		17
12 yr. olds		8		8		8
Mean Age in months	129.43 (12.06)		129.66 (11.45)		129.64 (11.65)	
Mean WISC-III Vocabulary raw scores	26.25 (6.30)		26.47 (5.85)		29.83 (7.61)	
Mean WISC-III Vocabulary scaled scores	8.85 (2.46)		8.87 (2.30)		10.51 (3.13)	

Note. Standard deviations are in parentheses each story, the examinee is asked to retell the story. After a delay of 30 minutes, the examinee is again asked to recall the stories (Wechsler, 1987). The Visual Reproduction (VR) subtest is defined as a measure of figural memory. The examinee is presented with four different geometric designs. After each design is exposed for 10 seconds, the examinee is asked to reproduce it from memory. As in LM, after a 30 minute delay the individual is asked to reproduce the four designs.

Interscorer reliability reported in the test manual for Logical Memory and Visual Reproduction is .99 and .97 respectively. Raw score totals for LM and VR differed between raters by only .365 and 1.50 raw score points respectively (Wechsler, 1987). These findings were confirmed by Sullivan (1996) who reported an interrater reliability of .98 for Logical Memory, concluding that for trained clinicians the scoring procedures supplied in the manual are highly reliable. Factor analysis of the Wechsler Memory Scale - R supports a two factor solution representing (1) a general memory and learning factor and (2) an attention-concentration factor (Wechsler, 1987). However, visual memory, verbal memory, and delay recall subtests are clinically useful when examining individual test performance, particularly when individuals produce marked differences in these measures (Wechsler, 1987). For example, Reid and Kelly (1993) found individuals with head injuries performed more poorly on WMS-R than controls, particularly on tasks measuring retention, therefore, validating this index with a head injured population. Just as these indices have proven useful with a head injured population they may also prove to be useful with a reading disabled population, providing evidence of differing performance patterns between reading disabled and non disabled individuals.

In further validity studies, Compton, Sherer, and Adams (1992) found that LM (immediate and delay) and VR (immediate and delay) loaded on separate verbal and figural factors. Wong and Gilpin (1993) also found through hierarchical clustering that the visual and verbal indices created by Wechsler are supported by the clustering of LM and VR into verbal and nonverbal areas. However, research is still equivocal regarding the overall validity of these indices. Roth, Conboy, Reeder, and Bell (1990) were unable to find support for separate verbal and nonverbal factors with a sample of head injured patients, but did find support in separate factors for immediate and delay scores. Roth et al.(1990) argue that the association of similar material between immediate and recall inflates their correlations, therefore a proportion of the correlation is based on the use of same stimuli. This results in a higher correlation of LM I with LM II than of LM II with another verbal delay score. Because of the overlap of material used in this subtest, statistical analyses were performed to partial out the common variance between measures. Roth et al. (1990) found separate factors for immediate and delay tasks. However, after this analysis further research has been unable to replicate these findings. Elwood (1993), for example, did not find evidence for a separate delay factor even though he attempted to take into consideration the overlap of similar material by using a savings score. Saved scores were calculated using the ratio of recall on delay tasks with recall on immediate tasks. This procedure allows the determination of possible differences between retrieval of material in immediate memory and long-term storage.

Selective Reminding Test. The Selective Reminding Test (SRT) was developed as a method of measuring several components of memory and learning concurrently (Buschke, 1973). Originally developed as a research instrument, this procedure has gained considerable clinical credibility in the assessment of verbal learning and memory deficits (Clodfelter, Dickson, Wilkes, Johnson, 1987). The SRT is composed of 12 semantically unrelated words. The examiner reads the entire list of words on the first trial and asks the examinee to repeat as many words as can be remembered. On subsequent trials only the words the examinee did not recall are presented. For children, this test has been adapted to only include eight trials instead of the original 10 trials used in the adult version. The test is discontinued before all trials are administered if the examinee lists all 12 words on two consecutive trials.

If a word is repeated on two successive trials, the word is assumed to be recalled from long-term storage (LTS). Words that are consistently recalled on the remaining trials are considered to be a product of consistent long-term retrieval (CLTR). Those words that are retrieved from LTS on some trials but not others are assumed to be random long-term retrieval (RLTR). When words are not retrieved on two consecutive trials, individual retrieval is thought to be based on short-term retrieval (Beatty, Krull, Wilbanks, Blanco, Hames, & Paul, 1996).

Clodfelter et al. (1987) developed alternate forms of the SRT that are statistically similar. The words are composed of four to eight letters and consist of two syllables. Clodfelter et al. (1987) provide support for the use of noncategorical words when composing a list. They argue that a categorical list is easier to store and retrieve, resulting in a ceiling effect. They also found alternate forms to be significantly correlated (r = .56 - .85). The words chosen for use with the normative participants and the reading disabled participants in this study were taken from Clodfelter et al.'s Form A, which included the following 12 words: garden, doctor, metal, city, money, cattle, prison, clothing, water, cabin, tower, and bottle.

Beatty, Krull, Wilbanks, Blanco, Hames, and Paul (1996) explored the validity of the definitions of STM, LTS, CLTR, and RLTR with adult normal and MS patient participants. Their findings provide validity for STR, RLTR, CLRT, and LTS. Words that were consistently retrieved (CLTR) were more likely to be recalled after a delay than words retrieved randomly (RLTR). Lowest retrieval was for words in STM. Although not statistically significant, Trahan, & Quintana (1990) found that females generally outperform males in the acquisition phase.

Consonant Trigrams Task. The Consonant Trigrams Task (CTT) is a procedure based on the Brown-Peterson Paradigm (Brown, 1958; Peterson & Peterson, 1959). The examinee is aurally provided with three consonants followed by a distractor that consists of a number from which the examinee counts backwards. After a designated delay period the examiner signals the examinee to recall the three consonants. Because verbal material gains obligatory access to the phonological store, irrelevant and possibly interfering speech is avoided by signaling recall through knocking rather than a verbal signal (Gathercole, 1994).

The Consonant Trigrams Task (CTT) is a useful technique for examining short-term retention in the presence of a distractor. The distractor task used for children is somewhat different from that used with adults. Children are asked to count backwards by ones, while adults count backwards by threes. This difference reduces the influence of arithmetic ability on the test performance of children. Immediate recall of the total number of consonants without the distractor task is calculated. Three delay periods of 3, 9, and 18 seconds are also calculated, across five trials each, obtaining five scores, one at each of the time intervals, and a total of remembered consonants. An additional score can also be obtained, providing an index of the number of times a letter is recalled from the previous trial. The latter is a measure of persevarative responses across trials.

Although early research suggested that forgetting in this task was a result of an interference effect, an alternate explanation in current use is that counting backwards interferes with an individual's ability to use rehearsal in the maintenance of consonants in memory (Vallar & Baddeley, 1982). Generally, this procedure is resistant to difference in age, education, or gender; however, there are trends toward better performance by individuals in younger age groups, individuals with more than a high school education, and for women (Lezak, 1995). This task has proven particularly useful for assessment of head-injured individuals. Patients with left temporal damage generally recall less than controls (see Lezak, 1995) and patients with left temporal epilepsy have demonstrated impaired performance (Giovagnoli & Avanzini, 1996).

Continuous Visual Memory Test. The Continuous Visual Memory Test (CVMT) is a test of visual learning and memory (Trahan & Larrabee, 1988). Unlike the Visual Reproduction (VR) task of the WMS-R, the Continuous Visual Memory Test (CVMT) does not have a motor component, which has been speculated to confound memory performance (Trahan, Larrabee, Fritzsche, & Curtiss, 1996). The

CVMT was designed to be an uncontaminated test of visual memory. Trahan, Larrabee and Quintana (1990) cite five characteristics included in the design that promote purity in measurement: 1. a recognition memory format; 2. use of complex ambiguous designs not easily susceptible to verbal labeling; 3. a large number of stimuli including classes of perceptually similar stimuli; 4. limited exposure time to each item; 5. and a delayed recognition task.

The test consists of 112 complex designs consisting of seven point polygons, hollow 10-point polygons, and patterns of line segments (Trahan, Larrabee, Fritzche, & Curtiss, 1996). Each design is exposed for two seconds and the examinee is asked to state whether the design is "new," (a design that has not been seen before), or whether the design is "old," (representing a design that has been repeated). Seven designs are repeated six times throughout the test.

Following a 30 minute delay, recognition and visual discrimination tasks are completed. On the delayed-recognition task, the examinee is asked to determine, from seven designs, which design was repeated six times. This delay-recognition score has been found to be a pure measure of visual memory (Larrabee, Trahan, & Curtiss, 1992). In the discrimination task, each recurring design is presented alone on one page and along with similar items on a facing page. The examinee is asked to identify the item that matches the test item.

A number of scores can be obtained from the CVMT: the total score, involving the total number of correct identifications of new or old; and a *d* prime score involving a measure of learning and memory sensitivity. The *d* prime score is based on signal detection theory and considers both the subject's correct recognition of a recurring item (old) as well as their identification of a new item as one previously seen (Trahan, Larrabee, & Quintana, 1990). Delay and recognition scores are generated based on the total number correct out of seven designs (Trahan & Quintana, 1990).

Earlier work by Trahan, Larrabee, & Quintana (1990) demonstrated that patients with right-hemisphere lesions performed worse than patients with left-hemisphere lesions on the CVMT. Trahan et al. (1990) suggest their results provide support for the clinical utility of the CVMT by showing it to be sensitive to memory impairment due to lesions.

