MEMORY SPAN IN CHILDREN WITH READING DISABILITIES

by

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B.G.S. Simon Fraser University, 1985
P.D.P Simon Fraser University, 1986

A Thesis Submitted in Partial Fulfillment of

the Requirements for the Degree of

MASTER OF ARTS

in

THE FACULTY OF GRADUATE STUDIES

Department of Educational and Counselling Psychology
and Special Education

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

May, 1999

Department of Educational Psychology and Special Education

The University of British Columbia
Vancouver, Canada

Date May 13, 1999

ABSTRACT

Short term memory span for sounds and symbols and the acquisition of symbol-sound associations were investigated in dyslexic, compensated dyslexic, and normal readers. Tests of memory were administered to the two groups of children with a history of dyslexia and to age matched and reading level matched comparison groups. The memory tests included phonological pre- and posttests, visual iconic memory pre- and posttests, visual span pre- and posttests, and a sound-symbol training procedure.

The dyslexic children showed deficits in phonological rehearsal and immediate phonological memory relative to both age and reading level matched comparison groups. They also had deficits in iconic memory relative to the age matched group, and iconic memory as well as visual memory span relative to the reading level matched group when age was used as a covariate. This suggests that both types of deficit may represent a developmental difference rather than a developmental lag.

Training scores were significantly lower for dyslexic children than for either comparison group. They were unrelated to visual and phonological memory, but strongly related to reading scores. Following the sound-symbol training, the phonological and visual posttests were administered using only the name-associated sounds and symbols. Scores on phonological memory span increased significantly for all groups, though the increase was significantly smaller for the dyslexic group than either comparison group. Dyslexics are assumed to show a smaller phonological score increase because they do not develop familiarity with the sounds as easily, and do not benefit from the multiple codes.

Visual memory scores decreased following the sound symbol training, more for normal than dyslexic readers. This is interpreted as interference of verbal coding with a predominantly visual task. Dyslexic readers may be less inclined than normal readers to attempt to use the phonological strategy for this task.

In most respects, the compensated dyslexic group's scores were equivalent to those of the comparison groups. Compensated dyslexics demonstrated superior phonological rehearsal, iconic memory and associative memory to those who were still dyslexic. This may represent gains in phonological rehearsal, development of stronger visual memory, and/or greater ability to form associations between sounds and symbols.

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ACKNOWLEDGMENTS

I gratefully acknowledge the assistance of my daughter, Rachael Bloomfield, who carried out all the testing for this research project with thoroughness and creativity. I also appreciate the contributions of the members of my committee: Thanks to Dr. Linda Siegel for her guidance, to Dr. Marshall Arlin for the inspiration, and to Dr. Jim Enns for his support. And to Dr. David Jones, my very patient cheerleader, thank you for being there.

Visual and Phonological Memory Span in Children with Reading Disabilities

CHAPTER 1: INTRODUCTION

Goals and Objectives of the Study

The term dyslexia *is frequently used here as a synonym for the term* reading disability *(Siegel, 1993). It is not to be taken as diagnostic in the individual case. Rather it is descriptive of the group of participants who have a documented history of severe learning disabilities affecting their ability to learn to read despite responsible teaching. Its only definitive criterion is a reading level at or below the 27th %ile for a child's age group without obvious handicapping conditions.*

Short term memory span for sounds and symbols was studied in relationship to memory for newly learned sound symbol associations, and to reading, in normal and dyslexic readers. The existence of short term memory deficits in dyslexic readers, especially for phonology, is supported by extensive research. Some of the existing research uses tasks that have uncertain relevance to reading and reading instruction, so it is sometimes unclear whether and how the demonstrated deficits are related to reading. In this study, a particular remedial phonics task - acquisition for sound-symbol associations - was studied in relationship to measures of phonological and visual memory and measures of decoding and word reading. The participants were a group of children with a history of dyslexia enrolled in a remedial phonics program. These children entered the program as beginning readers. Comparison groups of normal elementary aged readers also participated. Memory profiles of the reading impaired children were related to their achievement in the remedial program, and compared to those of normal readers of matched age and reading ability. The objectives were to determine the roles played by phonological and visual deficits in acquisition of symbol-sound knowledge, and examine the effects of remediation on memory profiles.

Dual route models of reading state that both visual and phonological processes are involved in fluent reading (e.g. Calfee, Lindamood, & Lindamood, 1973; Coltheart, Curtis, Atkins & Haller, 1993; Siegel, 1986, 1993; Stanovich, 1986, 1988; Stanovich & Siegel, 1994; Vellutino & Scanlon, 1982). Words may be read by a direct visual route; the meaning of the word is retrieved from memory directly from the printed form with no phonetic analysis (Siegel, 1986; Siegel & Ryan, 1988; Stanovich, 1988; Stanovich & Siegel, 1994; Vellutino & Scanlon, 1982). The phonological route involves conversion of a word to a phonological representation which is used to retrieve meaning from memory (Siegel, 1986). Children who acquire strength in whole word reading or knowledge of sound-symbol associations for use in phonetic analysis but not both types of information, have difficulty in developing reading skill (Vellutino & Scanlon, 1982).

Visual and phonological processes play important roles in early reading skill acquisition as well as in fluent adult reading (Eden, Stein, Wood & Wood, 1995; Lovett, 1992; Mauer & Kamhi, 1996; Siegel, 1986; Slaghuis, Lovegrove & Davidson, 1993; Stanovich, 1988; Vellutino & Scanlon, 1982; Vandervelven & Siegel, 1995). Beginning readers must learn to apply acquired knowledge of grapheme-phoneme associations to decode unfamiliar words. Children with reading disabilities experience such difficulty in learning the letter-sound correspondences constituting basic decoding skills (Fernald, 1943; Gillingham & Stillman, 1987; Siegel, 1993; Slingerland, 1971; Snowling, 1980; Spalding &

Spalding, 1986; Stanovich, 1986a, 1988) that tests of decoding (reading of nonwords) are considered among the best diagnostic measures of dyslexia (Siegel, 1993, Siegel & Heaven, 1986; Siegel & Ryan, 1988, 1989a; Stanovich & Siegel, 1994; Torgesen Wagner, Simmons & Laughon, 1990). Visual memory is thought to develop earlier in very young children than phonological memory (Siegel, 1986; Siegel & Ryan, 1988), and to play the largest role in the initial stages of word recognition (Hitch, Halliday, Dodd, & Littler, 1989; Hitch, Halliday, Schaafstal, & Schraagen, 1988). As children develop the ability to phonologically rehearse, phonological memory plays a greater role in the subsequent stages of beginning reading (Gathercole & Baddeley, 1989, 1990; Stanovich, 1988; Torgesen & Morgan, 1990).

Phonological deficits associated with dyslexia may represent a normal pattern of language skill development but at a slower rate, or a qualitatively different pattern of language development (Siegel & Ryan, 1988). Observed difficulties specific to phonological perception are characterized as deficits, because children with reading disability show poorer performance on some phonetic tasks than do younger children matched for reading age (Siegel, 1986, 1993; Siegel & Ryan, 1988; Stanovich, 1988; Torgesen, Wagner & Rashotte, 1994). Observed impairments in short term memory for linguistic stimuli (e.g. letter sequences) are considered a developmental lag. Performance of dyslexic children on phonological memory tasks was shown to approximate that of younger children of equivalent reading age (Siegel, 1986; Siegel & Ryan, 1988).

Visual deficits observed in dyslexic individuals may also reflect earlier stages in normal development. Reading disabled individuals might then be expected to perform similarly to younger normal readers in tests of visual memory span. Younger children have been shown to have longer lasting iconic memories (Gummerman & Gray, 1972), so this might also be true for dyslexic children. It has been suggested that younger children rely more on visual memory than verbal for visual stimuli (Hayes & Schulze, 1977; Walker, Hitch, Doyle & Porter, 1994) and namable pictures (Hitch, Halliday, Dodd, & Littler, 1989; Hitch, Halliday, Schaafstal, & Heffernan, 1991). Dyslexic readers apparently also rely on visual coding strategies in reading, possibly to compensate for deficient phonological coding ability (Siegel, Share, & Geva, 1995; Stanovich, 1988; Stanovich & Siegel, 1994).

Research offers evidence that deficits in phonological perception and memory (for letter sounds) and visual perception and memory (for letter forms) may constrain learning of sound-symbol associations (associative memory). Memory is dependent on perception, and evidence exists for abnormalities in both visual and phonological perception in individuals with dyslexia. Many contemporary researchers attribute reading disability largely to phonological awareness (perception) and encoding (memory) limitations (Gathercole & Adams, 1993; Gathercole & Baddeley, 1989, 1990; Gathercole, Willis & Baddeley, 1991; Hulme & Tordoff, 1989; McDougall, Hulme, Ellis & Monk, 1994; Mark, Shankweiler, Liberman, & Fowler, 1977; Siegel, 1986, 1993; Siegel & Ryan, 1988; Torgesen, Wagner, Simmons & Laughon, 1990; Vandervelven & Siegel, 1995; Vellutino & Scanlon, 1982). There is also some empirical evidence that part of the disability may be in visual perception and memory of the forms of letters or their position in a sequence (Corkin, 1974; Eden, Stein, Wood & Wood, 1995; Farnham-Diggory & Gregg, 1975; Galaburda & Livingstone, 1993; Lovegrove & Brown, 1978; Lovegrove, Billing & Slaghuis, 1978; Mauer & Kamhi, 1996; Morrison, Giordani & Nagy, 1977; Noelker & Schumsky, 1973; Senf & Freundl, 1971; Slaghuis, Lovegrove & Davidson, 1993; Spring & Capps, 1974; Swanson, 1978, 1983, 1984).

Phonological awareness is often assessed with tests of perception of the sound components of words (Gathercole & Baddeley, 1989, 1990; McDougall, Ellis, Hulme & Monk, 1994; Siegel, 1993; Torgesen & Morgan, 1990; Torgesen, Wagner & Rashotte, 1994). These tests indicate that dyslexic individuals have difficulties with phonological perception that persist into adulthood (Siegel, 1993). Verbal memory span limitations have been demonstrated on letter-string repetition and memory scanning tasks (Farnham-Diggory & Gregg, 1975; Siegel & Ryan, 1988; Spring & Capps, 1974). These are thought to reflect a phonological encoding disability (Gathercole & Adams, 1993; Gathercole & Baddeley, 1989, 1990; Gathercole, Willis & Baddeley, 1991; Hulme & Tordoff, 1989; McDougall, Hulme, Ellis & Monk, 1994; Mark, Shankweiler, Liberman, & Fowler, 1977; Siegel, 1993; Siegel & Ryan, 1988; Stanovich, 1988; Swanson, 1978, 1983, 1984; Torgesen & Morgan, 1990; Torgesen, Wagner & Rashotte, 1994; VandeVoort, Senf, & Benton, 1972; Zurif & Carson, 1970). Difficulties with phonological encoding are often most profound for items at the beginning of a sequence, representing a specific problem with phonological rehearsal. This is called a serial position effect. Serial position effects can demonstrate strengths and weaknesses in particular memory strategies.

Visual limitations associated with dyslexia have also been attributed to both perceptual (Badcock & Lovegrove, 1981; DiLollo, Hansen, & McIntyre, 1983; Eden, Stein, Wood & Wood, 1995; Galaburda & Livingstone, 1993; Lovegrove & Brown, 1978; Lovegrove, Billing & Slaghuis, 1978; Slaghuis, Lovegrove & Davidson, 1993) and memory processes (Corkin, 1974; Enns, Bryson & Roes, 1995; Morrison, Giordani & Nagy, 1977; Noelker & Schumsky, 1973; Senf & Freundl, 1971; Spring & Capps, 1974; Swanson, 1978, 1983, 1984). The concept of visual perceptual deficits in dyslexia was recently considered "thoroughly debunked," (Stanovich, 1988, page 601). However, investigation of the early stages of visual information processing in dyslexic individuals continues to find abnormalities in processing of transient visual stimuli.

Several studies have demonstrated longer than normal durations of visible persistence in dyslexic children (DiLollo, Hansen, & McIntyre, 1983; Eden, Stein, Wood & Wood, 1995; Galaburda & Livingstone, 1993; Lovegrove & Brown, 1978; Lovegrove, Billing & Slaghuis, 1978; Slaghuis, Lovegrove & Davidson, 1993) and in younger children (Gummerman & Gray, 1972). Visible persistence refers to the persistence of an image for periods up to 300 msec after a visual stimulus has been removed. This is credited to persisting activity in the neurons of the visual system (Coltheart, 1980; DiLollo, Hansen, & McIntyre, 1983). Longer visible persistence in children with reading problems is attributed to slow recovery from stimulation of cells in the visual transient system (DiLollo, Hansen, & McIntyre, 1983). Findings concerning visible persistence suggest that visual perceptual deficits can not be discounted in the study of dyslexia. These perceptual deficits could result in impaired visual memory, and interfere with reading (Farmer & Klein, 1995; Slaghuis, Lovegrove & Davidson, 1993).

In early investigations, visible persistence was identified with iconic memory (DiLollo & Dixon, 1988; Gegenfurtner & Sperling, 1993; Weichselgartner & Sperling, 1985). Coltheart (1980) has distinguished visible persistence from iconic memory. Both terms refer to the fact that visual information persists in an unrecoded form for some time after the physical offset of the evoking stimulus. Visible persistence is phenomenological, based on persisting photoreceptor and neural activity at various stages in the visual pathways after stimulus termination.

Iconic memory is not necessarily visible, or dependent on persisting activity in the neurons. For a short time after the removal of a visual stimulus, an observer may have access to as much information about the visual characteristics of the stimulus in its unrecoded internal representation as is available when the stimulus itself is present. This is what is meant by iconic memory (Coltheart, 1980). Experimental techniques requiring an observer to report on what appears visible may measure visible persistence. Techniques requiring recall of what was seen may assess iconic memory. It is clear that visible persistence and iconic memory are different, but not clear whether they can be quantitatively related.

Abnormally persistent images, a perceptual phenomenon, may interfere with the sequential aspects of reading by generating overlapping or superimposed images of letters (Farmer & Klein, 1995; Slaghuis, Lovegrove & Davidson, 1993).

Since accurate perception is a prerequisite for memory, visible persistence could adversely affect visual memory (Farmer & Klein, 1995; Klein & Farmer, 1995). However, more persistent visual images could represent a strength in some individuals for some tasks. Visual memory deficits in dyslexic children have mainly been demonstrated in studies of visual memory span. Studies of visual memory have shown no impairment, and even possible superiority, of immediate memory (Huba & Vellutino, 1990; Spring & Capps, 1974; Swanson, 1978, 1984, 1986). In two visual memory studies, children with reading disabilities had equal or better memory for the last items in a sequence (recency items). Their memory was only impaired for earlier list items (Spring & Capps, 1974; Swanson, 1984). Farmer and Klein (1995) have explained how visible persistence could cause difficulties with sequential ordering tasks. The possibility that visible persistence and iconic memory may be related, and that longer durations of visible persistence may facilitate the performance of some tasks, has not been explored.

Although there is evidence that deficits in phonological processing (of letter sounds) and visual processing (of letter or word forms) may constrain learning of symbol-sound associations (associative memory) (Eden, Stein, Wood & Wood, 1995; Lovegrove, Billing & Slaghuis, 1978; Mauer & Kamhi, 1996), the roles of the two types of memory in associative learning is not yet clear. Additionally, specific difficulties with associative memory have been reported in children with reading disabilities (Birch & Belmont, 1964; Ceci, Lea, & Ringstrom, 1980; Morrison & Manis, 1980; Swanson, 1983, 1984, 1986; Torgesen, 1979; Vellutino, Steger, Harding, & Philips, 1975; Vellutino & Scanlon, 1979 for a review). For skilled readers, a verbal label for a visual image (e.g. a sound associated with an image) will improve recall of the image ("additivity," Paivio 1971, 1986; Daniel & Ellis, 1972). For reading disabled subjects, verbal labels may not facilitate, and may in fact reduce image recall (Swanson, 1983; 1986). This might make learning to associate symbols with sounds more difficult than memorizing only the symbols or sounds.

As the foregoing discussion indicates, phonological, visual, and associative perception and memory deficits have been demonstrated in reading disabled populations. Each type of deficit has been credited with a causal role in the genesis of reading disability. This research investigated the roles of visual and phonological memory spans in memory for newly learned symbol-sound associations in children with reading disabilities. In this study, children with normal reading skills and children with reading disability were pretested on memory spans for sequences of "pseudowords" and "pseudoletters." They were then taught to associate 10 pseudowords with unique pseudoletters. The three post-tests were tests of iconic memory and memory span for the names and forms of the named pseudoletters.

Six hypotheses were tested in this study. The primary hypothesis was that, in comparison to children with normal reading skills, children with reading disabilities have deficits in visual memory for novel pseudoletter forms as well as in phonological memory for novel pseudoletter names. The second hypothesis was that scores on visual and phonological memory span would be positively associated with reading scores. The third hypothesis was that children with reading disabilities have deficits in memory span for newly learned sound-symbol associations in comparison with normal readers. The fourth hypothesis was that both visual and phonological memory spans would be positively correlated with memory span for newly learned sound-symbol correspondences in both normal and dyslexic readers. The fifth hypothesis was that learning names for symbols would increase memory span for the symbols in normal readers, but not in children with reading disabilities. The sixth hypothesis was that, in comparison to children with normal reading skills, children with reading disabilities would show lower recall of items at the beginning of visual and phonological sequences, but similar recall of items at the end of sequences.

In this study, two comparison groups of children with normal reading skills are used. One group has a reading level equivalent to that of the dyslexic group. The other comparison group is equivalent to the dyslexic group in age. This makes it possible to identify cognitive differences associated with dyslexia, but not specifically tied to reading level. Such differences are interpreted as deficits rather than as slow development.

Rationale For the Method and Procedures

Three experimental tasks and a training intervention were used in this study. The first two experimental tasks tested memory span for unfamiliar syllables ("nonwords") and shapes ("invented letters"). The third task was sequential recall of newly learned associations between symbols and sounds. These tasks were chosen because they resemble the type of learning that occurs in a beginning remedial phonics instruction program. Assessment of memory span for names and forms of invented letters allowed quantitative measurement of verbal, visual, and cross modal components of a single task related to beginning decoding skills.

Sequential span tests were appropriate for several reasons. Differences between disabled and good readers on verbal, visual and cross modal sequential span tasks have been demonstrated in other studies (Farmer & Klein, 1995; Klein & Farmer, 1995; Torgesen, 1979). Studies of serial memory for letter and digit strings have consistently shown impairment among reading disabled subjects, possibly due to superior use of phonetic coding of the visual stimuli in skilled readers (Farnham-Diggory & Gregg, 1975; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979; Siegel & Linder, 1984; Siegel & Ryan, 1988; Spring & Capps, 1974). Non-word repetition tests, which can be presented in a sequential span format, have been used by several authors (Gathercole & Adams, 1993, Gathercole & Baddeley, 1989), and seem to be an accurate reflection of phonological coding ability. Non-word repetition tests are able to capture (although not separate) both perceptual and encoding aspects of phonological memory (Farmer & Klein, 1995).

Deficits in visual sequential memory in poor readers were documented by Senf and Freundl (1971), Noelker and Schumsky (1973), and Morrison, Giordani and Nagy (1977). Researchers have suggested that visible persistence may interfere with sequential processing of text (Di Lollo, Hanson, & McIntyre, 1983; Eden, Stein, Wood & Wood, 1995; Lovegrove, Billing & Slaghuis, 1978; Lovegrove & Brown, 1978; Lovegrove, Heddle & Slaghuis, 1980; Slaghuis, Lovegrove & Davidson, 1993). Reading group differences in cross modal serial span were found by Swanson (1983, 1984), and Katz, Shankweiler and Liberman (1981).

Memory span tasks were used to clarify the degree to which children with learning disabilities have difficulty with letter forms (visual memory), letter sounds (phonological memory), or the association between the two (cross-modal memory). The results revealed differences between normal and disabled readers related to stimulus modality (phonological vs. visual), serial position effects, the effect of naming on memory, and the degree of stimulus novelty. The objectives were to determine whether children with reading disabilities have more difficulty with the tasks than the normal readers, whether the difficulty was related to reading, and whether their performance on the memory measures revealed strategic differences.

CHAPTER 2: LITERATURE REVIEW

In this study, the relationship of phonological and visual memory deficits to memory for newly learned sound-symbol associations and to reading was explored in groups of dyslexic and normally reading elementary aged children. The relationship of memory to reading skills and reading disabilities has been extensively studied. A complex picture has emerged, but the involvement of memory deficits in reading disability has been supported. It is not clear, however, whether the deficits involve phonological, visual, and/or cross modal memory processes. Whether documented deficits are the cause of, the result of, or unrelated to reading disability has also remained controversial. The relationship of memory profiles and reading scores to a particular reading-related task - memory for sound-symbol associations - is explored here. Whether cognitive deficits related to dyslexia represented strategic deficits that can be remediated or structural abnormalities that must be circumvented is also debatable. This research is designed to help clarify some of these issues.

The focus of basic research in reading disability has changed substantially over time, inspiring some heated theoretical debate (Keogh, 1990). Historically, theoretical literature and empirical studies concerning reading attempted to establish links between visual perceptual problems and reading difficulties. Attempts were made to use visual perceptual training in remediation of reading disability (deHirsch, Jansky & Langford, 1966; Johnson & Myklebust, 1967). The results did not generally support the training approach or the hypothesized association between visual perceptual deficits and reading disabilities (Hulme, 1988; Morrison & Manis, 1982).

In the last three decades, many researchers have documented associations between phonological awareness and phonological memory and reading difficulties. Studies of this type currently compose the largest volume of the published research literature concerning reading disability. Much of this research is based on a theoretical model of memory proposed by Baddeley (1986). This model has been useful in describing some of the problems observed in dyslexic children. It has also been helpful in describing the development of memory and of some language functions in children. Remedial efforts based on phonological awareness have had some success (Torgesen, Wagner, & Rashotte, 1994). Early remedial intervention programs based on this memory model have also had success (Lovett, 1992; Torgesen, 1990).

Some research throughout the history of the field has demonstrated cross modal or associative deficits related to reading disability (Birch & Belmont, 1964; Ceci, Lea, & Ringstrom, 1980; Swanson, 1983, 1984, 1986; Torgesen, 1979; Vellutino, Steger, Harding, & Philips, 1975; Vellutino & Scanlon, 1979; Zurif & Carson, 1970). Documented cross modal deficits have, in many cases, been attributed to the verbal aspects of the tasks used. Remedial programs including explicit training in phonological awareness and sound-symbol relationships seem to have generated the highest success rates (Gathercole & Baddeley, 1993; Lovett, 1992; Torgesen & Morgan, 1990; Torgesen, Wagner, & Rashotte, 1994). Serial ordering deficits have also been reported in reading disabled individuals, particularly, but not always, with verbal stimuli (Corkin, 1974; Mason, 1980; Torgesen, 1979, Farmer & Klein, 1995).

Visual and Verbal Memory and Reading Ability

The Baddeley Model of Memory

A theory of working memory (WM) developed by Baddeley and colleagues (Baddeley & Hitch, 1974; Baddeley, Ellis, Miles, & Lewis, 1982; Baddeley, Logie & Ellis, 1988; Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Baddeley, 1986; Gathercole & Adams, 1993; Gathercole & Baddeley, 1989, 1990a,1990b, 1993; Gathercole, Willis, & Baddeley, 1991; Hitch & McAuley, 1991) has served as a theoretical model in investigations of the relationship of memory to reading disability. This model of memory has been used to account for individual differences in short term memory capacity and control processes. It has been used to define the roles and interaction of verbal and visual memory in complex processes, and to explain empirical observations concerning those processes and reading disability (Cantor, Engle & Hamilton, 1991; Swanson, 1993, 1994). Short term memory (STM) functions are subsumed in Baddeley's model.

Baddeley's model of working memory (Baddeley, 1986; Baddeley & Hitch, 1974; Gathercole & Baddeley, 1993) has two independent short-term memory functions, for modality specific temporary encoding of verbal and visual information. The first of these is a two part phonological loop, the basis for verbal memory, since verbal material is encoded and stored in phonological form (Baddeley, 1986; Gathercole & Baddeley, 1990b, 1993). It includes a passive phonological storage buffer, specialized for obligatory encoding of auditory-verbal input (especially speech); and an articulatory control process for conversion of visual input into phonological form.

The visuo-spatial scratch pad is the second STM component of working memory. It is specialized for reception and retrieval of visual images. The contribution of verbal and visual short-term memories to immediate memory and long term learning are mediated by the control processes of a central executive component, the third part of the model.

The Baddeley model is therefore based on 3 separable components, each of which has been shown to make a contribution to reading skills. Tests of working memory reflect the function of the central executive and its slave systems (Cantor, Engle & Hamilton, 1991; Swanson, 1993, 1994).

Evidence for the role of the phonological loop in reading ability has been supplied by Baddeley, 1986; Gathercole & Adams, 1993; Gathercole & Baddeley, 1989, 1990a, 1990b, 1993; and Gathercole, Willis, & Baddeley, 1991. That the visuo-spatial scratch pad (VSSP) also plays a role in reading ability has been supported, less directly, by research. (Swanson, 1994; see Farmer & Klein, 1995 for a review). The visuo-spatial scratchpad is a slave system specialized for the processing and storage of visual and spatial information, and of verbal material that is subsequently encoded in the form of imagery. (Gathercole & Baddeley, 1993). Although Gathercole and Baddeley (1993) claim that there is little evidence that the VSSP plays a significant role in language, Eddy and Glass (1981), and Glass, Millen, Beck and Eddy (1985) demonstrated that visual imagery plays an important role in reading.

Individuals, both with and without learning disabilities, differ in capacity of all three of these components. Since this is a capacity model it is suitable for the investigation of individual differences in memory. The memory deficits associated with reading disabilities may reflect weaknesses in any one of the three components of the system, or deficits in the integration of memory processes.

Working memory, as measured empirically, reflects the contribution of the short term memory systems and the central executive to visual and verbal memory tasks. Working memory has been shown to correlate with measures of intelligence and general scholastic aptitude (Swanson, 1994; Turner & Engle, 1989). Working memory performance is related to overall intellectual ability as well as reading skills in normal readers. Individuals with reading disabilities have sufficient overall intellectual ability to learn how to read, but do not learn, presumably because of specific cognitive deficits. The deficits may therefore relate to the relatively passive functioning of either or both of the STM systems or to the automatic integration of these functions; rather than to the more conscious control processes of the central executive system, which are more strongly related to general intellectual ability (Swanson, 1994).

The exploration of memory in this study is based on Baddeley's theoretical model. Phonological and visual memory, as described in this paper, are assumed to represent capacities of the STM systems described by Baddeley and his colleagues. The theoretical basis for the assumption that visual and verbal memory may both be important to reading is provided by the dual-route theory of reading. According to this theory, words can be read in two ways: by the "direct visual" and "indirect" routes. The direct visual route involves the word being detected by the visual input logogen specialized for the visual form of that lexical item. The phonological form of the word becomes available after the word has been identified by the input logogen, via activation of the corresponding output logogen. The indirect route involves phonologically recoding of the letter string. (Gathercole & Baddeley, 1993).

Memory is task-specific; findings concerning one type of memory function do not necessarily generalize to others. To elucidate the role of memory in a specific language process, it is necessary to study it in a relevant context. This paper focuses on the involvement of the memory systems in the development of decoding skills. Specifically, the proposed investigation concerns the effects of phonological and visual memory deficits on acquisition and memory of letter-sound correspondences. The question of whether observed lower level deficits actually cause or are caused by reading delay was discussed by Stanovich (1986) and Fernald (1943). While the design of this proposed study will not elicit causal conclusions, the focus is on lower level (structural) deficits and their relationship to mastery of letter-sound correspondences.