Procedure

The normative participants were tested individually by a research assistant. Each session took approximately one hour and the children received the tests in the following order : WMS-R LMI, WMS-R VRI, CTT, WISC-III Vocabulary subtest, WMS-R LMII, WMS-R VR II, SRT, CVMT, SRT-delay, and CVMT-delay. The children in the normative study also received the Wisconsin Card Sorting Test (WCST), which is a measure of higher level thinking skills. In the current study, the participants who had been identified as reading disabled received the same tests in a similar order to the normative study participants. However, the participants in the current study did not receive the WCST. Additionally, these participants were first administered the Reading subtest from Wide Range Achievement Test Third Revision (WRAT3). Each child was tested in a quiet room in his or her school by a graduate student trained in test administration.

Chapter Four

Results

Each section of this chapter is introduced with the hypothesis that guided the analysis of the data. The first section outlines the correlational analysis using the data of the children aged nine to 12 years old from the normative database (Miller, Paniak, and Murphy, 1993). The correlations were conducted on variables from the five tests of learning and memory that were administered to the normative participants. Initial analysis explores the relationship between the WISC-III Vocabulary raw scores and selected variables from the normative database. This same analysis was then conducted with the data collected from children with a reading disability. The intercorrelations between the variables from the tests of verbal and visual learning and memory are then presented.

The next series of analyses presented include comparisons between the children with a reading disability and the two matched control groups. This series begins with an analysis of group performance on each of the five tests of learning and memory: WMS-R Logical Memory (LM), Selective Reminding Test (SRT), the Consonant Trigrams Task (CTT), WMS-R Visual Reproduction (VR), and the Continuous Visual Memory Test (CVMT). The final analysis involves discriminate function analysis exploring the efficacy of variables found to be significantly different at predicting group membership.

Hypothesis One

It is hypothesized that higher correlations will be found between the verbal memory measures and the WISC-III Vocabulary score than between visual/spatial memory measures and the WISC-III Vocabulary. It is also hypothesized that instruments measuring the same stimulus modality will show higher correlations than those measuring different modalities, i.e., visual/spatial memory versus verbal memory stimuli. Likewise, it is anticipated that there would be a high correlation between immediate and delay measures of each instrument because of the overlap in stimuli.

Correlational analysis between WISC-III Vocabulary and verbal and visual/spatial variables for the normative sample. Results are presented in table 2. Variables were considered to be strongly correlated if the relationship was above .7. Moderate correlations were interpreted with relationships between .3 and .7, and weak relationships were interpreted for correlations below .3 (Glass & Stanley, 1970).

For tests of verbal learning and memory for the entire normative group of 477 students aged nine - 12 years old there were significant correlations ($p<.01$) between WISC-III Vocabulary raw scores and variables from the Logical Memory subtest (LM), the Selective Reminding Test (SRT) and the Consonant Trigrams Task (CTT). For the Logical Memory (LM) test significant correlations were found between WISC-III Vocabulary and LM I, LM II, but not LM saving score. The saving score is an index of retention, that is the proportion of material recalled between the immediate and delayed trials. In the case of Logical Memory, the saving score is an index of the information retained between LM I and LM II.

For the Selective Reminding Test (SRT), significant correlations were found between Vocabulary and the total recall score (TR), LTR, STR, LTS, RLTR, CLTR, total reminders, recall at trial 8, delayed recall, cued recall and delayed cued recall.

These correlations were weak to moderate. As found with LM, there was not a significant correlation between the WISC-III Vocabulary score and the SRT saving score. For the Consonant Trigrams Test, there was a significant correlation with the total score, perseverative responses and delay scores at three seconds, nine seconds and 18 seconds. These variables produced correlations that were weak to moderate.

Insert table 2 about here

With regards to the visual/spatial tests, there were also significant correlations between WISC-III Vocabulary raw scores and variables from Visual Reproduction (VR) and the Continuous Visual Memory Test (CVMT)(see table 2). Correlations were significant (p. $< .01$) between the WISC-III Vocabulary score and VR I, VR II and VR saving score as well as between the CVMT total score, and CVMT delay score (see table 3).

Correlational analysis between WISC-III Vocabulary and verbal and visual/spatial variables for the RD sample. For the reading disabled group, there were similar moderate correlations between WISC-III Vocabulary and many of the verbal measures (see table 2). For example, moderate correlations were found with LM I, LM II, SRT total recall, SRT LTR, and SRT CLTR. The remainder of the

Table 2

Correlations Between WISC-III Vocabulary Raw Score and Verbal and Visual Variables

Measure	Normative Sample (N = 477)	RD (N=53)
WMS-R Logical Memory I	.521**	.522**
WMS-R Logical Memory II	.500**	.544**
WMS-R Logical Memory Saving Score	.067	.142
SRT Total Recall	.331**	.344*
SRT LTR	.290**	.330*
SRT LTS	.256**	.267
SRT STR	-.160**	-.247
SRT RLTR	-.189**	-.108
SRT CLTR	.288**	.308*
SRT Total Reminders Given	-.324**	-.354**
SRT Trial 8	.218**	.274*
SRT Delay	.212**	.209
SRT Cued Recall	.272**	.357**
SRT Delayed Cued Recall	.238**	.338*
SRT Saving Score	.049	.003
Consonant Trigrams Task 3"	.327*	.037
Consonant Trigrams Task 9"	.344**	.085
Consonant Trigrams Task 18"	.350**	.271*
Consonant Trigrams Task Perseverative Responses	-.186**	.217
Consonant Trigrams Task Total Score	.422**	.167
WMS-R Visual Reproduction I	.396**	.052
WMS-R Visual Reproduction II	.382**	.135
WMS-R Visual Reproduction Saving Score	.143**	.123
CVMT Total	.357**	.196
CVMT Delayed Recognition	.349**	.215

Note. SRT LTR = Selective Reminding Test Long-term recall, SRT LTS = Selective Reminding Test Long-terms storage, SRT STR = Selective Reminding Test Short-term recall, SRT RLTR = Selective Reminding Test Random long-term retrieval, SRT CLTR = Selective Reminding Test Consistent long-term Retrieval, CVMT Total = Continuous Visual Memory Test Total Score, CVMT Delayed Recognition = Continuous Visual Memory Test Delayed Recognition.
*$p > .05$ **$p > .01$

verbal memory variables produced low correlations with WISC-III Vocabulary, as did the visual/spatial variables.

Insert table 3 about here

Correlational analysis between verbal and visual/spatial variables for the normative sample. In terms of the intercorrelations between test variables, Logical Memory I was, as expected, significantly and strongly correlated with Logical Memory II (see table 3). LM I was not, however, significantly correlated with LM savings score. Correlations between LM I and the SRT variables were low to moderate. Logical Memory I was only modestly correlated with most of the variables from the Consonant Trigrams Task.

Similarly, Logical Memory II was significantly correlated ($p<.01$) with most SRT variables. There was not a significant correlation between Logical Memory II and the SRT saving score. Similar to the results of LM I, LM II was modestly correlated with all the variables from the Consonant Trigrams Task. These correlations were found to be significant ($p<.01$) for all the CTT variables.

As expected, the Selective Reminding Test (SRT) total recall score (TR) was also significantly correlated with its own subscores: LTR, LTS, STR, RLTR, CLTR, total reminders given, recall at trial 8, delayed recall, cued recall, delayed cued recall and saving score. Correlations ranged from moderate to high. The SRT TR score was

Table 3
Correlations Between Verbal Variables for the Normative Sample

	LMI	LMII	LMSS	SRTtot	LTR	LTS	STR	RLTR	CLTR	Remind	Trial 8	Del`	CR	Del CR	SRTSS	CTT 3	CTT 9	CTT18	Persev	CTTtot
LMI	1.00																			
LMII	.922**	1.00																		
LMSS	.083	.431**	1.00																	
SRTtot	.343**	.378**	.182**	1.00																
LTR	.321**	.360**	.184**	.967**	1.00															
LTS	.307**	.340**	.166**	.899**	.968**	1.00														
STR	-.218**	-.257**	-.157**	-.727**	-.878**	-.918**	1..00													
RLTR	-.145**	-.171**	-.108*	-.561**	-.465**	-.254**	.202**	1.00												
CLTR	.287**	.326**	.177**	.926**	.901**	.777**	-.690**	-.803**	1.00											
Remind	-.336*	-.368**	-.171**	-.988**	-.957**	-.902**	.722**	.511**	-.895**	1.00										
Trial 8	.193**	.239**	.170**	.721**	.695**	.584**	-.519**	-.654**	.787**	-.640**	1.00									
Del	.171**	.219**	.191**	.664**	.669**	.619**	-.557**	-.378**	.635**	-.638**	.573**	1.00								
CR	.213*	.252*	.114*	.529**	.519**	.453**	-.410**	-.381**	.536**	-.508**	.457**	.503**	1.00							
Del CR	.175**	.233**	.182**	.556**	.560**	.511**	-.464**	-.318**	.532**	-.544**	.447**	.649**	.725**	1.00						
SRTSS	.028	.043	.073	.129**	.156**	.202**	-.179**	.154**	.030	-.171**	-.207**	.653**	.188**	.447**	1.00					
CTT3	.211**	.205**	.031	.152**	.113*	.090	-.017	-.110*	.130**	-.152**	.113*	.076	.097*	.076*	-.004	1.00				
CTT9	.196**	.222**	.114*	.269**	.241**	.211**	-.143	-.158**	.240**	-.272**	.171*	.221**	.225**	.269**	.099*	.521**	1.00			
CTT18	.214**	.190**	-.001	.241**	.217**	.206**	-.128	-.119**	.205**	-.276**	.130**	.186**	.183**	.179**	.103*	.423**	.515**	1.00		
Persev	-.132**	-.167**	-.086	-.143**	-.139**	-.123**	.106*	.095*	-.140**	.140**	-.093*	-.117*	-.096*	-.122**	-.051	-.487**	-.469**	-.291**	1.00	
CTTtot	.261**	.260**	.061	.274**	.237	.211**	-.120	-.160	.238**	-.276**	.170**	.199**	.208**	.215**	.086	.798**	.836**	.790**	-.510**	1.00

Note. LMI = Logical Memory I, LMII = Logical Memory II, LMSS = Logical Memory Saving Score, SRTtot = SRT Total Recall, LTR = SRT Long-term Recall, LTS = SRT Long-term Storage, STR = SRT Short-term Recall, RLTR = SRT Random Long-term Retrieval, CLTR = SRT Consistent Long-term Retrieval, Remind = SRT Total Reminders, Trial 8 = SRT Recall at trial 8, Del = SRT Delayed Recall, CR = SRT Cued Recall, Del CR = SRT Delayed Cued Recall, SRTSS = SRT Saving Score, CTT0 = Consonant Trigrams Task 0", CTT3 = Consonant Trigrams Task 3" delay, CTT9 = Consonant Trigrams Task 9" delay, CTT18 = Consonant Trigrams Task 18" delay, Persev = CTT Perseverations, CTTtot = Consonant Trigrams Task Total Score. $^{*}p > .05$. $^{**}p > .01$.

also significantly correlated with CTT total score, perseverative responses, CTT 3", CTT 9", and CTT 18", but these correlations were weak to modest.