Involvement of Memory in Reading and Strategic Differences in Dyslexic Readers

"Critics quite rightly challenge both the conceptualizations and the operational definitions that have guided both research and practice in learning disabilities. Yet, lack of agreement is not necessarily bad..." (Keogh, 1990, page 16) Discussion has focused on structural features vs. control processes in memory (Shankweiler & Crain, 1986; Torgesen 1978-1979), automatic vs. strategic coding (Stanovich, 1986; Swanson, 1984), phonological vs. semantic processing (Spear

& Sternberg, 1986; Swanson, 1984), phonological rehearsal vs. speech rate (McDougall, Hulme, Ellis & Monk, 1994); and verbal vs. visual vs. integrative memory deficits (Vellutino & Scanlon, 1982; Morrison & Manis, 1982 for reviews; Eden, Stein, Wood & Wood, 1995; Swanson, 1986). Skilled reading involves many language and memory processes. As the focus of this paper is on short term memory for sounds and symbols, and acquisition of letter-sound associations, discussion of research is limited to studies relevant to this domain.

That both visual and verbal memory are involved in reading has been established in research concerning working memory (Baddeley, Logie, Nimmo-Smith & Brereton, 1985; Gathercole & Baddeley, 1993; Siegel, 1992, 1994; Siegel and Ryan, 1989b) and short term memory processes (Baddeley & Wilson, 1988; Gathercole & Baddeley, 1993; Siegel & Linder, 1984; Siegel & Ryan, 1988; Spear & Sternberg, 1986). Studies by Daneman and Carpenter (1980, 1983) demonstrate the importance of verbal sequential processing in skilled adult reading. Skillful reading involves simultaneous processing and storage of perceived text in iterative cycles. The reader must store pragmatic, semantic, and syntactic information from the text, and use it in parsing, disambiguating, comprehension, and integration of subsequent text (Daneman & Carpenter, 1980; Stanovich, 1986). The involvement of visual memory processes in skilled adult reading has been detailed to some extent by studies of eye fixation times during reading (Daneman, Carperter & Just, 1982). Storage of intermediate products and processing of new information are both essential to reading.

That visual memory can play a role in decoding is demonstrated in studies of memory for letters (Walker, Hitch, Doyle & Porter, 1994). Phonological coding of letters is typically observed in adults (Walker, Hitch & Duroe, 1993). When use of phonological memory is prevented by articulatory suppression, deleterious effects of visual similarity suggest that visual memory can also be used in this task (Walker, Hitch & Duroe, 1993). When a task selectively disrupts performance on another concurrent operation, it is generally assumed that common processing systems are involved (Brooks, 1967; Nelson & Brooks, 1973; Farmer, Berman, & Fletcher, 1986; Logie, Zucco & Baddeley, 1990). Alphabetic characters can apparently be coded either visually or phonologically.

Since visual and verbal memory processes can both be used in decoding of text, skilled reading may involve some optimal strategic combination of the memory processes. Strategic differences in memory processes between good and poor readers have been suggested (Gathercole & Baddeley, 1990; Katz, Shankweiler, & Liberman, 1981; Lennox & Siegel, 1993; Shafrir & Siegel, 1994; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979; Siegel, Share & Geva, 1995). A study of retention of letters presented both auditorily and visually demonstrated that recall was more impaired by verbal shadowing (use of verbal retroactive inhibition to prevent phonological rehearsal) in good readers than in poor readers (Huba & Vellutino, 1990). Poor readers in this study actually performed better than good readers when verbal/phonological coding was prevented by an articulatory shadowing task. Younger normal readers were more impaired by rhyming letter names than older disabled readers. The authors suggest that good readers make use of phonological codes in memory tasks, while poor readers seem to use other strategies. That good readers were more affected than poor readers by phonetically similar letter names was also demonstrated by Shankweiler, Liberman, Mark, Fowler, and Fischer (1979). Siegel and Linder (1984) also observed this in young disabled readers (ages 7 and 8), although not in older ones (ages 9-13). Maintenance strategies used for decoding tasks by poor readers may be qualitatively different from those used by good readers (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979; Shafrir & Siegel, 1994; Siegel, 1993), may rely more on orthographic coding (Siegel, Share & Geva, 1995) and may vary with age.

The use of different memory strategies by disabled readers is assumed by some researchers to be compensatory for memory weaknesses. Gathercole and Baddeley (1990) have suggested that language disordered children may resort to use of visual coding strategies to compensate for weak phonological encoding abilities. Katz, Shankweiler, and Liberman (1981) claim that poor readers will use other inefficient coding strategies for linguistic material in preference to using impaired phonological ones. Adults with reading disabilities reported consistently using visual scanning strategies in preference to phonological ones in learning verbal material (Shafrir & Siegel, 1994). Reliance on visual memory has also been documented in neurologically impaired adults with verbal memory deficits (Baddeley, Papagno & Vallar, 1988; Vallar & Baddeley, 1987; Warrington & Shallice, 1972). The suggestion is generally that visual memory strategies are less efficient for reading processes, but are used in compensation for phonological deficits. Alternatively, possibly visual memory is a particular strength for dyslexic children.

The potential complexity of the interplay between verbal and visual memory processes is illustrated by reasearch concerning memory for meaningful verbal material. Verbal memory coding apparently predominates in an immediate recall paradigm (Bahrick & Bahrick, 1971; Bartlett, Till & Levy, 1980; Schooler & Engstler-Schooler, 1990), and is particularly important for verbal responses (Schooler & Engstler-Schooler, 1990). However, visual memory may generally be more durable than phonological memory. Bahrick & Bahrick (1971) suggested that immediate recall is dependent on the effectiveness of verbal encoding; but that after an extended interval, verbal recall is based on recoded visual memory. Although verbal and visual memory normally support each other (Atwood, 1971; Klatzky & Rafnel, 1976; Nelson & Brooks, 1973; Paivio, 1971, 1986) this is not always the case (Bartlett, Till & Levy, 1980; Brandimonte, Hitch & Bishop, 1992a, 1992b; Eddy & Glass, 1981; Glass, Millen, Beck, & Eddy, 1985; Schooler & Engstler-Schooler, 1990).

Reading is a working memory process which requires additive combination of verbal and visual memory processes at both the simple decoding level and at higher integrative levels of processing. Paivio (1971, 1986) developed a theoretical dual coding model to describe the function of visual and verbal coding in memory. Verbal and visual processes are viewed as alternative coding schemes, or systems of symbolic representation. The verbal code functions in abstract, logical thinking, as compared to the concrete, analogical mode characterizing the visual code. Verbal representations are sequential, while visual ones are simultaneous. Theoretically, the two coding systems may be accessed independently through perceptual processes, and interconnect at a "referential level" equated with semantic processing. Integration of verbal and visual components of a task has been referred to as referential coding (Paivio, 1986). Referential ability was studied by Bucci (1984) and Bucci and Freedman (1978). This ability was shown to be independent of verbal representational coding and other verbal abilities, an observation consistent with the definition of reading disabilities as a specific rather than general deficit. Flexibility in use of phonological and visual memory strategies would facilitate skilled reading.

The automaticity of imaginal-verbal recoding in skilled reading has been questioned (Paivio, 1986); it may be that this does not occur with language disordered individuals. Swanson (1986) suggested that this type of coding may be impaired in individuals with reading disabilities.

It seems clear that phonological memory plays an important role in skilled reading. The role of visual memory is less clear, but may also be important, especially in reading disabled individuals. Memory processes involved in integration of verbal and visual codes may also be a significant determinant of skilled reading.

Memory Codes and Beginning Reading Skills

In this study, age and reading level comparison groups were used. This is done to allow conclusions to be drawn as to whether cognitive differences observed in dyslexic children represent a developmental delay in language skills, or a qualitatively different pattern of development. Both of these alternatives have been supported by research. In exploration of the roles of phonological and visual memory in emergent decoding skills, consideration of normal memory development seems appropriate. To allow comparison of the dyslexic children tested to younger children with matched reading skills, some information is presented here about the development of phonological, visual, and cross modal memory in children at the age when reading skills first normally begin to develop.

Memory differences inherent in reading disabled populations may reflect the persistence of earlier typical developmental stages, rather than eccentric development. According to Vellutino and Scanlon (1982), individuals differ in the extent to which they favor the “word-specific” or “rule-based” approach to word identification. If children acquire either a repertoire of whole words they can identify on sight, or a repertoire of symbol-sound associates for use in phonetic analysis, but not both types of knowledge, they will have difficulty in developing fluency in reading. The word-specific knowledge required for sight reading, and the rule-generated knowledge required for decoding, are both important determinants of reading skill.

Acquiring skill with English orthography is complicated by the visual similarity that characterizes letters and words in the English language. The beginning reader must process more visual information more laboriously than more experienced readers, for whom the process is automatized. Developmental studies of memory have indicated that young children and beginning readers rely on visual memory more than verbal in image recall (Hitch, Halliday, Dodd &

Littler, 1989; Hitch, Halliday, Schaafstal, & Heffernan, 1991; Hitch, Woodin & Baker, 1989; Mann & Liberman, 1984; Paivio, 1986; Stanovich, 1986; Walker, Hitch, Doyle, & Porter, 1994). The ability to spontaneously subvocally rehearse does not develop until the preschool years (Gathercole & Adams, 1993; Hulme & Mackenzie, 1992); consequently, verbal memory is less effective in younger children than adults.

Lack of spontaneous use of a phonological rehearsal strategy is assumed to be a main reason for the reliance on visual memory observed in younger children (Hayes & Schulze, 1977; Hitch, Halliday, Schaafstal & Heffernan, 1991; Hitch, Halliday, Schaafstal & Schraagen, 1988; Hitch, Woodin & Baker, 1989; Walker, Hitch, Doyle & Porter, 1994). This may also be true for dyslexic children. Reading skills and rehearsal capabilities seem to develop concurrently, so that in the elementary years children rely on verbal memory rather than visual to support the recognition of letters (Walker, Hitch, Doyle & Porter, 1994) and words (Stanovich, 1986). Stanovich (1986) suggested that as reading become more skilled, visual/orthographic strategies again predominate, except for some unfamiliar words.

Visual memory in serial recall studies has been distinguished by a one-item recency effect (superior recall of final list items due to use of a short term storage buffer) and no primacy effect (superior recall of initial list items due to phonological rehearsal, Spring & Capps, 1974) (Baddeley & Hitch, 1974; Broadbent & Broadbent, 1981; Hitch et al, 1988; Hitch, Woodin & Baker, 1989; Philips & Christie, 1977a, 1977b; Walker et al, 1994). Broadbent and Broadbent

(1981) developed the concept of iconic store to describe the mechanism responsible for recency effects, which is considered to be a different, more passive mechanism than the pre-recency mechanism (Philips & Christie, 1977b). The difference between these two mechanisms has been credited to some type of visual rehearsal, possibly associated with eye movements (Baddeley, 1986).

The Baddeley model of working memory postulates a visuo-spatial scratch pad as the basis for visual STM (Baddeley, 1986; Farmer, Berman & Fletcher, 1986; Logie, 1986). Studies based on this component of Baddeley's model have provided developmental data about visual memory. Visual memory seems to improve with age (Hitch, Woodin & Baker, 1989; Walker, Hitch, Doyle & Porter, 1994). The ability to focus attention on specific visual stimuli in the presence of distracters seems to improve with age (Enns & Akhtar, 1989). Speed of transfer of visual information from iconic (temporary) storage to STM seems to increase with age through the elementary school years (Gummerman & Gray, 1972). The ability to operate on and transform images in visual memory may also improve with age (Hitch, Halliday, Schaafstal & Schraagen, 1988). Studies by Brandimonte, Hitch and Bishop (1992a) have shown that children's ability to perform mental operations on visual images was independent of higher order capabilities such as awareness of logical structure and comprehension.

Visual and spatial memory appear to be distinct, in that memory for form and color seems to be independent of memory for location, although both are presumably functions of the visuo-spatial scratchpad (Baddeley, 1986). Children apparently access visual memory through spatial rather than surface features.

Developmental changes in use of visual memory codes have been demonstrated (Hitch, Halliday & Littler, 1989; Hitch, Halliday, Schaafstal & Heffernan, 1991; Hitch, Halliday, Schaafstal & Schraagen, 1988; Hitch, Woodin & Baker, 1989; Walker, Hitch, Doyle & Porter, 1994).

The tendency for young children to rely on visual memory is very pervasive, and was demonstrated in a probed location study of recall of letters, in which children were required to recognize the location of one of three colored shapes that had appeared in a random spatio-temporal order, or to remember a shape's color or spatial location (Walker, Hitch, Doyle & Porter, 1994). That visual memory was used in the recall of the letters was demonstrated by manipulation of visual similarity. Characteristic visual serial position curves were observed as well (Walker, Hitch, Doyle & Porter, 1994).

The concept of object file is introduced in the discussion of this study. An object file is a schema of that object with associated modality specific (e.g. visual or verbal) attributes. Young children can derive information about feature associations from the most recent object file just as effectively as older children, but are somewhat less able to access the memory traces of object files that are no longer current. Thus, visual recency effects are relatively stable with age, while pre-recency performance improves. Spatial features (e.g. location, shape) were shown to be more important than surface features (e.g. color) in accessing an object's file. For the age range studied by Walker et al (5 to 7 years), there was developmental change in ability to access the object file, but not in its contents. Visual encoding appears to be constant with age, while recall improves with the development of strategic behavior. Some aspects of visual memory are clearly developmental, while others are not.

Visual rather than phonological coding of pictures was demonstrated in young children (5 years old) by the finding that visual similarity impairs recall performance more than phonological similarity (Hitch, Woodin & Baker, 1989; Hitch Halliday, Schaafstal & Schraagen, 1988). Hitch et al (1989) noted that at 5 years of age, visual inputs gain obligatory access to visual working memory, but that the adult control processes necessary for them to gain access to phonological storage are not developed. For 5 year olds, effects of word length were minor, and visual retroactive interference produced greater disruption. For children at this developmental stage, the reflexive preference for verbal coding noted by Schooler and Engstler-Schooler (1990) is not developed. Recall performance for pictured objects was sensitive to verbal similarity in 10 year olds, as indicated by effects of word length, and the greater disruption caused by auditory-verbal than visual retroactive interference. Thus, in 5 year olds, but not in 10 year olds, visual memory codes predominated for this task.

The type of visual memory observed in young children may be equated with iconic storage, the temporary visual storage buffer described by Broadbent and Broadbent (1981). Iconic memory is not durable, and is strongest for recency items (Walker, Hitch, Doyle & Porter, 1994). Iconic memory is considered to be more detailed than durable visual memory, but less stabilized by semantic associations (Coltheart, 1980). Normally, iconic storage is not age dependent, so is a good in young children as adults, and perhaps as good in dyslexics as in skilled readers.

Hitch et al (1989) noted that verbal memory masks visual in older subjects,

but does not eliminate it. Eleven-year-old children were more affected by phonological similarity in recall of pictured objects than by visual similarity. When articulatory suppression was used, effects of visual similarity became apparent. That the articulatory suppression resulted in reliance on visual memory was confirmed by postlist interference tasks. The mixed visual-verbal task produced greater decrements than the visual task when articulatory suppression was not used, but with the suppression, the visual interference task produced more impairment. Auditory-verbal postlist interference did not entirely remove recency effects, suggesting a residual visual component of recall in older children. Schooler and Engstler-Schooler (1990) supported this finding in their work with recall of pictures of faces, showing that masked visual memories can be retrieved when verbal ones are blocked. Older children presumably can use visual and phonological strategies in accordance with task demands. As children develop mature rehearsal skills, these increasing supplement and overshadow visual memory (Hitch, Woodin & Baker, 1989; Hitch, Halliday, Schaafstal & Schraagen, 1988).

In adults, visual memory for images is more enduring than phonological memory for names (Nelson & Brooks, 1973), and provides parallel (simultaneous) encoding of different stimuli or stimulus properties. In a label training study of random shapes, in which participants learned to associate shapes with names, visual recognition memory was stable over a week, while memory of verbal labels decreased significantly over this period (Bahrick & Bahrick, 1971). Schooler and Engstler-Schooler (1990) showed that mental images overshadowed by verbal coding could be retrieved by imposing a time limit on the retrieval task. It may be that access to mental images is faster than access to their verbal representations,

although verbal coding is the strategy of choice if it is not blocked (Schooler and Engstler-Schooler, 1990). If dyslexic individuals have verbal and/or visual coding deficiencies, this may affect their choice of memory codes.

Preference for visual strategies has been documented in reading disabled children and adults (e.g. Huba & Vellutino, 1990; Shafrir & Siegel, 1994; Siegel, 1986; Siegel, Share & Geva 1995). Reading disabled children may rely on visual memory for developmental reasons. If verbal memory processes do not develop, or not normally, reliance on visual memory may persist. If this were the case, phonological memory performance in dyslexic readers could be expected to resemble that of younger children, and visual memory performance might be more similar to that of age-matched comparison students. An alternate possible interpretation is that some aspects of visual memory are areas of particular strength for these individuals. Disabled readers showed superior recall of recency items in one visual serial memory study (Spring & Capps, 1974).

Some studies of children with reading disorders have shown that memory performance of older reading impaired children is comparable to that of younger normal readers of matched reading age (Baddeley, Ellis, Miles & Lewis, 1982). Bryant and Impey (1986) observed that the notion of that dyslexics are held back because their "functional architecture" is different, must be wrong. "We have found the same functional architecture in normal children... Now that we have shown that these 'symptoms' exist as strikingly in many of our normal children, this claim is surely untenable." (Bryant & Impey, 1986, page 134). These findings support an interpretation of learning disabilities as a developmental delay in cognitive skill development. If this is the case, dyslexia should respond well to remediation with normal instruction, given sufficient time. Stanovich emphasized, in his discussion of "Matthew effects" in reading, that this is often not true (Stanovich, 1986).

Stanovich (1988) has noted that learning disabled individuals are not only delayed in level of development of language skills relative to their age, but also in rate of development (Torgesen, Wagner, Simmons & Laughon, 1990). The lag in rate, more than that in skills, suggests an underlying cognitive difference, as a result of which a normal asymptote is never reached (Stanovich, 1988). The memory performance of dyslexic participants in this study was compared to that of reading level comparison students to assess the possibilities that dyslexic individuals show either delayed but normal development, or deficits in functional architecture. Weak reading-related performance of dyslexic individuals on visual and phonological measures would be more suggestive of differences in functional architecture.

According to the model of reading disability advanced by Swanson (1986), reading disability may represent a cross modal deficit, causing lack of flexibility in choice of memory strategies. Memory has modality-specific and amodal aspects. Skilled readers are flexible in use of information processing strategies, and can process visual information within a modality-specific knowledge system or an amodal (not relating to a particular sense modality) conceptual one, presumably selecting the least effortful strategy. Disabled readers may, in contrast, because of the difficulty in semantically processing visual and verbal input, favor information processing through the developmentally earlier visual modality system (Swanson, 1986). According to Coltheart (1980), iconic memories are encoded into durable (long term) storage through attachment of semantic associations. Through this process, detail is sacrificed to persistence. Perhaps an encoding bottleneck is the impediment for disabled readers, resulting in detailed but unstable iconic memories.

Memory and Reading Disabilities

Visual Memory and Reading Disabilities - The Case Against Visual Deficits

Studies of visual processing and visual memory deficits in relation to reading disability have produced equivocal results (Morrison & Manis, 1982; Vellutino & Scanlon, 1982 for reviews). The ability of visual tasks to discriminate between normal and disabled readers seems to be related to the type and pacing of the task involved (Eden, Stein, Wood & Wood, 1995), the age of the subjects (Arnett & DiLollo, 1979), and the complexity of task demands, specifically its storage and processing requirements. Simple stimuli, short retention intervals, and longer exposure times tend to reduce or eliminate reading group differences. Paired associate memory paradigms have not identified reading group differences in visual memory (Torgesen & Murphey, 1979; Vellutino, Steger, Harding & Philips, 1975; Vellutino, Harding, Philips & Steger, 1975). Tests of recognition memory (Vellutino, Steger, DeSetto & Philips, 1975) have not generally been successful in discriminating reading groups.

In this section, the case against visual deficits will be presented, with observations as to how methodology may influence the results. The focus of the section is mainly the methodological issues. In a later section (page 41), the case **for** rapid visual sequential processing deficits will be presented.

> Perhaps the most popular of the many theories offered in explanation of specific reading disability is the perceptual deficit hypothesis. According to this theory, poor readers suffer a constitutional disorder in spatial organization which disrupts visual perception and visual memory... We... suggest that orientation and sequencing problems, such as those described by Hermann (1959) and Orton (1925), are a consequence rather than the cause of reading disorder, and are occasioned by the failure to internalize linguistic codes that program spatial constancy (Vellutino & Scanlon, 1982, p. 199).

Visual memory is believed by some researchers to be normal in children with reading disabilities (McDougall, Hulme, Ellis & Monk, 1994; Spear & Sternberg, 1986; Swanson, 1986; Vellutino & Scanlon, 1982). Studies of naming speed for objects, colors and animals (Katz & Shankweiler, 1985) showed no reading related effects. Investigation of recognition memory for items in sets of designs, faces, and syllables showed reading group related differences for syllables only (Liberman, Mann, Shankweiler, & Werfelman, 1982). Disabled readers were deficient in serial memory for strings of written letters, but this may be attributed to the phonological aspect of the task (Shankweiler, Liberman, Mark, Fowler & Fischer, 1979). Paired associate memory for learned responses to novel stimuli showed reading group differences only when a verbal response was required

(Torgesen & Murphey, 1979). Serial recognition memory for abstract geometric shapes was not significantly better in good readers (McDougall, Hulme, Ellis & Monk, 1994). These studies seem to indicate that disabled children are deficient in recall of letters (Bakker, 1972; Katz & Shankweiler, 1985; Shankweiler, Liberman, Mark, Fowler & Fischer, 1979), nonwords (Liberman, Mann, Shankweiler, & Werfelman, 1982; Martin, 1982), and words only (Torgesen & Murphey, 1979; Swanson, 1986; Katz, Shankweiler, & Liberman, 1981). Performance of poor readers in these studies was equal to that of good readers on non-linguistic stimuli.

Torgesen and Murphey (1979) investigated the relationship of reading skill to performance on paired associate lists, requiring verbal or non-verbal responses to visual stimuli (letter-like figures). They found that the reading groups differed significantly only on tasks requiring verbal responses. They attributed this to the isolation of processing deficits in poor readers to the phonological domain. What was actually tested was cross-modal associative memory, memory for an association between a sound and a symbol. No pure phonological test was included.

In a study of reproduction memory for 3-, 4- and 5-letter Hebrew words, the performance of poor readers was lower than but not significantly different from that of good readers, although the types of errors made were different (Vellutino, Steger, Kaman & DeSetto, 1975). Another study using Hebrew characters showed that over a 24 hour and 6 month period, recognition of the characters was as good in poor as normal readers (Vellutino, Steger, DeSetto & Philips, 1975). However, recall in this study was so low in both groups that there may have been floor effects. Another visual memory experiment that seems to have involved floor effects was the visual memory span portion of the study by McDougall, Ellis, Hulme and Monk (1994). In this study, this first level of the visual span test involved two stimuli. The second level was to have involved three stimuli, but it seems neither group was successful at the three stimuli level. In this study, IQ was determined using two visual memory and two language subtests from the WISC, and then was used as a covariate in the analysis. This may have masked an actual reading group related difference in visual memory, if one existed.

In a paired associate study, poor readers performed as well as skilled readers on a non-verbal learning task, but significantly worse when verbal associations were required (Vellutino, Steger, Harding & Phillips, 1975). The performance criteria in this study were - "the procedure(s) continued... for seven (ten) trials or until a subject achieved a criterion of two consecutive errorless trials (page 78)" - makes the results difficult to interpret. The report does not specify the number of trials used for each subject, or the mean number per group. It is possible that the children with reading disabilities were exposed to more repetitions of the stimuli to be learned than the normal readers.

In two recognition memory studies, poor readers performed as well as good ones in visual recognition of words presented tachistoscopically, although they did

not perform as well in pronouncing or spelling of those words. Poor readers also performed as well as normal readers in recognition recall of numerals and geometric designs (Vellutino, Steger, & Kandel, 1972). This study involved ceiling and floor effects, and the observation that the task most clearly differentiating normal from impaired readers was reading. It does reinforce the hypothesis of Siegel, Share and Geva (1995) that reading disabled children may rely on more orthographic than phonological memory strategies for words. Siegel, Share and Geva (1995) suggested that memory deficits in the dyslexic group were unique to the phonological domain, and did not involve vision. Recognition recall of slowly presented visual images is a relatively simple visual memory task, with low discriminating power for reading groups.

In a study of paired associate learning, good readers were more successful in learning associations between visual stimuli (line drawings that were difficult to name) and verbal responses (nonword trigrams) than poor readers, but the groups performed equivalently when matching visual stimuli to learned visual responses (Vellutino, Harding, Phillips, & Steger, 1975). Vellutino et al. concluded

that reading disabled children were only impaired on tasks involving verbal processing. Pure tests of verbal/phonological memory (e.g. tests like pseudoword repetition or phoneme deletion that do not involve a visual component) were not included in the Vellutino et al studies. This is true in many of the studies of visual and verbal STM and reading disabilities, and is a design weakness of these studies.

Serial recall study of pictured objects and amorphous scribbles with good and poor readers showed differential effects related to codability (Katz, Shankweiler &

Liberman, 1981). Good readers performed significantly better on tests of pictured objects, that could be verbally coded. Performance of both reading groups was lower for scribbles, but there was no significant difference between the groups. Relative to good readers, the performance of the disabled readers was impaired for the labeled, but not for the unlabeled stimuli. This study emphasizes the idea that use of verbal labels with visual stimuli influence disabled and normal readers in different ways, and that the labels are not as facilitative of memory in children with reading disabilities. The authors suggest that this demonstrates a verbal deficit, but again solely verbal and solely visual tests were not used. In order to accurately assess the contribution of phonological memory to performance on a cross modal task, a test of phonological memory should be included in the paradigm. This has typically been neglected.

Differences in the relative difficulty of visual and verbal tasks used across studies can influence results and their interpretation. In the Vellutino et al (1975) study, the visual task involved recognition memory, while the verbal task required a recall response. Recognition responses are generally considered easier than recall ones (Vellutino and Scanlon, 1982). The visual task in this paradigm may have been easier, and so a less sensitive reflection of actual differences between groups.

The tasks used in the visual and verbal studies cited in this section typically tested the verbal aspect of cross modal memory in one direction only (visual stimulus to verbal response). One study in which memory for visual responses to verbal prompts was tested involved naming of toys (Gathercole & Baddeley, 1990). In this study, poor readers did have more difficulty identifying the toy from the name when the name was a non-word. Possibly retrieval of a visual image from a sound is more difficult that recall of a name for an image (Nelson, Reed & McEvoy, 1977). More difficult tasks seem more to be more sensitive discriminators of ability groups in reading.

Despite this evidence against the role of visual memory deficits in reading disability, there are lines of investigation which challenge the conclusions reached in some of the studies mentioned above. Some research concerning visual sequential and spatial memory and visible persistence supports the hypothesis that visual deficits exist in dyslexic populations. My contention, based on previous research, is that visual as well as verbal deficits are present in reading disabled populations, and that these do affect the cross-modal task of memory for letter-sound correspondences in a sequential paradigm (like reading). However, the visual deficits may be related to rapid sequential processing, and may only be identifiable through measures that probe this specifically. Many of the visual memory studies cited in this section, that have not found differences relating to reading ability used methodology requiring more static or iconic memory, which may not be a weakness, and may even be a strength in reading disabled populations.