The Continuous Visual Memory Test total score was moderately correlated ($p<.01$) with Visual Reproduction I , Visual Reproduction II, and Visual Reproduction saving score (see table 4). Correlations were also moderate between Visual Reproduction I and Visual Reproduction II, and between Continuous Visual Memory Test total score and Continuous Visual Memory Test delayed recognition.

Insert table 4 about here

In terms of the intercorrelations between the verbal and visual/spatial memory tests in the normative sample, only minimal correlations were found between these tests (see table 5). For example, Logical Memory I was minimally correlated with VR I and VR II. Likewise there were only minimal correlations between LM I and the CVMT total score and CVMT delayed recognition. The same pattern was observed with LM II, where there were statistically significant but only minimal correlations with the visual/spatial variables: VR I, VR II, VR saving score, CVMT total score, CVMT delayed recognition. A similar result was also found between the SRT total score and the variables of the visual/spatial tests: VR I, VR II, VR savings score, CVMT total score, and CVMT delayed recognition. Mild to moderate

Table 4

Correlations Between Visual Variables for the Normative Sample

	VRI	VRII	VRSs	Cvmtot	CVMDel
VRI	1.00				
VRII	.645**	1.00			
VRSS	-.054	.716**	1.00		
Cvmtot	.321**	.329**	.130**	1.00	
CVMDel	.379**	.374**	.137**	.525**	1.00

Note. VRI = Visual Reproduction I, VRII = Visual Reproductions II, VRSS = Visual Reproduction Saving Score, CVMtot = Continuous Visual Memory Test Total Score, CVMDelay = Continuous Visual Memory Test Delay.
**p* > .05 ***p* > .01

correlations were found between CTT total score and the visual/spatial variables: VR I, VR II, VR saving score, CVMT total score, and CVMT delayed recognition.

Insert table 5 about here

Insert table 6 about here

Correlational analysis between verbal and visual/spatial variables for the reading disabled sample. In terms of the intercorrelations between test variables, there was a similar pattern of correlations to that found with the normative sample, but fewer of the correlations were found to be significant ($p < .05$). Logical Memory I was significantly and strongly correlated with Logical Memory II (see table 6) and LM I was not significantly correlated with LM Savings Score. Correlations between LM I and the SRT variables were low to moderate, with significant correlations only found with SRT total recall, LTR, delayed recall, and delayed cued recall. For the CTT variables there was only a significant correlation with CTT at the 18 second delay.

Logical Memory II was significantly correlated ($p<.05$) with SRT total recall, total reminders, delayed recall, and delayed cued recall. The remainder of correlations with SRT variables were not significant. Similar to the results of LM I,

Table 5

Correlations Between Verbal and Visual Memory Variables for the Normative Sample

	LMI	LMII	LMSS	SRTtot	LTR	LTS	STR	RLTR	CLTR	Remind	Trial 8	SRTDel`	CR	Del CR	SRTSS	CTT 3	CTT 9	CTT 18	Persev	CTT tot
VRI	.223**	.226**	.036	.154**	.129**	.125**	-.057	-.062	.117*	-.156**	.086	.186**	.172**	.186**	.142**	.202**	.280**	.281**	-.118**	.311**
VRII	.227**	.237**	.057	.272**	.241**	.209**	-.136**	-.192**	.256**	-.276**	.181**	.312**	.262**	.312**	.189**	.240**	.288**	.259**	-.167**	.320**
VRSS	.087	.100*	.067	.210**	.191**	.152**	-.122**	-.193**	.223**	-.213**	.156**	.235**	.188**	.244**	.123**	.136**	.126**	.087	-.116*	.142**
CVMtot	.194**	.195**	.046	.283**	.274**	.244**	-.206**	-.206**	.285**	-.274**	.249**	.248**	.253**	.231**	.049	.199**	.284**	.282**	-.142**	.313**
CVMDel	.213**	.199**	.010	.235**	.246**	.240**	-.219**	-.114*	.221**	-.226**	.175**	.209**	.212**	.224**	.090*	.199**	.276**	.279**	-.188**	.313**

Note. LMI = Logical Memory I, LMII = Logical Memory II, LMSS = Logical Memory Saving Score, SRTtot = Selective reminding Test Total Recall, LTR = Selective Reminding Test Long Term Recall, LTS = Selective Reminding Test Long Term Storage, STR = Selective Reminding Test Short Term Recall, RLTR = Selective Reminding Test Random Long Term Retrieval, CLTR = Selective Reminding Test Consistent Long Term Retrieval, Remind = Selective Reminding Test Total Reminders Given, Trial 8 = Selective Reminding Test Recall at Trial 8, SRTDel = Selective Reminding Test Delay, CR = Selective Reminding Test Cued Recall, Del CR = Selective Reminding Test Delayed Cued Recall, SRTSS = Selective Reminding Test Saving Score, CTT0 = Consonant Trigrams Task 0", CTT3 = Consonant Trigrams Task 3" delay, CTT = Consonant Trigrams Task 9" delay, CTT18 = Consonant Trigrams Task 18" delay, Persev = Consonant Trigrams Task Perseverative Responses, CTTtot = Consonant Trigrams Task Total Score, VRI = Visual Reproduction I, VRII = Visual Reproduction II, VRSS = Visual Reproduction Saving Score, CVMtot = Continuous Visual Memory Test Total Score, CVMDelay = Continuous Visual Memory Test Delay.

*p > .05 **p > .01*

Table 6

Correlations Between Verbal Variables for the RD Sample

	LMI	LMII	LMSS	SRTtot	LTR	LTS	STR	RLTR	CLTR	Remind	Trial 8	Del'	CR	Del CR	SRTSS	CTT 3	CTT 9	CTT18	Persev	CTTtot
LMI	1.00																			
LMII	.872**	1.00																		
LMSS	-.023	.419**	1.00																	
SRTtot	321*	.280*	-.028	1.00																
LTR	.291*	.232	-.081	.955**	1.00															
LTS	.181	.134	-.105	.930**	.932**	1.00														
STR	-.075	.010	.192	-.787**	-.851**	-.909**	1.00													
RLTR	-.048	-.169	-.246	-.134	-.066	.066	-.078	1.00												
CLTR	.237	.247	.045	.900**	.858**	.804**	-.731**	-.509**	1.00											
Remind	-.311	-.272*	.026	-.986**	-.946**	-.917**	.767**	.088	-.867**	1.00										
Trial 8	.270	.220	-.065	.685**	.625**	.563**	-.554**	-.607**	.804**	-.610**	1.00									
Del	.358*	.368*	.135	.614**	.526**	.480**	-.307*	-.284*	.598**	-.579**	.589**	1.00								
CR	.262	.215	-.006	.563**	.532**	.536**	-.498**	-.045	.502**	-.557**	.484**	.452**	1.00							
Del CR	.381*	.368**	.055	.606**	.563**	.546**	-.468**	-.199	.581**	-.586**	.574**	.553**	.732**	1.00						
SRTSS	.179	.246	.254	.172	.102	.103	.129	.085	.049	-.187	-.107	.703**	.050	.116	1.00					
CTT3	-.009	.033	.125	-.091	-.139	-.108	.126	-.145	-.004	.073	-.113	.016	.231	.174	.138	1.00				
CTT9	.083	.049	-.062	.031	-.105	-.045	.068	-.072	-.017	.069	.043	.102	.042	.145	.139	.298*	1.00			
CTT18	.299*	.159	-.184	.242	.233	.212	-.247	-.117	-.274*	-.225	.328*	.198	.293*	.155	-.042	.145	.234	1.00		
Persev	.129	.149	-.025	.140	.203	.098	-.068	-.021	.098	-.153	.080	.070	-.093	-.084	.003	-.503**	-.101	.091	1.00	
CTTtot	.122	.099	-.005	.077	.031	.065	-.066	-.168	.163	-.082	.153	.181	.254	.237	.128	.700**	.691**	.615**	-.264	1.00

Note. LMI = Logical Memory I, LMII = Logical Memory II, LMSS = Logical Memory Saving Score, SRTtot = SRT Total Recall, LTR = SRT Long-term Recall, LTS = SRT Long-term Storage, STR = SRT Short-term Recall, RLTR = SRT Random Long-term Retrieval, CLTR = SRT Consistent Long-term Retrieval, Remind = SRT Total Reminders, Trial 8 = SRT Recall at trial 8, Del = SRT Delayed Recall, CR = SRT Cued Recall, Del CR = SRT Delayed Cued Recall, SRTSS = SRT Saving Score, CTT0 = Consonant Trigrams Task 0", CTT3 = Consonant Trigrams Task 3" delay, CTT9 = Consonant Trigrams Task 9" delay, CTT18 = Consonant Trigrams Task 18" delay, Persev = CTT Perseverations, CTTtot = Consonant Trigrams Task Total Score. *p > .05. **p > .01.