Tests of Serial Recall

Studies of visual sequential memory have been more successful in identifying visual deficits related to reading disability. It has been suggested that visual sequential memory deficits (Corkin, 1974; Farnham-Diggory & Gregg, 1975;

Morrison, Giordani & Nagy, 1977; Noelker & Schumsky, 1973; Senf & Freundl, 1971; Spring & Capps, 1974; Swanson, 1978, 1983, 1984) and deficits in rapid visual sequential processing (Eden, Stein, Wood & Wood, 1995; Farmer & Klein, 1995; Galaburda & Livingstone, 1993; Lovegrove & Brown, 1978; Lovegrove, Billing & Slaghuis, 1978; Slaghuis, Lovegrove & Davidson, 1993) may be causally related to reading disability. This suggests that a timed sequential visual memory test might be effective in identifying any existing impairments in a population with reading disabilities.

Serial recall tasks, as memory paradigms, have been shown to differentiate good and poor readers in some studies. The digit span subtest of the Wechsler Intelligence Scale for Children (WISC) is a measure of verbal sequential memory that has been used to differentiate good and poor readers. Studies of WISC subtest profiles relative to reading ability have been extensively reviewed by Huelsman (1970) and Rugel (1974). Of the 26 studies considered in both reviews, 15 found significant differences in performance between good and poor readers on the Digit Span Test. The Digit Span Test was 1 of 3 subtests which reliably differentiated good and poor readers in elementary and junior high school. The reliability of this test has been questioned (Torgesen, 1978-1979). Torgesen stated that it is the least reliable of the WISC subtests, with a reported average 5-month stability coefficient for the visual sequential memory task of 0.46.

Auditory and visual sequential memory subtests of the *Illinois Test of Psycholinguistic Abilities (ITPA)* have also been used to predict or differentiate reading problems, with inconsistent results. Test-retest reliabilities for the ITPA subtests are below optimal levels: of 36 subtest coefficients reported, 27 were below 0.60 and 18 below 0.50 (Salvia and Ysseldyke, 1991). However:

"The largest share of psychometric data related to the performance of reading disabled children on serial memory tasks comes from studies investigating the performance profiles of these children on intelligence tests and the Illinois Test of Psycholinguistic Abilities (ITPA)... (Torgesen, 1978-1979, page 65)."

Studies of serial memory using other test instruments have also demonstrated reading skill-related differences (Farmer & Klein, 1995). The weight of empirical evidence suggests that reading disabled children show relative deficiencies on tasks which require the repetition of sequentially presented aural or visual stimuli (Farmer & Klein, 1995; Gathercole & Baddeley, 1989, 1990a, 1993; Lovegrove, Billing & Slaghuis, 1978; Lovegrove & Brown, 1978; Siegel & Ryan, 1988; Torgesen, 1978-1979).

Serial Position Curves - Data Presentation

Serial position curves are often used to describe memory for sequences. These curves show levels of recall for individuals or groups at each position in the sequence. Presenting data in this way gives more information about how the sequence is remembered than simply recording a single score. Data from memory span studies are typically reported with serial position curves. Distinctive features of these curves distinguish verbal and visual memory strategies (Broadbent & Broadbent, 1981; Hitch et al, 1988; Hitch, Woodin & Baker, 1989; Philips & Christie, 1977a, 1977b; Walker et al, 1994).

Serial position curves for verbal material and normal readers are characteristically bow-shaped, showing both primacy and recency effects. The primacy effect (higher recall of the earliest list items) is attributable to verbal mnemonic processes - the subject has more opportunity to subvocally rehearse or chunk earlier than middle list items (Baddeley, 1986; Baddeley & Hitch, 1974; Broadbent & Broadbent, 1981; Hulme & McKenzie, 1992).

As was previously mentioned, rehearsal capabilities increase with age through the school years in normal readers, until adult levels are reached (Hitch, Halliday & Littler, 1989). It has been suggested that this does not occur, or not normally, in children with reading disabilities. Serial position curves for verbal material obtained from reading disabled populations show reduced or no primacy effects (Noelker & Schumsky, 1973; Spring & Capps, 1974). The recency effect (higher recall of the last few list items) is attributed to a more passive echoic sensory memory mechanism, and is seen in studies of verbal sequential memory with reading disabled subjects.

A characteristic visual serial position curve is initially flat with a sharp rise at the end, the visual recency effect. Iconic storage is responsible for visual recency effects according to Broadbent and Broadbent (1981), and is considered to be a different, more passive mechanism than the pre-recency mechanism (Philips & Christie, 1977). Younger children have been shown to have longer lasting iconic memories that older children or adults, but to process iconic information more slowly (Gummerman & Gray, 1972).

Visual Sequential Memory - The Case For Visual Deficits

Visual deficits have been demonstrated in reading disabled children in some research. In several studies, visual sequential memory impairment was demonstrated in dyslexic readers (Corkin, 1974; Farmer & Klein, 1995; Farnham-Diggory & Gregg, 1975; Morrison, Giordani & Nagy, 1977; Morrison & Manis, 1982; Noelker & Schumsky, 1973; Senf & Freundl, 1971; Spring & Capps, 1974; Swanson, 1978, 1983, 1984; Torgesen, 1978-1979). Dyslexic children have shown deficits related to visual stimulus identification (Enns, Bryson and Roes, 1995; Manis & Morrison, 1982) and to spatial memory (Enns, Bryson and Roes, 1995; Mason, 1980, Morrison & Manis, 1982). Perceptual differences relating to visible persistence have also been documented in reading disabled groups (Badcock & Lovegrove, 1981; Eden, Stein, Wood & Wood, 1995; Galaburda & Livingstone, 1993; Lovegrove & Brown, 1978; Lovegrove, Billing & Slaghuis, 1978; Slaghuis, Lovegrove & Davidson, 1993).

Early research on visual serial memory sought merely to establish the existence of visual sequential impairments in reading disabled subjects, assuming that if these existed, they would impede reading. These studies sometimes employed tasks rather remote from actual reading processes. Matching spatial (simultaneous), temporal (sequential), and spatial/temporal sequences of light flashes to corresponding dot patterns was compared in normal and retarded readers in one paradigm (Blank, Weider, & Bridger, 1967). Children with reading disabilities performed significantly less well than normal readers in making matches between physically different stimuli, even though they were both presented in the visual modality.

In a visual memory task involving recognition of previously viewed dot patterns, group differences were not found (Blank, Weider & Bridger, 1967). When spatial and temporal arrays, composed of dot patterns and sequences of light flashes were used, reading-related differences were found. Simultaneous and sequential visual displays affected good and poor readers differently. Lack of reading-related decrements on the spatial task, which involved visual simultaneous presentation, suggests that impaired visual memory performance in the disabled group did not involve iconic memory. A sequential deficit was present in the reading disabled group.

Another study that found differences related to reading ability used a recorded sequence of rhythmic taps and clicks (Zurif & Carson, 1970), and analogous sequences of light flashes. This study assessed intramodal recognition memory for the sequences as well as intermodal matching of auditory and visual temporal sequences. Normal readers showed significantly better performance than dyslexic subjects on all three tasks. Slow processing of transient stimuli, and the potentially confused images that could develop as a result, could generate the effects observed with flashing lights and tones. The impact of this on specific beginning reading tasks is not clear, however, since light flashes and clicks are not part of normal reading instruction.

A study of visual serial memory for abstract geometric patterns revealed reader group differences with longer retention intervals (Morrison, Giordani & Nagy, 1977). In this study, with short retention intervals (0 to 300 ms.) reading group differences were not apparent. With longer intervals (300 to 2000 ms.) there were significant differences between good and disabled readers in memory for sequences of abstract forms. The retention interval over 300 ms. represents the change from perception to memory (Slaghuis, Lovegrove & Davidson, 1993), so the findings suggest that the reading groups are similar in visual perception, but that reading disabled subjects have shorter memory spans.

Since good readers may use verbal codes for visual stimuli, these findings may also reflect the observation that verbal encoding is a slower process than visual encoding (Schooler & Engstler-Schooler, 1990), although use of abstract stimuli is intended to reduce verbal encoding. The longer interval may allow the verbal coding to take place, emphasizing the verbal performance advantage of good readers. Alternatively, if poor readers rely on iconic storage for the task, the longer intervals may allow more trace decay. So either verbal or visual deficits could explain the findings of this study. Delay intervals also produced recall decrements that distinguished children by reading ability in a study of serial spatial recall (Corkin, 1974).

Noelker and Schumsky (1973) hypothesized that sequential memory was composed of memory for form and memory for position (separate visual and spatial memories, also hypothesized by Baddeley, 1986). They investigated memory for form, position, and sequence separately in normal and retarded readers. The test of memory for form involved selection of the one of four amorphous shape arrays that matched a previously studied sample. Item exposure times in this study were long, approximately 10 seconds per array. The memory for position test used random series of black and white circles, which were studied for 10 seconds and then removed. The participant had to reconstruct the original series from a new random arrangement of cards. The sequencing task was similar to the position task but four sided shapes were used instead of circles. All three tasks distinguished good and poor readers, but the position task was the best single discriminator. Since sequences of black and white circles can be remembered verbally, either visual of verbal deficits could cause the position task to identify the greatest reading related differences.

Serial position curves obtained by Noelker and Schumsky (1973) for the position and sequencing tasks differed by reading group. The characteristic inverted u shape (showing primacy and recency effects) (Broadbent & Broadbent, 1981; Hitch, Halliday, Schaafstal & Schraagen, 1988; Hitch, Woodin & Baker, 1989; Philips & Christie, 1977a, 1977b; Walker, Hitch, Doyle & Porter, 1994), was observed in the data for normal readers. The serial position functions for disabled readers were flatter than those of the controls. They showed slightly reduced primacy and recency effects, with errors at all serial positions. The implications of reduced recency in this study are unclear, because simultaneous rather than sequential presentations of series was used. Reading disabled subjects may not study the array by left to right scanning (Spring & Capps, 1974). The difference in the curves does suggest strategic differences between the reading groups.

Deficits in visual stimulus identification and location in reading disabled children have been reported (Enns, Bryson & Roes, 1995). In this study, children were presented with an array of letters, and a probe letter. When the probe was presented after the array, disabled readers had significantly more difficulty than good readers in reporting the presence or absence of the probe in the original array. When the children were required to specify the location of the probe letter in the original array, dyslexic readers had more difficulty regardless of whether the probe preceded or followed the array. Further, correlational analysis showed that visual similarity or letters, rather than phonological similarity of their names, influenced search efficiency.

Mauer and Kamhi (1995) studied grapheme-phoneme correspondence learning in elementary aged children. They taught groups of reading disabled children and normal readers to associate sounds with letter-like graphemes. The disabled readers had more difficulty in learning the associations than did the normal readers. Both visual and phonological processing skills were associated with success at this task. Although phonological short term memory was the best predictor of performance, visual processing skills were highly correlated with learning when the graphemes were visually similar, accounting for 39% of the variance in performance.

Research has demonstrated the existence in reading disabled populations of visible persistence, the continued visibility of a stimulus after its offset (Badcock & Lovegrove, 1981; DiLollo, Arnett & Kruk, 1982; DiLollo, Hanson & McIntyre, 1983; Eden, Stein, Wood & Wood, 1995; Lovegrove, Billing & Slaghuis, 1987; Lovegrove & Brown, 1978; Lovegrove, Heddle & Slaghuis, 1980; Slaghuis, Lovegrove, & Davidson, 1993). Some children with reading disability have a longer than normal separation threshold for visual stimuli; that is, they require a longer interval between presentation of two stimuli to be able to tell that two discrete stimuli were shown. Some researchers have claimed that for younger children, it is now clear that rapidly presented stimuli are processed less accurately and more slowly by reading disabled than by normal children (Eden, Stein, Wood & Wood, 1995; Willows, 1990).

Visible persistence is assessed with tasks in which a sustained perception will allow the participant to see a different image than would be seen if it were not. For example, visible persistence might be necessary to allow integration of two halves of a composite picture. Some reading disabled individuals may see superimposed or overlapping images when processing visual sequential stimuli as a result of visible persistence. Reading disability has been interpreted in terms of these perceptual findings. Historically, some discussion has focused on whether memory deficits in children with reading disabilities are structural (inherent and modular), strategic (learned and amenable to remediation), or developmental in nature. Visual deficits related to visible persistence would be structural, modular, and not subject to remediation through central processes.

Although the studies of visible persistence (Eden, Stein, Wood & Wood, 1995; Lovegrove & Brown, 1978; Slaghuis, Lovegrove & Davidson, 1993), contrast sensitivity (Galaburda & Livingstone, 1993), and visual evoked potentials (Galaburda & Livingstone, 1993) have documented reading group differences, the relevance of this to beginning decoding skills is not clear. As Hulme (1988) noted, these visual processing deficits could be a result of reading disability, or not directly related to learning to read. Since memory is highly task specific, findings relevant to one task can not be widely generalized.

In summary, studies of visual memory and reading ability have both challenged and supported the role of visual deficits in a reading disabled population. Complex tasks, fast presentation rates, and longer delay intervals tend to elicit group differences, suggesting potential differences in visual processing rate and retention. Reading disabled subjects have generally been shown to be worse than normals at matching visual stimuli only if the exposure times were short (between 0.1 and 1.0 seconds) and the children were below 8 years of age (Lyle & Goyen, 1975; Willows, 1990). Visual deficits in dyslexic readers are most likely related to pre-recency retention strategies. Iconic storage may be an area of compensatory strength in disabled readers. Perceptual differences related to visible persistence may account for performance deficits observed in a reading disabled population on sequential memory tasks.