LM II was modestly correlated with all the variables from the Consonant Trigrams Task. These correlations were found to be significant ($p<.05$) for all the CTT variables.

As expected, the Selective Reminding Test (SRT) total recall score (TR) was also significantly correlated with its own subscores: LTR, LTS, STR, CLTR, total reminders given, recall at trial 8, delayed recall, cued recall, and delayed cued recall. Correlations ranged from moderate to high. TR was not significantly correlated with RLTR or saving score. The SRT TR score was not significantly correlated with the CTT variables.

The Continuous Visual Memory Test total score was moderately correlated ($p<.05$) with Visual Reproduction I , Visual Reproduction II, and Visual Reproduction saving score (see table 7). Continuous Visual Memory Test total score was significantly correlated with Continuous Visual Memory Test delay score ($p < .01$). Visual Reproduction I was significantly correlated with Visual Reproduction II, and Visual Reproduction II was significantly correlated with VR saving score.

Insert table 7 about here

In terms of the intercorrelations between the verbal and visual/spatial memory tests in the RD sample, only minimal correlations were found between these tests (see table 8), and the only significant ($p < .05$) finding was between Visual Memory II and

Table 7

Correlations between Visual Variables for the RD Sample

	VRI	VRII	VRSS	Cvmtot	CVMDel
VRI	1.00				
VRII	.560**	1.00			
VRSS	.035	.838**	1.00		
Cvmtot	.388**	.451**	.296*	1.00	
CVMDel	.569**	.432**	-.125	.426**	1.00

Note. VRI = Visual Reproduction I, VRII = Visual Reproductions II, VRSS = Visual Reproduction Saving Score, CVMtot = Continuous Visual Memory Test Total Score, CVMDelay = Continuous Visual Memory Test Delay.
*$p > .05$ **$p > .01$

Consonant Trigrams Task 18 second delay. For example, Logical Memory I was minimally correlated with VR I and VR II.

Insert table 8 about here

The WISC-III Vocabulary raw score was most highly correlated with LM I and LM II for both the normative sample and the RD sample. A surprising finding is the number of moderate correlations found between the WISC-III Vocabulary raw score and the visual memory variables for the normative sample. This same result was not found for the RD sample, where correlations were quite low.

As anticipated, there were generally higher correlations between variables from the same domain. Verbal memory variables generally showed moderate correlations with verbal memory variables from a different test but were only mildly correlated with variables from visual memory tests. Visual memory variables were moderately correlated with other variables from visual tests. Similarly, variables from within the same test showed moderate to high correlations with one another.

Hypothesis Two

It is anticipated that the RD group will differ from the control groups with regard to performance on verbal measures of learning and memory. It is also

Table 8

Correlations Between Verbal and Visual Memory Variables for the RD Sample

	LMI	LMII	LMSS	SRTtot	LTR	LTS	STR	RLTR	CLTR	Remind	Trial 8	SRTDel'	CR	Del CR	SRTSS	CTT 3	CTT 9	CTT 18	Persev	CTT tot
VRI	-.053	-.078	-.034	.051	.091	-.002	-.050	-.262	.148	-.006	.187	.079	.079	.130	-.048	.142	.037	.151	-.033	.130
VRII	-.084	-.102	.030	.152	.107	.017	.035	-.219	.184	-.132	.119	.156	.070	.072	.150	.088	-.032	.295*	.077	.166
VRSS	-.067	-.063	.074	.110	.031	-.020	.112	-.109	.102	-.113	.013	.131	.053	-.005	.206	.053	-.040	.225	.086	.130
CVMtot	.083	-.002	-.120	.100	.090	.081	-.071	-.073	.125	-.102	.101	.068	.141	-.065	.019	.206	.053	.251	.014	.237
CVMDel	.042	.030	-.021	.185	.206	.098	-.097	-.107	.154	-.196	.028	-.060	.104	.139	-.068	.104	-.132	.086	.171	.014.

Note. LMI = Logical Memory I, LMII = Logical Memory II, LMSS = Logical Memory Saving Score, SRTtot =Selective reminding Test Total Recall, LTR = Selective Reminding Test Long Term Recall, LTS = Selective Reminding Test Long-term Storage, STR = Selective Reminding Test Short-term Recall, RLTR = Selective Reminding Test Random Long-term Retrieval, CLTR = Selective Reminding Test Consistent Long-term Retrieval, Remind = Selective Reminding Test Total Reminders Given, Trial 8 = Selective Reminding Test Recall at Trial 8, SRTDel = Selective Reminding Test Delay, CR = Selective Reminding Test Cued Recall, Del CR = Selective Reminding Test Delayed Cued Recall, SRTSS = Selective Reminding Test Saving Score, CTT0 = Consonant Trigrams Task 0", CTT3 = Consonant Trigrams Task 3" delay, CTT = Consonant Trigrams Task 9" delay, CTT18 = Consonant Trigrams Task 18" delay, Persev = Consonant Trigrams Task Perseverative Responses, CTTtot = Consonant Trigrams Task Total Score, VRI = Visual Reproduction I, VRII = Visual Reproduction II, VRSS = Visual Reproduction Saving Score, CVMtot = Continuous Visual Memory Test Total Score, CVMDelay = Continuous Visual Memory Test Delay.

$*p > .05$ $**p > .01$

expected that the reading disabled group will perform lower on both the immediate recall and 30 minute delay portions of these tests, and that an analysis of the saving scores will show that the difficulties these children encounter rest in the encoding of information rather than its storage and retrieval.

WMS-R Logical Memory. A MANOVA was computed across groups on three variables from the WMS-R Logical Memory subtest (see table 9). Using the Wilks' Lambda criterion with an alpha level of .05, the MANOVA did not show significant results for the group factor $F(6, 306) = 2.173, p > .05$.

Insert table 9 about here

Selective Reminding Test. Results of a MANOVA computed across groups on variables from the Selective Reminding Test was significant for the group factor $F(18, 296) = 2.665, p < .001$. Univariate analysis showed significant differences ($p < .01$) between total recall (TR), long term storage (LTS), consistent long term retrieval (CLTR), random long term retrieval (RLTR), trial 8 recall, total reminders, cued recall (CR), delayed recall, and delayed cued recall (CR30) (see table 10). Post hoc Bonferroni comparisons yielded significant differences between the RD participants and both control groups ($p < .01$) on each of these variables, while none of the comparisons between the control groups were significant.

Effect sizes were calculated based on the mean difference between the RD group and control group divided by the standard deviation of the control group. When

Table 9

Mean Scores, *F* Values, and Effect Size for the Reading Disabled Participants and the Control Participants on the Logical Memory Test of the WMS-R

Variable	RD	Control 1	Control 2	*F*(2, 156)	Effect size
LM I	21.87(7.32)	20.22(7.39)	20.77(7.75)	.712	.164
LM II	17.51(6.62)	18.00(7.22)	18.04(7.25)	.159	.073
LM Saving Score	80.20(18.11)	88.70(20.10)	85.26(13.52)	3.169	.399

Note. Standard deviations are in parentheses. Control group 1 = participants matched on age, gender, and WISC-III Vocabulary. Control group 2 = participants matched on age and gender. LMI = Logical Memory I, LMII = Logical Memory II, LMSS = Logical Memory Saving Score.

results showed no significant differences between the control groups and similar findings with respect to any differences found with the RD group and each control group, effect sizes were averaged. Effect sizes between .20 and .49 are deemed to be small, those above .5 are medium, and above .8 are large (Cohen, 1992). The effect size is large for TR, LTS, CLTR, total reminders, cued recall, delayed cued recall, and trial 8, and medium for RLTR (see table 7).

Insert table 10 about here

Overall results from the comparisons between the performance of RD participants and controls on tests of learning and memory using verbal stimuli produced mixed findings. It was expected that the RD participants would have the most difficulty with the verbal tests and perform lower than controls on these measures. Although this is true for the performance of the RD participants on the Selective Reminding Test, this is not true for their performance on the Logical Memory test, where their performance was found to be similar to that of controls.

Hypothesis Three

Because the Consonant Trigrams Task relies on working memory, and reading disabled children have been shown to have difficulty maintaining phonological

Table 10

Mean Scores, *F* Values, and Effect Size for the Reading Disabled and Control Participants on the Selective Reminding Test

Variable	RD	Control 1	Control 2	*F*(2, 156)	Effect size
Total Recall (TR)	67.42(10.54)	74.85(7.60)	75.47(7.62)	14.07**	1.017
Delayed recall	8.89(2.24)	10.23(1.56)	10.09(1.58)	8.68**	.964
Saving score	90.26(21.67)	95.07(14.60)	90.2(10.78)	1.55	.168
CLTR	41.47(17.39)	56.47(16.16)	58.51(16.35)	16.57**	.985
LTS	64.87(14.07)	72.72(9.91)	73.98(9.70)	9.93**	.866
RLTR	17.42(8.41)	11.98(7.98)	11.23(7.58)	9.45**	.749
Recall trial 8	9.79(1.83)	10.83(1.27)	11.19(1.18)	13.16**	1.003
Cued recall	8.43(2.42)	9.94(1.46)	10.15(1.54)	13.48**	1.076
Cued delayed recall	8.74(2.29)	10.34(1.37)	10.45(1.55)	15.39**	1.136
Total reminders	38.34(9.26)	32.00(6.85)	31.64(6.78)	12.63**	.957

Note. Standard deviations are in parentheses. Control group 1 = participants matched on age, gender, and WISC-III Vocabulary. Control group 2 = participants matched on age and gender. CLTR = Selective Reminding Test Consistent Long-term Retrieval, LTS = Selective Reminding Test Long-term Storage, RLTR = Selective Reminding Test Random Long-term Retrieval, Recall trial 8 = Selective Reminding Test Recall at Trial 8.
**p<.01

representations in memory, it is anticipated that performance on this task will be lower for the children with a reading disability than that of the control groups. Similarly, it is also expected that as the difficulty level of the task increased with the inclusion of longer delay periods, the children with a Reading Disability will show increasingly poor performance.