Cross-Modal Memory Span

Some authors have also suggested that deficits may exist in integration of verbal and visual memory codes (Birch & Belmont, 1964; Ceci, Lea, & Ringstrom, 1980; Swanson, 1983, 1984, 1986; Torgesen, 1979; Vellutino, Steger, Harding, & Philips, 1975; Vellutino & Scanlon, 1982 for a review). Memory studies using named and unnamed stimuli (Katz, Shankweiler and Liberman, 1981; Swanson, 1986; Torgesen and Murphey, 1979; Vellutino and Scanlon, 1982) indicate that skilled readers have a facility for additive combination of visual and verbal cues relative to disabled readers. Skilled readers showed superior recall of named stimuli, but disabled readers did not (Katz, Shankweiler & Liberman, 1981; Torgesen & Murphey, 1979; Vellutino & Scanlon, 1982). In one study, reading disabled subjects showed better recall of unnamed than named stimuli (Swanson, 1986). Swanson suggested that referential (cross-modal) coding may be impaired in individuals with reading disabilities.

However, some writers state that visual memory and visual processing are unaffected in reading disabled populations (McDougall, Hulme, Ellis & Monk, 1994; Spear & Sternberg, 1986; Swanson, 1986; Vellutino & Scanlon, 1982). These authors suggest that apparent deficits in cross modal memory really reflect phonological processing difficulties. Deficits in language specific functions like phonological processing and verbal short term memory are assumed to underlie impaired cross-modal performance (Hulme, 1988; Katz, Shankweiler & Liberman, 1981; McDougall, Hulme, Ellis & Monk, 1994; Mann & Liberman, 1984; Mark, Shankweiler, Liberman & Fowler, 1977; Vellutino & Scanlon, 1982).
That skilled readers have a facility for additive combination of visual and verbal cues is supported by serial recall studies using named and unnamed stimuli (Katz, Shankweiler & Liberman, 1981; Swanson, 1986; Torgesen & Murphey, 1979; Vellutino & Scanlon, 1982). Skilled readers showed superior recall of named stimuli; this was not true for disabled readers (Katz, Shankweiler and Liberman, 1981; Torgesen & Murphey, 1979; Vellutino & Scanlon, 1982).

Three studies comparing visual and cross-modal sequential memory in disabled readers were conducted by Swanson (1978, 1983, 1984). These studies employed abstract angular shapes, some of which were assigned names suggestive of their form and some of which were unnamed. In the first of these studies (Swanson, 1978), normal readers remembered more named than unnamed shapes. Disabled readers remembered slightly fewer of the named shapes. Verbal labels benefited normal readers, but the disabled readers seemed to be disrupted in memory by the labels. Swanson stated that verbal labels in the case of learning disabled readers can be viewed as a mediator to which visual stimulus features were not associated.

Coltheart (1980) described iconic visual memories as being stabilized by attachment of meaningful information ("lexical stabilization"). A documented superiority of visual memory for pictures over verbal memory for their names in normal subjects has been attributed to the relative ease with which verbal labels can be retrieved from images, resulting in a dually coded memory trace for visual stimuli (Nelson, Reed & MacEvoy, 1977).

Ceci, Lea and Ringstrom (1980) studied auditory and visual recall in 10 year old normal and disabled readers. The reading disabled children had deficits in auditory and/or visual memory. In a cued recall paradigm, reading disabled children only exhibited deficits with semantic category cues. Ceci, Lea and Ringstrom (1980) noted that reading disabled children are not able to semantically elaborate memories in their impaired processing modality.

The second of Swanson's studies (1983) also showed significant positive effects for verbal labels in normal but not in reading disabled subjects. Verbal codes were particularly important in differentiating groups at primacy positions, emphasizing the role of verbal rehearsal in the memory task. No reading related differences in recall of unnamed shapes were observed.

The third study (Swanson, 1984) incorporated labels suggestive of the associated form and irrelevant labels. Both types of names improved recall of the good readers, while reading disabled subjects exhibited better recall for unnamed pictures. Skilled readers were able to recall and sketch more shapes when they were organized by semantic category. The superior performance with unnamed shapes suggests an actual interference effect between the verbal and visual memory codes. Similar effects were observed for relevant and irrelevant labels, and these did not differ by reading group. Swanson (1986) suggested that it is not verbal coding per se, but rather integrative verbal coding of visual stimuli that defines reading related differences. Learning disabled readers were superior to good readers on recency recall (Swanson, 1984), reflecting the findings of Spring and Capps (1974).

In consideration of the findings from these studies, Swanson observed that children of normal intelligence, who have specific problems in reading, fail to use multiple codes in an additive fashion. Skilled readers code visual forms into a referential system, in which multiple codes interconnect at a semantic or superordinate level. Inclusion of verbal codes in a semantic categorization impaired the performance of the disabled readers because the two coding systems are functionally independent for them. Disabled readers use visual codes in isolation (Swanson, 1986; Swanson, 1983).

Meaningful labels have been shown to increase recall in several studies (Paivio, 1971, 1986, 1991a; Nelson, Reed and MacEvoy, 1977). A study comparing the effects of meaningful and nonmeaningful labels on normal adults found, as did Swanson, that nonmeaningful labels served to increase recall, through not to the same extent as meaningful ones (Klatzky & Rafnel, 1976). The authors stated that a meaningful label affects picture encoding by providing a conceptual interpretation for the picture, while a nonmeaningful one provides an ad hoc associative cue. Studies of label training by Torgesen and Murphey (1979), and Gathercole and Baddeley (1990) illustrated differential effects of labels on skilled and less skilled readers.

A study of verbal encoding in visual serial memory (Katz, Shankweiler & Liberman, 1981) used serial presentation of pictures of common objects and unrecodable scribbles to compare memory span in the presence and absence of verbal coding. The recall task used here required the subject to view the visual stimuli, presented simultaneously, and then to reconstruct the sequence from a random arrangement of cards showing the same stimuli. Serial position curves represented numbers of correct items correctly placed in position. Performance was close to chance level in both groups on the nonrecodable trials. With recodable stimuli, good readers averaged significantly stimuli per serial position than the for poor readers (Katz, Shankweiler & Liberman, 1981).

Serial position curves for recodable and non-recodable stimuli were different in form. In the recodable condition, strong primacy and recency effects were evident, indicating maintenance rehearsal. For the scribbles, neither effect was pronounced. The display time in this study was relatively long (4.0 seconds), and the presentation of the array simultaneous rather than sequential. The long display time would facilitate verbal rehearsal in the recodable condition, so increasing group differences. The simultaneous format would reduce the role of sequential processing in the reading disabled group, so decreasing possible group differences. Poor readers had more difficulty with both tasks in this study, but the significant difference between the groups was in use of a phonological memory strategy for the visual material.

The results reported by Katz et al (1981) are similar to those reported by Swanson (1986), but the interpretation is a little different. Swanson used the same visual stimuli in his named and unnamed conditions. In the named condition, participants were taught to associate names with the geometric shapes prior to the recall test. Swanson was able to make a more meaningful comparison between the two types of memory trial, and found that the use of labels facilitated recall in the skilled readers, and may have obstructed it in learning disabled readers. His conclusions concerned cross modal (integrative) processing deficits, rather than just phonological deficits.

However, neither of these reports included a test of phonological memory. Had a phonological sequential memory test been included, it would have been clearer whether phonological memory was really the main difference between the groups, or only one of the differences. It would have allowed the researchers to draw some conclusions as to how much of the observed cross-modal deficit was attributable to deficient verbal encoding.

Senf and Freundl (1971) studied cross modal memory span for auditory and visual digit strings in normal and disabled readers. Group differences in order memory were found. The largest group difference occurred when auditory and visual stimuli were alternated, and the children were asked to first report all the stimuli in one modality and then in the other. Senf and Freundl suggest that auditory material may interfere with the reception of the visual items. Verbal coding is the natural strategy choice in immediate recall (Bahrick & Bahrick, 1971;

Bartlett, Till & Levy, 1980; Schooler & Engstler-Schooler, 1990), and for verbal responses (Schooler & Engstler-Schooler, 1990).

Memory scanning speed was measured in study of auditory and visual sequential recall of letter strings (Farnham-Diggory & Gregg, 1975). Poor readers in this study showed more variable memory span scores, a result of deteriorating performance over time. For good readers, the decrement over time was reversed with a switch of presentation modality. This did not happen with the low reading group. Additionally, over time the auditory and visual memory scanning rate of good readers remained synchronous. For disabled readers, auditory scanning speed decreased over time, gradually lagging relative to visual retrieval. The difference in verbal and visual memory scanning rates over time offers a possible mechanism for interference effects.

Some findings concerning visual memory and reading disability suggest that observed reading-related visual decrements really reflect differences in the phonological encoding of the visual stimuli. Observed reading related visual differences may represent verbal rather than visual deficits (Hulme, 1988; Katz, Shankweiler & Liberman, 1981; McDougall, Hulme, Ellis & Monk, 1984; Swanson, 1983, 1984, 1986; Torgesen & Murphey, 1990; Vellutino & Scanlon, 1981). Alternatively, integrative memory deficits may exist in reading disabled individuals independent of visual and phonological memory (Swanson, 1986). Integrative impairments may also be the result of impairments in both visual and auditory processing functions (Farmer & Klein, 1995).

Phonological Memory Span

Researchers have used Baddeley's model of working memory (Baddeley & Hitch, 1974; Baddeley, 1986) to demonstrate phonological encoding of verbal material in memory (Gathercole & Baddeley, 1991). Connections between various aspects of phonological memory and reading have been extensively described. Verbal/phonological short term memory and working memory deficits specific to language processing have been a focus of current basic research in reading disability. Some authors have named phonological deficits as the central cause of reading disability. Reduced phonological awareness and phonological synthesis skills (Torgesen, Wagner & Rashotte, 1994), indicated by non-word repetition and non-word reading (Baddeley, Ellis, Miles & Lewis, 1982; Baddeley, Logie & Ellis, 1988; Gathercole & Adams, 1993; Gathercole & Baddeley, 1989,1993; Gathercole, Willis & Baddeley, 1991; Siegel & Heaven, 1986; Siegel & Ryan, 1988; Slaghuis, Lovegrove & Davidson, 1993) and phoneme deletion performance (McDougall, Hulme, Ellis & Monk, 1994), have been demonstrated in reading disabled populations.

Lower articulation rates (associated with reduced cumulative rehearsal capabilities) have been documented in children with reading disabilities (Hulme & Mackenzie, 1992; Hulme & Tordoff, 1989). Lower articulation rates have been related to memory span (Case, Kurland & Goldberg, 1982; Cohen & Heath, 1990; Hitch & McAuley, 1991; Hulme & Tordoff, 1989; McDougall, Hulme, Ellis & Monk, 1994). Differential effects of articulatory suppression, phonetic complexity and confusability (Hulme & Tordoff, 1989; Mark, Shankweiler, Liberman, & Fowler, 1977; Siegel & Ryan, 1988), word length effects (Hitch, Halliday, Dodd & Littler, 1989; Hitch, Halliday & Littler, 1989), naming tasks (Gathercole & Baddeley, 1990; Katz, Shankweiler & Liberman, 1981; Swanson, 1986; Torgesen, Wagner & Rashotte, 1994; Torgesen & Houck, 1980), letter matching tasks (Baddeley, Logie, Nimmo-Smith & Brereton, 1985), word span tasks (Gathercole & Adams, 1993), and homophony (Baddeley, Ellis, Miles & Lewis, 1982; Baddeley, Logie, Nimmo-Smith & Brereton, 1985) were shown in younger subjects and subjects with low reading skills relative to those with high reading skills. Phonological memory skills are positively correlated with single word reading, reading comprehension, and vocabulary acquisition (Gathercole & Baddeley, 1990; Gathercole, Willis & Baddeley, 1991).

The existence of phonological encoding deficits in individuals with reading disability has been demonstrated in many studies (e.g. Baddeley, Logie & Ellis, 1988; Gathercole & Adams, 1993; Gathercole & Baddeley, 1989, 1990; Gathercole, Willis & Baddeley, 1991; Katz, Shankweiler & Liberman, 1981; Mark, Shankweiler, Liberman & Fowler, 1977; Stanovich, 1988; Torgesen & Morgan, 1990; Shankweiler and Crain, 1986; Stanovich, 1986, 1988; Torgesen, Wagner & Rashotte, 1994; Torgesen, Wagner, Simmons, & Laughon, 1990; Vellutino and Scanlon, 1982; Vellutino, Steger, Harding, & Philips, 1975). At the time when children are acquiring knowledge of letter-sound correspondences, phonological memory processes are considered particularly critical (Gathercole & Baddeley, 1990; Torgesen, Wagner, Simmons, & Laughon, 1990; Torgesen, Wagner & Rashotte, 1994). Phonological memory has been shown to play a central role in natural vocabulary acquisition, and in tasks requiring learning of new names (Gathercole & Baddeley, 1990, 1991; Papagno & Vallar, 1992).

Baddeley's model of working memory (Baddeley, 1986; Baddeley & Hitch, 1974) has been used as the theoretical basis of many studies of phonological encoding of verbal material in memory (Baddeley, 1986; Gathercole & Baddeley, 1993). The phonological loop of verbal short term memory (STM) is used to explain connections between various aspects of phonological memory and reading. There are two components of the loop (Baddeley, 1986; Gathercole & Baddeley, 1993; Vallar & Baddeley, 1982). One is a phonological store, in which verbal material is represented in a phonological code. Verbal traces decay from the store in about 1.5 to 1.9 seconds in the absence of active maintenance rehearsal (Baddeley & Hitch, 1974; Baddeley, Lewis & Vallar, 1984; Hulme & Mackenzie, 1992). An articulatory control process specialized for maintenance rehearsal of verbal material is the second component of the phonological loop. Spoken language gains obligatory access to the phonological store. For visual information, the articulatory mechanism is required if verbal encoding is to take place (Baddeley, Lewis & Vallar, 1984; Baddeley, Papagno & Vallar, 1988; Baddeley & Wilson, 1988; Salame & Baddeley, 1982). The rehearsal process verbally encodes visual information into the store (Baddeley, 1986; Vallar & Baddeley, 1982), and supports maintenance of verbal material. Verbal memory span is related to speech rate, which is related to the speed at which a subject can subvocally articulate (McDougall, Ellis, Hulme, & Monk, 1994).