Consonant Trigrams Task. A one-way ANOVA computed on the total score of the Consonant Trigrams Task showed a significant difference between the three groups, the RD group and two matched control groups, $F(2, 156) = 10.15, p < .001$. Post hoc Bonferroni comparisons showed significant differences in the total score from the reading disabled group and both the control groups, but no significant difference was noted between the control groups.

A MANOVA was computed across the four delay measures and the perseverative responses from the Consonant Trigrams Task (see table 11). Using the Wilks' criterion, the MANOVA was significant for the group factor $F(10, 304) = 5.489, p < .001$. Between subject analysis indicated significant differences ($p < .05$) for the perseverative responses and the 3 second, 9 second, and 18 second delay conditions. Post hoc Bonferroni comparisons yielded significant differences between the RD participants and both control groups for perseverative responses, 3 second delay, and 9 second delay. Results at the 18 second delay showed a significant difference between the RD participants and the control participants matched on age, gender, and WISC-III Vocabulary, but not for those matched on age and gender. There were no significant differences noted between control groups or between the three groups for immediate recall (0") (see table 8 and figure1). The effect size is medium for CTT total score, perseverative responses, 3 second delay, and 9 second delay. For the 18 second delay, the effect size between the RD group and control group 1 is medium and between the RD group and control group 2 is small (see table 11).

Consistent with expectations, the RD participants performed lower than both control groups on variables from the Consonant Trigrams Test, except for the immediate recall condition (0"). Because the immediate (0") condition is relatively easy and does not tax processing resources, the insignificant finding on this score is not surprising.

Insert table 11 about here

Insert figure 1 about here

Hypothesis Four

It is expected that there will be no difference in the performance of the reading disabled group and the two control groups on the visual/spatial measures of learning and memory.

WMS-R Visual Reproduction. A MANOVA was computed across the three variables of the WMS-R Visual Reproduction subtest (see table 12). Using the Wilks' criterion, the MANOVA was significant for the group factor $F(6, 308) = 3.163, p < .01$. Between subject analysis indicated significant differences for VR II

Table 11

Mean Scores, *F* Values, and Effect Size for Reading Disabled and Control Participants on the Consonant Trigrams Task

Variable	RD	Control 1	Control 2	*F*(2, 156)	Effect size
Total Score	34.06(5.31)	38.21(6.30)	38.70(5.83)	10.15**	.727
Perseverations	9.94(5.69)	13.11(4.80)	12.62(3.43)	6.89**	.721
0”	14.77(.58)	14.91(0.45)	14.89(0.32)	1.27	.343
3”	8.83(2.68)	10.09(2.57)	10.60(2.33)	6.90**	.625
9”	5.45(2.17)	6.74(2.83)	7.00(2.18)	5.28**	.504
18”	5.19(2.21)	6.28(2.13)	6.21(2.47)	3.82*	.512[a] .413[b]

Note. Standard deviations are in parentheses. Control group 1 = participants matched on age, gender, and WISC-III Vocabulary. Control group 2 = participants matched on age and gender.

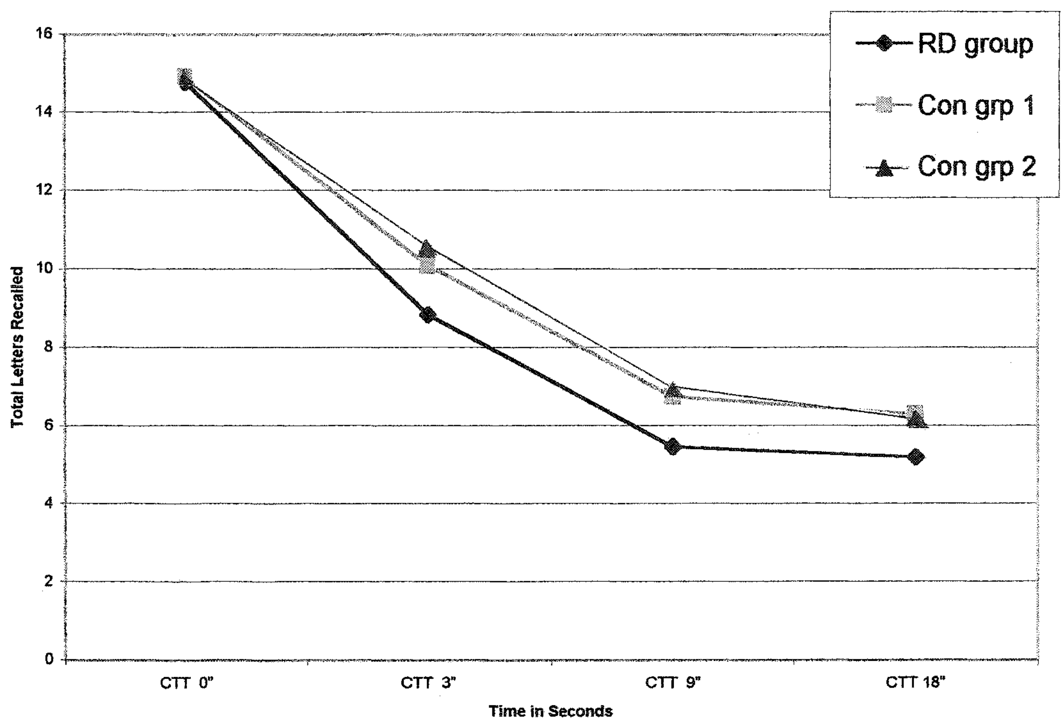
[a]Effect size between RD and control group 1.

[b]Effect size between RD and control group 2.

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

Figure 1

Total Number of Letters Recalled on the Consonant Trigrams Task



Note. Con grp 1 = participants matched on age, gender, and WISC-III Vocabulary. Con grp 2 = participants matched on age and gender.

$F(2, 156) = 7.582, p<.01$ and VR Saving Score $F(2, 156) = 6.688, p<.01$. Post hoc Bonferroni comparisons conducted between the groups on Visual Reproduction II and VR saving score yielded significant differences ($p < .05$) between the RD participants and both control groups. The effect size between the RD participants and the control groups is in the medium range for both. There was no significant difference between control groups.

Insert table 12 about here

Continuous Visual Memory Test. The performance of each of the three groups on the two variables from the Continuous Visual Memory Test are presented in table 13. Results of a MANOVA computed across groups on the Continuous Visual Memory Test variables did not show significant results for the group factor, $F(4, 310) = 1.005, p > .05$.

Insert table 13 about here

Comparisons between groups on visual spatial variables produced mixed results. Consistent with expectations, the performance of the RD participants was similar to that of the two control groups on the Continuous Visual Memory Test.

Table 12

Mean Scores, *F* Values and Effect Size for the Reading Disabled and Control Participants on the Visual Reproduction Test of the WMS-R

Variable	RD	Control 1	Control 2	F(2,156)	Effect size
VR I	29.47(4.44)	29.98(4.74)	30.79(4.51)	1.13	.200
VR II	22.26(6.26)	25.79(6.89)	26.85(5.85)	7.58*	.648
VR Savings Score	75.64(17.94)	84.98 (18.22)	87.72(17.74)	6.69*	.600

Note. Standard deviations are in parentheses. Control group 1 = participants matched on age, gender, and WISC-III Vocabulary. Control group 2 = participants matched on age and gender. VRI = Visual Reproduction I, VRII = Visual Reproductions II, VR Saving Score = Visual Reproduction Saving Score.
*$p > .05$

Table 13

Mean Scores, *F* Values, and Effect Size for the Reading Disabled Participants and the Control Participants on the Continuous Visual Memory Test

Variable	RD	Control 1	Control 2	$F(2, 156)$	Effect size
Total score	72.04(8.53)	70.02(10.16)	68.91(8.91)	1.639	.288
Delayed recognition	4.38(1.55)	3.94(1.77)	3.92(1.67)	1.253	.262

Note. Standard deviations are in parentheses. Control group 1 = participants matched on age, gender, and WISC-III Vocabulary. Control group 2 = participants matched on age and gender.

However, the results from the WMS-R Visual Reproduction subtest were mixed. While, the RD participants performed similar to both control groups on the immediate recall condition (VRI) trial, they performed lower on the long delay condition (VRII) and percentage of information retained (saving score).

Hypothesis Five

To evaluate the efficacy of test variables to discriminate between the ability groups, the test variables from the SRT and CTT that showed a statistically significant difference between the groups were examined using a discriminant function analysis. It is anticipated that based on previous research SRT CLTR and SRT TR will prove to be good discriminators (Snow, English, & Lange, 1992).

Insert table 14 about here

Because the within test correlations were moderate to high (see tables 14), a stepwise discriminant function analysis was performed to determine if any of the variables from each of the three tests where the RD group performed significantly lower would best discriminate between the RD group and the control group matched on age, gender, and WISC-III Vocabulary once variance associated with the other variables was accounted for. The analysis was performed using 15 variables selected from the Selective Reminding Test, Consonant Trigrams Test, and Visual

Table 14
Pooled Within Group Correlations Among Predictor Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. SRT total score	1.00														
2.SRT delayed recall	.600	1.00													
3.SRT CLTR	.889	.603	1.00												
4.SRT LTS	.930	.458	.788	1.00											
5.SRT RLTR	-.262	-.378	-.638	-.052	1.00										
6.SRT recall trial 8	.669	.549	.793	.577	-.564	1.00									
7. SRT cued recall	.483	.424	.452	.445	-.160	.422	1.00								
8.SRT cued recall delay	.520	.549	.498	.445	-.265	.453	.750	1.00							
9.SRT total reminders	-.987	-.568	-.848	-.918	.205	-.579	-.470	-.505	1.00						
10. CTT Persev	.009	.048	-.026	-.051	-.012	-.030	-.063	-.056	-.020	1.00					
11.CTT 3" delay	.035	.055	.105	.036	-.136	.016	.156	.126	-.052	-.512	1.00				
12. CTT 9" delay	.109	.139	.166	.103	-.163	.147	.143	.204	-.101	-.226	.432	1.00			
13. CTT 18" delay	.255	.160	.229	.216	-.091	.255	.229	.151	-.238	-.051	.286	.425	1.00		
14. VR II	.210	.203	.271	.117	-.268	.167	.211	.209	-.195	-.018	.156	.167	.224	1.00	
15. VR SS	.207	.190	.264	.108	-.249	.115	.188	.144	-.206	.030	.080	.173	.194	.829	1.00

Note. SRT total score = Selective Reminding Test Total Recall, SRT delayed recall = Selective Reminding Test 30 minute Delay, SRT CLTR = Selective Reminding Test Consistent Long Term Retrieval, SRT LTS = Selective Reminding Test Long Term Storage, SRT RLTR = Selective Reminding Test Random Long Term Retrieval, SRT recall trial 8 = Selective Reminding Test Recall at Trial 8, CTT Persev = Consonant Trigrams Task Perseverative Responses, CTT3 = Consonant Trigrams Task 3" delay, CTT = Consonant Trigrams Task 9" delay, CTT18 = Consonant Trigrams Task 18" delay, VRII = Visual Reproduction II, VRSS = Visual Reproduction Saving Score.

Reproduction. Predictors were SRT TR, SRT trial 8 recall, SRT LTS, SRT CLTR, SRT RLTR, SRT total reminders, SRT cued recall, SRT delayed recall, SRT delayed cued recall, CTT perseverative responses, CTT 3 second delay, CTT 9 second delay, CTT 18 second delay, VR II and VR savings score. One discriminant function was identified. The function had an eigenvalue of .478, accounted for 32% of the variance, and had a canonical correlation of .569, $x^2(15, N=103) = 40.01$. $p < .01$. The pooled within-groups correlations between the variables and the discriminant function are presented in table 15.

Insert table 15 about here

Three variables were retained by the stepwise analysis, SRT CLTR $F(1, 104) = 21.16$, CTT perseverations $F(2, 103) = 8.53$, CTT 3", $F(3, 102) = 13.65$. The overall results showed that 75.5% of the participants in the two groups were classified correctly. This means that moderate errors were made in classifying the two groups (see table 16).

Insert table 16 about here

Because variables representing aspects of verbal memory were those predominantly found to be significant in the comparison analysis showing lower performance of the RD group on these measures, there were only two variables of visual memory available (VR II and VR SS) to include in the discriminant function analysis, which did not prove to be good predictors of group membership.

Table 15

Correlations of Predictor Variables with the Discriminant Function

Variable	
SRT CLTR	.65
SRT TR	-.57
SRT Reminders	-.56
SRT RLTR	-.49
SRT trial 8	.46
SRT LTS	.46
CTT Perseverative Responses	.44
SRT delayed recall	.44
CTT 3"	.35
SRT delayed cued recall	.34
SRT cued recall	.33
CTT 18"	.30
VR II	.26
VR saving score	.24
CTT 9"	.22

Note. SRT CLTR = Selective Reminding Test Consistent Long Term Retrieval, SRT TR= Selective Reminding Test Total Recall, STR Reminders = Selective Reminding Test Total Reminders Given, SRT RLTR = Selective Reminding Test Random Long Term Retrieval, SRT trial 8 = Selective Reminding Test Recall at Trial 8, SRT LTS = Selective Reminding Test Long Term Storage, CTT Perseverative Responses = Consonant Trigrams Task Perseverative Responses, SRT delayed recall = Selective Reminding Test 30 minute Delay, CTT 3" = Consonant Trigrams Task 3" delay, SRT delayed cued recall = Selective Reminding Test 30 minute cued delayed recall. SRT cued recall = Selective Reminding Test cued recall, CTT 18" = Consonant Trigrams Task 18" delay, VRII = Visual Reproduction II, VRSS = Visual Reproduction Saving Score, CTT 9" = Consonant Trigrams Task 9" delay.

Table 16

Classification Results for Predictor Variables

	Predicted group membership	
Group	RD	Controls
RD	73.6%	26.4%
Controls	22.6%	77.4%

Note. RD = reading disabled group. Controls = control group matched on age, gender, and WISC-III Vocabulary.

Chapter Five

Discussion

The results of this study will be discussed in association with the hypotheses posed in Chapter 2. To review, this study sought to examine the performance of nine to 12 year old children with a reading disability on tests of visual and verbal memory. The performance of adults on memory tests has been extensively investigated, and although there is a growing literature on the learning and memory capabilities of children, it is has not yet reached the expanse of that available for adults. Similarly, there are also fewer tests of memory and learning available for children than for adults. This is despite some progress with the development of larger memory batteries, such as the Wide Range Assessment of Memory and Learning (WRAML) (Sheslow & Adams, 1990) and the Test of Memory and Learning (TOMAL) (Reynolds and Bigler, 1994). Previous research using experimentally designed memory measures has shown that children with reading disabilities perform worse than their normal reading counterparts on some measures of memory. This study examined whether these findings were also evident in clinical tests of memory that were originally developed for use with adults.

Hypothesis One

It was hypothesized that higher correlations would be found between the verbal measures and the WISC-III Vocabulary score than between visual/spatial measures and WISC-III Vocabulary. It was also hypothesized that instruments measuring the same stimulus modality would show higher correlations than would those measuring different modalities, i.e. visual/spatial versus verbal material. It was anticipated that there would be a high correlation between immediate and delayed recall measures from the same test.

As anticipated, there were significant correlations in the normative sample between the scores on the WMS-R Logical Memory I (LM I) and Logical Memory II (LM II) and WISC-III Vocabulary, although these correlations were moderate (.521 & .500). Likewise, there was a moderate correlation between the Selective Reminding Test (SRT) total recall score and the WISC-III Vocabulary raw score (.331). The savings scores from both LM and the SRT were not correlated significantly with the WISC-III vocabulary score. The remainder of the SRT variables were only weakly correlated with WISC-III Vocabulary and ranged between -.160 and .290. Correlations in the same range were found for the reading disabled sample between WISC-III Vocabulary and WMS-R LM I, LM II, and SRT variables.

It has generally been found that measures of memory are correlated with measures of intellectual ability (Canter, Engle, & Hamilton, 1991; Erickson & Scott, 1977). This finding confounds the measurement of memory, making pure evaluation difficult. Likewise, the current results also show a relationship between ability, as measured by the WISC-III Vocabulary, and memory. However, the weak correlations between the saving score variables for the Logical Memory subtest and the Selective Reminding Test and the WISC-III Vocabulary suggest that there was little relationship between this variable and intellectual ability, indicating that the saving score might represent a purer measure of memory.

Similarly, in the normative sample, the majority of the variables from the tests measuring visual/spatial learning and memory showed moderate correlations with WISC-III Vocabulary, which ranged between .349 and .396. As found with the Logical Memory subtest and the Selective Reminding Test, the saving score variable from the Visual Reproduction subtest was only weakly correlated with WISC-III Vocabulary. Of particular interest is the finding of moderate correlations between WISC-III Vocabulary and both the acquisition score and the delayed recognition score of the Continuous Visual Memory Test (CVMT). In an adult patient population of individuals with right hemisphere cerebrovascular accident (RCVA) and left hemisphere cerebrovascular accident (LCVA), Trahan, Larrabee, and Quintana (1990) found modest correlations between WAIS-R subtests used as measures of ability and CVMT total score but not for the delayed task. For the RCVA, there was a correlation of .55 between the WAIS-R Block Design subtest and the CVMT total score, and a correlation of .29 between the WAIS-R Block Design and the delayed score. For the LCVA, there was a correlation of .40 between the WAIS-R Information subtest and the CVMT total score, and a correlation of .04 with the delayed score. These results were interpreted to suggest that the delayed task was a purer measure of memory because it lacked the confounding effects associated with intellectual ability. However, Snitz, Roman, & Beniak (1996) found that in a population of individuals with left and right seizure focus there were moderate to high correlations with measures of ability and the CVMT acquisition score and the CVMT delayed task. The findings of these studies suggest the possibility that intellectual ability contributes variably to the performance on this measure depending on the group of individuals being studied. Generally, the evidence appears to be inconclusive for adult neurological patients. However, given the large size of the normative sample used in the current study, it would appear that for normal children aged nine to 12 years old there is a relationship between verbal intellectual ability and the CVMT scores.