Research concerning the relationship of phonological memory to reading ability offers particular support for interest in sequential memory - memory for sequences of auditory or verbal stimuli (Morrison and Manis, 1982; Torgesen, 1979). Differences between skilled and dyslexic readers in phonological sequential span have been documented (Gathercole & Adams, 1993; Gathercole and Baddeley, 1989, 1990; Gathercole, Willis, & Baddeley, 1991; Martin, 1982; Stanovich, 1988; Torgesen, 1979; Torgesen, Wagner, & Rashotte, 1994; Torgesen, Wagner, Simmons, & Laughon, 1990). Studies of verbal serial memory have used sentences, words, non-words, digit strings, and letter strings to demonstrate reading related effects. A variety of experimental tasks produced significant differences in verbal sequential memory associated with reading ability.

One investigation of sequential memory for random digit strings in normal and dyslexic boys supported both the reading related phonological memory deficit, and the strength of immediate visual memory (Spring & Capps, 1974). These authors used probed recall of sequentially presented digits on briefly exposed cards in a series of eight. The score for each serial position was the number of correct responses to a probe for a card in that position. Participants were observed for visible evidence of verbal rehearsal (e.g. eye and lip movements). A relatively rapid presentation rate was used for the serial recall task (1.5 second per digit). Memory performance of dyslexic children on digit span was significantly below that of normal readers for all but the last few serial positions. Comparison of the curves therefore suggests that temporary storage of the digits did not differentiate the groups, but the effectiveness of verbal memory strategies did.

Measures of naming speed for numbers, colors and pictures were compared in the reading disabled and control groups (Spring & Capps, 1974). Eye movements of the participants were recorded, and those that scanned the stimulus array from left to right were classified as "scanners." This is assumed to be evidence for use of phonological rehearsal as a memory strategy. Those that did not were classified "non-scanners." The normal reading group contained one non-scanner, while 11 of 24 dyslexic children were non-scanners. No primacy effect was observed for dyslexic non-scanners, supporting the conclusion that cumulative rehearsal was not used, or not used effectively, by these children. Scanners recalled more in primacy and middle positions, but less in recency positions, and this effect was significant. Possibly the non-scanners rely more heavily on echoic (temporary) storage, reflected by recency recall.

Naming speed scores were analyzed by reading ability, by type of stimulus material, and in comparison to sequential memory measures. Performance on colors and pictures was slower than performance with digits in both groups, with a larger difference between dyslexic and normal subjects on digit-naming than on speed of naming colors and pictures. Significant correlations between memory and naming speed measures were obtained. A naming speed of one item per second was shown to separate scanners from non-scanners with 88% accuracy (Spring & Capps, 1974). This complex finding points to reciprocal interactions between lexical access, lower level cognitive processes (speech rate, verbal rehearsal), and reading. The suggestion is that when children have acquired naming capability at an appropriate rate, they will then learn verbal rehearsal strategies, which will replace visual ones. Spring and Capps (1974) claimed that naming speed and use of cumulative rehearsal accounted for 91% of the true variance of early and middle serial positions of the probed recall task. (Spring & Capps, 1974).

Several studies have documented processing rate differences between good readers and those with reading disabilities (Farnham-Diggory & Gregg, 1975; Lovegrove & Brown, 1978; McDougall, et al, 1994; Farmer & Klein, 1995). If slow processing characterizes subjects with reading disabilities, their memory for sequences could be particularly constrained by the rate of presentation and the length of the sequence. Phonological sequential memory paradigms would, therefore, have especially high discriminative power for reading ability groups.

In order to assess the interaction of stimulus type and reading ability, sequential memory for strings of animal names, non-meaningful syllables, and digits were compared (Torgesen & Houck, 1980). The performances of three reading ability groups did not differ significantly for the syllables, but there were large differences for words, and even larger differences for digits. Reading disabled children, both those with and without short term memory deficits, were slower than normal readers in naming of animals and digits (Torgesen & Houck, 1980). Possibly slow retrieval of name codes may account for some of the impairment in sequential memory in reading disabled children.

Differential effects of stimulus type were documented in a study of retention of verbal material and non-verbal rhythmic patterns in normal and poor readers (Richie & Aten, 1976). Participants indicated their retention of the presented patterns by pointing to a visual illustration corresponding to the auditory stimulus.

This task was significantly more difficult for the disabled readers. Serial memory for phonemes, words, and sentences was also measured in the two reading groups. Memory for phonemes and sentences differentiated the reading groups; memory for words did not, an observation which was attributed to familiarity with the words used. The measure which best differentiated the reading groups reflected the ability to retain sequences of phonemically similar words which differed by initial or final consonants. In the reading disability group, this ability was significantly correlated to scores on retention of auditory rhythmic sequences. Richie & Aten, (1976) conclude that retaining phonemes is in some way constrained by the ability to perceive temporal auditory patterns. The phonological loop, which supports phonological encoding of verbal material, may also support general auditory retention, as of sounds and music (Baddeley & Logie, 1991). Baddeley's model provides a common mechanism for auditory memory tasks that can explain associations between diverse findings.

Verbal sequential memory may be influenced by strategic behaviors under conscious control and amenable to training, but may also be dependent on structural limitations of an individual's cognitive processes. The possibility that reading disabled children were impaired in strategic components of memory was evaluated in a series of experiments (Torgesen & Houck, 1980). Stability of digit span scores in disabled readers over time suggested structural limitations. Rapid presentation (4 per second) and retroactive interference, which interferes with rehearsal, did not remove reading group differences in recall. This suggests that superior rehearsal strategies in the control group were not the main difference between the groups.

An experimental intervention which promotes chunking resulted in superior recall, but there was no interaction with reading group (Torgesen & Houck, 1980). Chunking is another memory strategy, and apparently it is also not the main distinguishing feature of the reading ability groups. These experiments support the idea that reading ability groups are defined by structural limitations of memory, rather than conscious strategic behaviors. Associations between naming speed, articulation rate, memory span and reading have been documented (Hulme & Mackenzie, 1992; Hulme & Tordoff, 1989; McDougall, Hulme, Ellis & Monk, 1994). These associations offer further support for the idea of structural limitations.

A further experiment examining structural limitations attempted to differentiate processing speed from memory (Torgesen & Houck, 1980). Supraspan digit lists were presented for coding (as high or low) to all participants, who were then asked to recall as many of the digits as possible. The children in the comparison group and both reading disability groups were able to recognize and process rapidly presented digits, but reading disabled children were not able to encode them for later recall. The authors suggest that phonological deficits operate at the encoding rather than perception stage. Processing speed did not differentiate the groups.

Slow presentation rate was shown to interact with reading ability (Torgesen & Houck, 1980), further supporting the concept of encoding deficits. Performance of reading disabled groups with and without short-term memory impairments decreased significantly as auditory presentations rate slowed from 1 digit per second to 1 digit per 2 seconds, while performance of the normal group remained stable (Torgesen & Houck, 1980). Verbal traces are believed to decay from the phonological store in about 1.5 to 1.9 seconds in the absence of active maintenance rehearsal, so the pacing reduction described represents a change from echoic to phonological memory (Baddeley & Hitch, 1974; Baddeley, Lewis & Vallar, 1984; Hulme & McKenzie, 1992). This auditory paradigm showed greater performance decrements in the disabled group with slower pacing, consistent with the idea of adequate temporary storage and phonological encoding deficits. This result would be consistent with the idea of a strategic deficit in phonological rehearsal.

Empirical support for the idea of strategic differences in subvocal rehearsal between reading groups was provided in several studies investigating recall of auditory letter strings in normal and poor readers (Shankweiler, Liberman, Mark, Fowler & Fischer, 1979; Siegel & Ryan, 1989). The effect of phonetic confusability was assessed with auditory presentation of sets of rhyming and non-rhyming consonants. Phonetic confusability is assumed to impair phonological rehearsal. Superior readers made fewer errors with both item types in the study by Shankweiler et al. (1979). The difference between reading groups was significantly greater for non-confusable items than for confusable sets, as indicated by a reading group x item type interaction. This finding suggests that the main difference between the reading groups was in use of rehearsal, which is impaired by the phonetic confusability. In Siegel and Ryan's (1989) research, reading disabled children had significantly higher scores on rhyming letters, suggesting possible use of a different memory strategy, not involving phonological rehearsal.

A longitudinal study of phonetic confusability and reading ability offers further support for strategic differences in rehearsal (Mann & Liberman, 1984). In a serial span test for word strings, better readers generally made fewer recall errors, but phonological similarity reduced the difference between the groups. Better readers were more penalized by the similarity, possibly reflecting greater reliance on phonological encoding. It was concluded that observed patterns reflect a deficiency in poor readers' use of a phonetic code - that poor readers have difficulty accessing or using a phonetic representation of the stimulus. Kindergarten children who made most errors had most difficulty with reading in first grade. This suggests, although it does not prove, a causal relationship between the phonological memory skills reflected by the phonological similarity effect and reading acquisition.

Although demonstration of reading skill related differences in phonological similarity effects suggests that cumulative rehearsal processes may differentiate normal and disabled readers, conflicting evidence was also reported (Shankweiler, Liberman, Mark, Fowler & Fischer, 1979). Serial position curves for both reading groups had the characteristic bow shape, with strong recency effects and less pronounced primacy effects. Existence of primacy effects in the serial position curves suggests that subvocal rehearsal is taking place. Since the shape of curves does not differ greatly by reading group, rehearsal processes seem to play similar roles in the memory strategies of both groups. The strategy is clearly less effective in disabled readers (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979).

A study of non-word repetition ability demonstrated partial support for impaired phonological rehearsal in low, relative to high, reading groups (Gathercole & Baddeley, 1989). Sensitivity to phonological similarity and word length in word lists in the low reading group indicates that these subjects do subvocally rehearse. For lists of five or more items, this sensitivity disappeared in the low reading group, suggesting a shift in strategy (Gathercole & Baddeley, 1989).

The difference between skilled and disabled readers with respect to phonological similarity was eliminated in a study that adjusted word lists to individual span scores (Johnson, Rugg, & Scott, 1987). When the lists used for the poor readers corresponded to measured memory span, this group *was* susceptible to impairment due to phonological similarity. Possibly children with reading disabilities do rehearse, but with a qualitative difference in their rehearsal processes. In another study, reading disabled children did not show sensitivity to the phonological similarity effect until age 10 for short exposure times and age 8 for longer times (Siegel and Ryan, 1988). This suggests that reading disabled individuals do learn to use a phonological rehearsal strategy, albeit later than normal readers and not as effectively.

Significant interactions between reading ability group and the length of the delay interval between phonetically confusable stimulus presentation and recall support the idea of group differences in rehearsal (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). The longer delay selectively impaired performance of the superior readers. Errors in the use of phonetic coding related to phonological similarity seem to be magnified over time. So delay benefits good readers, who can use it to rehearse, except where phonetic similarity is present. For skilled readers, the phonetic confusion is increased by rehearsal, resulting in impaired performance.

One study attempted to determine the extent to which verbal memory deficits and strategic differences determined performance on serial recall of letters in grade 2 and grade 6 children (Huba & Vellutino, 1990). Verbal retroactive interference (controlled verbalizing following offset of the stimuli to prevent subvocal rehearsal) was incorporated by the requirement to orally shadow auditory letter strings. The retroactive interference disrupts phonological encoding. Normal readers were significantly less accurate than poor readers in auditory recall with the retroactive interference, especially at the younger age level. It can be inferred from these findings that the generally superior performance of good readers on verbal serial memory tasks is dependent on control processes disrupted by retroactive interference.

It also appears that reading disabled children compensate for deficient control processes by adopting other recall strategies. The non-verbal strategy used by individuals in the reading disabled group was clearly a particular strength for them. This strategy may be used because it is a strength, or as a compensatory mechanism to circumvent other deficits. Research strongly supports the conclusion that impairment of verbal short term memory distinguishes reading disabled children.

Rationale for the Experimental Hypotheses

Knowledge of letter-sound correspondences is the basis of decoding, an essential skill for beginning readers. Children with dyslexia often experience extreme difficulty in learning the letter-sound correspondences constituting basic decoding skills despite normal speech functions (Orton, 1925-1946; Fernald, 1943; Snowling, 1980; Spalding & Spalding, 1986). Although there is evidence that deficits in phonological processing (of letter sounds) and visual processing (of letter or word forms) may constrain learning of symbol-sound associations (associative memory) (Eden, Stein, Wood & Wood, 1995; Lovegrove, Billing & Slaghuis , 1978; Mauer & Kamhi, 1996), the relative impact of the two types of deficit on this particular task is not clear. Claims have been made that dyslexic children do have visual deficits (DiLollo, Hanson & McIntyre, 1983; Eden, Stein, Wood & Wood, 1995; Enns, Bryson & Roes, 1995; Farmer & Klein, 1995; Lovegrove, Billing & Slaghuis , 1978; Mauer & Kamhi, 1996), that they do not have visual deficits (Vellutino & Scanlon, 1986), and that they may even have particular visual strengths (Siegel, Share & Geva, 1995).