The intercorrelations between test variables generally only produced weak to moderate correlations with the exception of a number of intra-test variables. Between test correlations ranged from .028 to .378 for the normative sample and from -.002 to .328 for the RD sample. In terms of intra-test correlations, there was a high correlation between LM I and LM II as well as between many of the SRT variables for both the normative and RD samples. Weak to moderate correlations were found within visual/spatial test variables for the normative sample (range = -.054 - .716), while weak to high correlations were found with the RD sample (range = .035 - .838). Correlations between verbal and visual memory variables were generally found to be somewhat lower for the RD sample (range = -.002 - .295) than for the normative sample (range = .036 - .320). These results suggest that the tests are measuring different aspects of learning and memory, even within the same modality, and therefore cannot be used interchangeably.

Hypothesis Two

It was anticipated that the children with a reading disability would differ from the control participants with regard to their performance on the verbal measures of learning and memory. It was expected that the reading disabled children would perform lower on both the immediate recall and 30 minute delayed recall portions of these tests, and that an analysis of the saving scores would show that the difficulties these children encounter rest in the encoding of information, rather than its storage and retrieval.

Results were variable on this hypothesis. Specifically, the children with a reading disability performed lower on list learning as measured by the Selective Reminding Test (SRT) but not on story memory as measured by the WMS-R Logical Memory subtest (LM). These findings are not in accordance with the view that because the primary deficit of children with a reading disability are in the language oriented tasks, they would then perform poorly on all verbally based memory tasks.

Korkman and Personen (1994) found that the learning disabled children in their study (identified by low spelling ability) performed poorly compared to normative results on retelling a story they had just heard, but performed normally when questioned on details pertaining to the story following a delay. These authors suggested that lower performance on retelling the story was related to language impairment rather than of memory impairment, which is contrary to the finding of the current study that suggested normal performance of the RD group on the immediate recall of the story. The lack of significant findings in the Korkman and Personen (1994) study on story memory, which was assessed by questions about the story, is similar to the results of the current study suggesting that children with a reading disability experience little difficulty with story memory. However, the structure of the story task used by Korkman and Personen (1994) may have added to the lack of significant findings following a delay because retention was assessed with the aid of eight questions. The contextual environment of the stories, in conjunction with a reduction in the burden of the task by not requiring the children to recall the story after a delay, may have facilitated better performance.

Similarly, it is possible that stories from the WMS-R Logical Memory subtest may not have taxed the verbal processes of the children with a reading disability. The contextual environment of the story may have provided some assistance to the children with a reading disability, and in effect buffered their difficulties in processing verbal information. There is some evidence to support this conclusion in the literature. For example, context has significant impact on human verbal memory in general (Spear & Riccio1994). Context facilitates the connections between information held in memory and new to-be-remembered information. Essentially, connections between the bits of information provide a better chance of recall occurring. Context in sentences has also been shown to be used more often by reading disabled children than by skilled readers in the identification of words (Perfetti, 1995). Therefore, these children may be primed to use context as a strategy to ease processing demands. In light of the different findings between this study and that of Korkman and Personen, the performance of children with a reading disability needs to be further evaluated, especially because different criteria were used in each study to define the target population. From the current study, it is generally concluded that Logical Memory is not sensitive to memory deficits in children with a reading disability.

It was anticipated that because reading disabled children have been shown to have primarily a language processing deficit, this deficit would be disabling at the initial stage of the process of remembering. It was thought that they would have lower scores at the immediate recall periods where information is initially encoded. Because of limited initial encoding, it would follow that after a long delay, the children with a reading disability would also perform lower than the matched control groups. As a consequence, this makes analysis of the process of retention difficult. Retention is seen as the ability to hold and retrieve the information that has been encoded. This problem has been approached with a saving score, which is a measure of the percentage of information from the immediate recall that is recalled after a delay. Current findings indicate that although the reading disabled group achieved a lower saving score and therefore retained a smaller percentage of information on Logical Memory compared to the matched controls, this difference was not statistically significant. Consequently, these findings support the conclusion that the reading disabled children were able to retain information in memory approximately as well as the control groups.

Similar results were also found in the performance of the children on the Selective Reminding Test where there was no difference in the proportion of the number of words recalled between the final acquisition trial and the recall trial following a 30 minute delay. Again, this suggests that the reading disabled children are able to recall the same amount of encoded information as the control groups, supporting the assumption that the children with a reading disability have less difficulty with storage and retrieval than with initial encoding of verbal information.

When addressing the location of processing deficits of children with a reading disability, the fact that they also showed lower performance than the control groups on SRT trials using phonemic cueing (cued recall), supports the conclusion that their difficulty occurred earlier in processing and likely in the acquisition phase of learning and remembering. Cueing provides assistance by alleviating the retrieval mechanism of its duties and allowing access to the information that is in storage. Because the cues provided no assistance to children with a reading disability, it is assumed that the information was not initially encoded. Alternatively, these children may have not benefited from the cues because the assistance was provided in phonemic form.

The results from comparisons of other Selective Reminding Test variables showed that the reading disabled children differed from the two control groups on long term storage (LTS), consistent long term retrieval (CLTR), and random long term retrieval (RLTR). The children with a reading disability were found to have fewer words in LTS and were less likely to retrieve these words consistently, which is shown in the higher number of RLTR scores. These variables are thought to measure storage and retrieval mechanisms. Additionally, CLTR is thought to measure higher level functions, such as organizational ability, rather than just basic memory factors (Buschke, 1974; Snow et al., 1992). Previous studies of the Selective Reminding Test with a reading disabled population have also found that this group of individuals perform significantly lower than controls on the CLTR variable (Fletcher, 1985; Snow et al., 1992). Exploring the relationship between CLTR and other measures of executive functioning would validate the utility of using this variable as an index of higher level skills, especially since researchers have in fact found evidence that reading disabled children generally show deficits in executive processes (Helland & Asbjornsen, 2000; Snow, 1998; & Swanson, 1999). These include skills such as divided attention, planning, shifting response mode, and abstraction abilities. However, although the organizational abilities may be implicated in the lower performance of the reading disabled children on the Selective Reminding Test CLTR, the design of the current study does not allow for the delineation between initial encoding difficulties and executive processing difficulties.

Hypothesis Three

Because the Consonant Trigrams Task (CTT) relies on working memory, and particularly because reading disabled children have been shown to have difficulty maintaining phonological representations in memory, it was anticipated that the children with a reading disability would show lowered performance on this task. Similarly, it was also expected that as the difficulty level of the task increased, and with the inclusion of longer delay periods, the reading disabled children would show increasingly poor performance.

Overall, the children with a reading disability recalled fewer overall letters (total score) and produced fewer perseverative responses than the control group. At specific time delays, the children with a reading disability recalled significantly fewer letters than both control groups at the three and nine second delays, and significantly fewer than the control group matched on age, gender, and WISC-Vocabulary at 18 seconds.

Generally, CTT is a useful task for exploring short-term memory deficits through the rapid decay of memory traces (Lezak, 1995). This task has proven particularly useful for assessment of head injured individuals. Patients with left temporal damage generally recall less than controls (see Lezak, 1995) and patients with left temporal epilepsy have demonstrated impaired performance (Giovagnoli & Avanzini, 1996). The distractor is designed as a verbal interference factor that prevents subvocal rehearsal (Vallar & Baddeley, 1982). With a normal adult population there is usually 100% recall with no delay. With a three second delay, 80% of letters are recalled, with a nine second delay, 70% to 80% are recalled correctly, and with an 18 second delay 50% to 80% are recalled. A longer delay period of 36-seconds is used with adults but not with children. At 36 seconds, adults have been found to recall approximately 67% of the letters correctly (see Lezak, 1995).

In the current study, the children recalled fewer letters at each time period than adults. Nevertheless, a similar pattern of decreasing recall over longer delays was evident across the RD and control groups. All three groups in the current study achieved over 98% accuracy on the immediate recall, no delay condition (0”). The children with a reading disability recalled 59% of the letters at the three second delay, 36% at the nine second delay, and 35% at the 18 second delay. Both control groups showed a similar decrease in recall. Control group 1, matched on age, gender and WISC-Vocabulary, recalled 67% at three seconds, 45% at nine seconds, and 42% at 18 seconds. Control group 2, matched on age and gender, recalled 71% at three seconds, 47% at nine seconds, and 42% at 18 seconds. This overall pattern is illustrated in Figure 1.

These results support the conclusion that load of task and allocation of resources may be involved in performance. Although it is well proven that in general children with a reading disability have language related difficulties, these children had no difficulty with immediate recall of the consonants because the task was simple and did not tax their memory system. However, as their system became burdened by the delay, their performance was poor. Interestingly, the children with a reading disability did not perform lower than the control group matched on age and gender for the longest delay (18"), but they did perform lower than controls matched on age, gender, and WISC-Vocabulary.

It was noted that although the children with a reading disability achieved lower mean scores at all three time delays (3", 9", & 18"), the actual difference in terms of the number of letters recalled was less at the 18 second delay. For all three groups there was a larger difference in the number of letters retrieved between three and nine seconds than between nine and 18 seconds. This finding may be due to developmental effects, where the 18 second recall task might be too difficult for children of this age. This is an area where future research might provide some clarity by including a wider age range for comparison.

An interesting finding was that the children with a reading disability had fewer perseverative responses. Based on the assumption that the processing deficits of these children result in an overload of their resources, the reading disabled children would be expected to have an elevated number of perseverations. For example, as they experience difficulty with the allocation of attentional resources, the last consonant recalled would be thought to still be available in memory because it was just retrieved and therefore essentially contain remnants of activation. These remnants of activation may be enough for the letter to be retrieved again in a subsequent trial, especially if the processing system is taxed and few resources are available to monitor previous retrieval. An alternative explanation that supports current findings would suggest that possibly for the RD sample the engrams of previously retrieved consonants degrade faster than for normal children. Because children with a reading disability have poor discriminability of like sounding (phonologically similar) consonants, these children would be predicted to produce more perseverations. It is possible that they may produce more perseverations during short time delays when previously identified consonants are still traceable, and few perseverations during long delays when these traces have disappeared. This would be an interesting hypothesis to explore but beyond the parameters of the current study.

Hypothesis Four

It was expected that there would be no difference in the performance of the reading disabled group and the two control groups on the visual/spatial measures of learning and memory.

The results related to this hypothesis produced somewhat mixed findings. Although there were generally few significant differences between the groups on visual/ spatial tests of learning and memory, two of the measures from the WMS-R Visual Reproduction subtest (i.e., VR II & VR saving score) were found to be significantly lower for the reading disabled children. There were no significant findings for the Continuous Visual Memory Test (CVMT). Of consideration in this finding is the assertion that the CVMT by design is difficult to code verbally and that one of the criticisms of the Visual Reproduction subtest is that the stimuli used in this test are able to be labeled verbally (Trahan et al., 1990). Therefore, the finding of lower performance for the children with a reading disability on VR II might be related to their lower skills in the verbal area.

The results from the CVMT are similar to that of previous research exploring various aspects of learning and memory ranging from memory span to acquisition and retrieval (Gould & Glencross, 1990; Patrice, Cassisi, & Hoeppner, 1999). Stanovich and Siegal (1994) stated that although deficits in the area of visual processing have been examined in reading disabled children, positive findings have not shown replicability. This is speculated to be the result of the information type; that is, reading disabled children are found largely to have difficulties with stimuli presented in a verbal format.

Hypothesis Five

To evaluate the efficacy of test variables to discriminate between ability groups, the test variables from the Selective Reminding Test (SRT) and the Consonant Trigrams Test (CTT) that showed a statistically significant difference in the comparison analyses were examined using a discriminant function analysis. It was anticipated that SRT CLTR, and SRT TR would prove to be good discriminators between groups because this been found in previous research (Snow et al., 1992).

The results from the stepwise discriminant analysis conducted with inter-test variables showed SRT CLTR to be a good discriminator between groups. However, the SRT TR score was not retained as a good discriminator. An important consideration in evaluating this result is the high correlation that exists between these variables. Each variable might have proved to be a good discriminator when included in the analysis without the other. CTT perseverations and recall following a three second delay also proved to be good discriminators. Because it is theorized that children with a reading disability perform lower when the burden of the task increases, it might have been expected that the CTT 18 second delay would have discriminated well between groups. However, this task proved to be difficult for all the children, reducing its ability to discriminate between groups. Only two variables from the visual/spatial measures were included in the stepwise discriminant analysis (i.e. VR II and VR SS) but was found to discriminate less well between the groups.

Summary

The findings of this study were generally variable to the posed hypotheses regarding the performance of children with a reading disability on tests of learning and memory. There were moderate correlations for the normative participants between most of the memory variables and verbal ability, which was estimated with the WISC-III Vocabulary subtest. However for the reading disabled participants, there were fewer variables that showed this level of relationship between the memory variables and verbal ability. Specifically, lower correlations were found between the measures of visual memory for the RD participants than for the normative participants. The lack of significant correlations between intellectual verbal ability and the saving score from the WMS-R Logical Memory subtest and the Selective Reminding Test suggests that saving scores, as a measure of percentage of information retained, lack the confounding relationship with intellectual ability found with other variables and therefore offer a purer measure of memory.

Of the five tests administered only two showed a pattern of deficits in children with reading disabilities: the Selective Reminding Test (SRT) and the Consonant Trigrams Task (CTT). Two of the tests showed no significant findings: WMS-R Logical Memory and the Continuous Visual Memory Test, while WMS-R Visual Reproduction produced mixed findings, where the children with a reading disability performed lower than control groups on delayed task (VR II) and the percentage of information retained (VR SS).

The pattern of results for the Selective Reminding Test suggests that children with a reading disability experience difficulty encoding words into long term storage. They were also more likely to recall these words inconsistently. However, because they were able to retain the same proportion of words from the last trial to the recall trial 30 minutes later, it is thought that encoding represents a much greater problem for these children. This is possibly related to a deficit in working memory. Similarly, the lower performance of children with a reading disability on the Consonant Trigrams Task is also thought to represent a working memory deficit. Generally, these results support the conclusion that children with a reading disability experience difficulty with verbal memory tasks that use word lists and letters, a conclusion found in both clinical and experimental studies. However, whether this finding is related to the poor processing of verbal information that then affects the ability to encode the information in memory or whether it is an actual deficit in memory is not able to be determined.

Implications for Clinical and Educational Practice

This study and studies of its type help to provide information and direction in the area of assessment. Although this research also offers information that is of some utility to educational practice in the classroom, its application is seen to be more indirect in nature. With regards to the former, research of this type can assist in the assessment of reading disabled children by providing a more precise method of psychometrically measuring and therefore understanding the difficulties these children experience. In the realm of clinical assessment, there are fewer assessment instruments available for use with children than with adults. With normative data now available for the five tests used in this study, this increases the number of tests clinicians have available to them. Studies of this type provide information regarding the typical performance of sub-populations on various measures, which is essential information for clinicians to have when working with these sub-populations to make accurate inferences about performance. For example, in the case of a child with a reading disability who also suffers subsequent traumatic brain injury or other neurological damage where the cause of memory problems might be controversial, in so far as whether the problem was pre-existing versus caused by the injury, a poor score on the Logical Memory subtest cannot be assumed to be pre-existing and therefore more likely related to a brain injury than is the case for a poor Selective Reminding Test score.

Although the focus of this research was not directed specifically to classroom practice, the information it can provide to this area is still regarded as useful. With more information available on how the children with a reading disability, both as a group and individually, process information, the better teachers will be prepared to teach them. Moreover, as this type of research speaks to the learning styles of these children, it is anticipated that the development of programs and curriculum materials would follow. Specifically, these data confirm other work in the area where children with a reading disability have difficulty processing and recalling verbal information that is presented orally (Kramer et al., 2000; Snow et al.,1992; van Strien, 1999). Furthermore, it has been shown that their memory system is easily overloaded and they are not able to encode information as quickly or efficiently as skilled readers (Swanson, 2000). Other research has demonstrated that reading disabled children also do not use strategies as effectively as do children who are not reading disabled (Cermak, 1983), which also reduces their ability to effectively encode information. However, this study also provided evidence that children with a reading disability might have less difficulty when verbal information is presented in a meaningful manner. Metacognitive training would also likely prove to be of some assistance to children with a reading disability, particularly in light of findings that good metacognitive skills can assist children with low academic performance (Swanson, 1990). Metacognition refers to a child's awareness of his or her own thinking processes and ability to monitor and change various cognitive actions (Swanson, 1996). Reading disabled children have generally been found to use metacognitive strategies but do so inefficiently (Swanson, 1996).

In terms of compensatory techniques that would be useful within the classroom, these children can be explicitly taught to use strategies to assist in the organization of information to be remembered. External strategies such as lists and chunking, and internal strategies such as applying meaning to the information that is being remembered may be effective. Similarly, teachers can use the same type of strategy when teaching, such as reducing overall load of information and emphasizing context to aid in the encoding of information. This could even translate into presenting information in a similar format with less complex syntax. The fewer cognitive resources that a child is using to process the information, the more resources that will then be available for working with the information provided. Also, teachers might simply check the level of verbal information that is encoded or learned on a frequent basis. Based on the findings that the reading disabled children showed good retention of information, it seems likely they will recall what they have been able to learn.

Resources for the reading teacher often focus on strategies that encourage the very same processes for all children, not only those with disabilities (Harvey & Goudvis, 2000; Oliver-Keene & Zimmermann, 1997). Many strategies encourage a focus on meaning so that the children are able to take away a more complete understanding of the materials they are reading. This can take the form of encouraging young readers to make explicit connections with what they know.

Teachers teach strategies naturally but not always explicitly, and where some children might be able to recognize the utility of strategies taught implicitly, the child with a learning disability may not. However by highlighting strategy use and incorporating it into the curriculum, children are provided a valuable tool in the learning and retention of the information being taught. Because a large amount of information is taught via text, the concepts of memory and verbal processing skills are highly related. Reading is essentially a verbal processing skill, and in the school environment, the product of reading is usually the retention of information. Therefore, a strategy that assists children in comprehending what they are reading is not only a reading strategy but also a strategy for learning and remembering. A teacher can encourage a child to create meaning from the text being read through the formation of various connections, such as connections to his or her own experience, connections with other text, or connections with bigger social issues (Harvey & Goudvis, 2000). The more attention a piece of text or information receives, the more likely it is to be recalled at a later time.

Future Research

The finding that the performance of the children with a reading diverged from expectations on the Logical Memory subtest spurs questions regarding the possible reasons for this finding, particularly whether the children were assisted by the contextual environment of the stories thereby diminishing the effects of verbal processing difficulties. Further exploration might also include an examination of memory for the "gist" of a story; that is, whether children with a reading disability are able to glean the essence of the information from the context in which it is presented.

The results of the Consonant Trigrams Task produced speculation regarding the possibility of "floor" effects influencing the findings for 18 second delay of this task. Further study would be useful in elucidating the effects of development on performance, which might spur the need for the creation of a less difficult test of this paradigm for this age group. From incidental observations during the administration of this test to the RD participants, it was noted that this task was more likely than any other to create signs of frustration in the children.

Finally, the mixed results on the performance of the children with a reading disability on tests of visual/spatial memory were contrary to the expectations of the study, as well as the general findings of research in this area as a whole. The abilities of children with a reading disability at processing visual/spatial information appear to require further research so that this area can be more clearly understood.

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