Additionally, specific difficulties with associative memory have been reported in children with reading disabilities (Birch & Belmont, 1964; Ceci, Lea, & Ringstrom, 1980; Morrison & Manis, 1980; Swanson, 1983, 1984, 1986; Torgesen, 1979; Vellutino, Steger, Harding, & Philips, 1975; Vellutino & Scanlon, 1979 for a review). For skilled readers, a verbal label for a visual image (e.g. a sound associated with an image) will improve recall of the image ("additivity," Paivio 1981, 1986). For reading disabled subjects, verbal labels may not facilitate, and may in fact reduce image recall (Swanson, 1983; 1986). This has been attributed to associative memory deficits specifically, but also to verbal requirements of the associative tasks. The phonological, visual, and associative perception and memory deficits that have been demonstrated in reading disabled populations have each been credited with a causal role in the genesis of reading disability. This research concerns the contributions of visual and verbal memory deficits to learning of letter-sound correspondences and to reading in children with dyslexia. It is designed to clarify some of the historical controversies in the context of remediation of dyslexic students.

Six hypotheses were tested in this study. The primary hypothesis was that, in comparison to children with normal reading skills, children with reading disabilities have deficits in visual memory for novel pseudoletter forms as well as in phonological memory for novel pseudoletter names. The second hypothesis was that scores on visual and phonological memory span would be positively associated with reading scores. The third hypothesis was that children with reading disabilities have deficits in memory span for newly learned sound-symbol associations in comparison with normal readers. The fourth hypothesis was that both visual and phonological memory spans would be positively correlated with memory span for newly learned sound-symbol correspondences in both normal and dyslexic readers. The fifth hypothesis was that learning names for symbols would increase memory span for the symbols in normal readers, but not in children with reading disabilities. The sixth hypothesis was that, in comparison to children with normal reading skills, children with reading disabilities would show lower recall of items at the beginning of visual and phonological sequences, but similar recall of items at the end of sequences.

Differences between reading ability groups were analyzed with t-tests comparing the group memory test scores when the groups were matched on age. Group memory scores were also compared using ANCOVA with age as a covariate when the groups were matched on reading ability, so that a significant age difference existed between the groups. The relationship of memory scores to word and pseudoword reading scores and to performance on the sound-symbol task was assessed with correlation analysis, controlling for age. Repeated measures 2-way ANOVA was used to assess the effects of the training on phonological and visual memory, and to identify differential effects related to reading ability. Serial position curves were compared with t-tests of scores at individual serial positions, and with 2-way repeated measures ANOVA and ANCOVA (controlling for age) of the relative performance at one serial position in comparison to another.

Three experimental tasks and a training intervention were used. The first two experimental tasks tested memory span for unfamiliar syllables ("nonwords") and shapes ("invented letters"). The third task was sequential recall of newly learned associations between symbols and sounds. These tasks were chosen because they resemble the type of learning that occurs in a beginning remedial phonics instruction program. Memory span tasks were used to reveal differences between normal and disabled readers related to stimulus modality (phonological vs. visual), serial position effects, the effect of naming on memory, and the degree of stimulus novelty. The objectives were to determine whether children with reading disabilities have more difficulty with the tasks than the normal readers, whether the difficulty was related to reading, and whether their performance on the memory measures revealed strategic differences.

Hypotheses

Assumptions and Definitions:

1) Verbal information is stored in phonological form in memory (Baddeley, 1986).

2) Definition - Sequential memory is short term memory for a series of stimuli, in the order in which they were presented. It includes memory for the items of the list, and memory for their order. Children with reading disabilities may have specific difficulties in this area for all types of stimuli (Torgesen, 1979).

3) Definition - Cross modal memory refers here to the ability to translate visual information into phonological form, or vice versa. In skilled readers, verbal and visual codes combine in an "additive" manner to facilitate semantic processing. This may not occur in disabled readers (Swanson, 1983, 1986).

Hypotheses as questions:

1) Do children with reading disabilities have deficits in phonological or visual relative to chronologically and reading age matched children with normal reading skills?

2) Are scores on the measures of phonological and/or visual memory significantly associated with reading skills in children with reading disabilities or in chronologically and reading age matched children with normal reading skills?

3) Do children with reading disabilities have deficits in memory span for symbol-sound correspondences relative to chronologically and reading age matched children with normal reading skills?

4) In children with reading disabilities, are deficits in memory span for symbol-sound correspondences related to visual or phonological memory spans?

5a) Do learned sound-symbol associations increase visual and phonological memory spans for the sounds or the symbols (facilitative effect of labeling)?

5b) If the influence of sound-symbol training different for reading disabled children and either control group?

6) Are serial position curves for visual and phonological spans significantly different for children with reading disabilities and normally reading chronologically and reading age matched comparison groups?

The Experimental Tasks - Rationale

In order to evaluate the short term memory systems both separately and in combination in the context of beginning decoding skills, it was necessary to devise an combined task which had separable purely visual and verbal components, and which closely resembled beginning reading acquisition. Sequential span tests were appropriate for several reasons. Differences between disabled and good readers on verbal, visual and cross modal sequential span tasks have been demonstrated in other studies (Farmer & Klein, 1995; Klein & Farmer, 1995; Torgesen, 1979). Studies of serial memory for letter and digit strings have consistently shown impairment among reading disabled subjects (Farnham-Diggory & Gregg, 1975; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979; Siegel & Linder, 1984; Siegel & Ryan, 1988; Spring & Capps, 1974).

Deficits in visual sequential memory in poor readers were documented by Senf and Freundl (1971), Noelker and Schumsky (1973), and Morrison, Giordani and Nagy (1977). Researchers have suggested that visible persistence may interfere with sequential processing of text (Di Lollo, Hanson, & McIntyre, 1983; Eden, Stein, Wood & Wood, 1995; Lovegrove, Billing & Slaghuis, 1978; Lovegrove & Brown, 1978; Lovegrove, Heddle & Slaghuis, 1980; Slaghuis, Lovegrove & Davidson, 1993). Reading group differences in cross modal serial span were found by Swanson (1983, 1984), and Katz, Shankweiler and Liberman (1981).

Assessment of memory span for names and forms of invented letters, as an experimental paradigm, allowed quantitative measurement of verbal, visual, and cross modal components of a single task related to beginning decoding skills. Data from the label training test helped to clarify processes involved in learning letter sound correspondences in disabled readers. By testing memory for the sounds, forms, and associations, it was possible to draw some conclusions about the degree to which children with learning disabilities have difficulty with the forms (visual memory), the sounds (phonological memory), and the association between the two. Tests of iconic memory were included to assess the possibility that dyslexic children have particular strengths in certain types of visual memory.

Non-Word Repetition Measures

A non-word repetition test was used to measure phonological sequential memory in comparison and reading disabled subjects. Non-word repetition tests are able to capture (although not separate) both perceptual and encoding aspects of phonological memory (Farmer & Klein, 1995). Non-word repetition and non-word reading measures have effectively discriminated subjects by reading ability in several studies (Gathercole & Adams, 1993; Gathercole & Baddeley, 1989, 1990; Gathercole, Willis & Baddeley, 1991; Martin, 1982; Perfetti and Hogaboam, 1975; Stanovich, 1988). Research with older children demonstrated non-word repetition deficits of four years below the subjects' chronological ages (Gathercole & Baddeley, 1990). Repetition ability in learning disabled children was significantly below both normal controls matched for chronological age and younger reading level matched controls. Use of the reading level matches showed that poor non-word repetition ability was not tied to reading level specifically, but rather contributed separate variance to language development (Gathercole & Baddeley, 1990).

Non-word repetition scores have been shown to have temporal stability as well as predictive utility (Gathercole & Adams, 1993; Gathercole & Baddeley, 1989). In a longitudinal study of the relationship between phonological memory and vocabulary development, Gathercole and Baddeley (1989) found that non-word repetition provided a predictive indicator of future verbal skills such as vocabulary. At ages 4, 5 and 6, mean repetition scores in the low repetition ability group were lower than those in the high repetition ability group, indicating reasonable reliability and stability of the measure (Gathercole & Baddeley, 1989).

Use of phonological memory measures was investigated in children at 2 and 3 years of age (Gathercole & Adams, 1993). Phonological memory assessment using non-word repetition measures was shown to be practicable in preschoolers, and to have diagnostic and predictive value in early detection of language disorders. There is evidence of temporal stability of scores on serial naming and memory measures (Torgesen, Wagner & Rashotte, 1994). Correlations between scores on these measures in kindergarten and first grade were .87 and .81 respectively. Correlations between scores in kindergarten and second grade for the same measures were .66 and .62 respectively. Phonological skills seem to be fairly stable during the early school years.

Gathercole and Baddeley (1989) suggested that non-word repetition tasks might be too easy for older children and adults; that this might be a limitation of the measure (Gathercole, Willis, & Baddeley, 1991). However, work with older children with reading disabilities also endorsed use of the non-word measure. Support for the use of a non-word naming test with older subjects is derived from a study that explored intercorrelations of a wide range of linguistic measures (Stanovich, 1988). Pseudoword naming scores were found to be among the best predictors of performance on the Metropolitan Reading Survey Test in third and seventh graders (Slaghuis, Lovegrove & Davidson, 1993). Significant Pearson r correlations between non-word repetition scores and reading rate, accuracy, and comprehension have been found. (Eden, Stein, Wood & Wood, 1995)

Nonword repetition tasks have been described as, "...an indicator of phonological recoding ability and potent predictor of reading ability at all levels." (Stanovich, 1988, page 593). Researchers working with these tests stated, "In our view, the non-word repetition measure is likely to provide a particularly sensitive test of the capacity of young children to maintain phonological material in the articulatory loop components of working memory," (Gathercole, Willis, & Baddeley, 1991, page 388), and "Tests of phonological awareness are among the best predictors of children's progress in learning to read and typically account for large amounts of variance in reading skills." (McDougall, Hulme, Ellis, & Monk, 1994, page 112)

Choice of a non-word repetition measure was partially based on its success in other research, but was also intended to reduce the influence of some potential confounds. Several studies of phonological sequential memory have used strings of words, letters and digits as target stimuli. However, memory for words certainly could be influenced by previous experience and personal associations to those words (Perfetti & Hogaboam, 1975). Additionally, in comparison of skilled readers and reading disabled subjects, familiarity with letter names could influence memory. Since children with reading disability often have problems with arithmetic as well, memory for digit strings could also be influenced by the disability. Use of non-words reduced the association value of target stimuli, hopefully reducing or eliminating some of the potential systematic confounds.

Use of a sequential memory paradigm for the non-words is supported by investigation of the relationship between non-word repetition scores and word length (Gathercole & Baddeley, 1990). Differences between reading ability groups were greatest for three and four syllable non-words. The groups did not differ on one and two syllable non-words. An auditory string of single syllable non-words is essentially the same as a multisyllabic non-word. It follows that, for children in the 4 to 5 year age group, strings of at least four non-words may be needed to discriminate subjects by reading ability. Longer strings were used in the proposed study, for children whose ages ranged from 9 to 12 years. A sequential memory format allowed assessment of the maximum capabilities of subjects. In a longitudinal study of phonological skills and reading, analytical phonological awareness and serial naming emerged as two of the most powerful predictors of subsequent reading (Torgesen, Wagner, and Rashotte, 1994).

In summary, non-word repetition measures were appropriate for this work for several reasons. They were effective in discriminating subjects by reading ability across the elementary school age range. They offered a relatively pure measure of phonological memory, uncomplicated by most potential confounds. Both serial naming and memory measures have demonstrated temporal stability at least in the early school years. Phonological awareness tests are powerful predictors of future reading ability. Lastly, they offered a sequential memory measure which parallels intended work on visual and cross modal sequential memory.

Visual Memory Measures

Sequential memory for the forms of invented letters is a task that circumvents some complications evident in other studies. Invented letters were similar to real letters, so that the requirement to remember them resembled early decoding instruction. Since the letters, before the label training intervention, were unfamiliar abstract stimuli, confounding effects of prior exposure were avoided. Invented letters were designed with a degree of abstraction that minimized chances for verbal encoding. Additionally, the names that were assigned to the letter forms resembled real alphabetic names, and were used for the phonological sequential memory test. Visual sequential memory for invented letters was used as an experimental task because, based on past research, it was likely to discriminate disabled readers, and it is relevant to beginning reading instruction, requiring processes involved in the mastery of letter sound correspondences. A test of visual iconic memory was included, to assess the possibility that dyslexic children might have a particular strength in this area.

Cross Modal Memory Span

Teaching the participants to form new associations between novel sounds and symbols also helped to remove confounding influences of prior exposure. Use of this test is theoretically based on Paivio's (1971) dual code theory, and revealed reading related effects on the additivity of the verbal and visual codes.

This procedure allowed a test of Swanson's hypothesis that reading disabled children are substantially disrupted by use of labels, as verbal and visual codes do not combine referentially for them.

CHAPTER 3: METHOD

Participants

Thirty-one students from Kenneth Gordon School (ages 8 years 1 month to 13 years 1 month) and thirty-one students from Pacific Academy (ages 6 years 9 months to 12 years 5 months) were tested (Table 1). The Kenneth Gordon students had histories of severe reading disabilities. Some of the students who entered Kenneth Gordon School with a history of reading disability as defined in this study, after a year or more of intensive remedial language training, scored sufficiently high on the WRAT 3 Word Reading subtest (WRAT 3, Wilkinson, 1993) and the Woodcock Reading Mastery Test Word Attack subtest (WRMT -R, Woodcock, 1987) so that they were classified as "compensated dyslexics." This is a novel distinction; it has no precedent in the literature concerning dyslexia. In this study, it was serendipitous, as it allowed observation of differences in basic cognitive skills in the two groups.

The dyslexics had WRAT 3 Word Reading subtest or Woodcock Reading Mastery Test - Revised Word Attack Subtest pseudoword reading scores at or below the 26th percentile. The wide range of scores on the WRAT 3 in the dyslexic group is attributed to differences in the amount of time spent in the remedial program, and the use of non-phonetic sight reading strategies for some high frequency words. The compensated dyslexics had Wide Range Achievement Test Word Reading Subtest scores and Woodcock Reading Mastery Test - Revised Word Attack Subtest scores at or above the 26th percentile, but had entered the remedial language program with measured reading scores below this level. Comparison participants had scores on both reading tests at or above the 35th percentile, and no history of reading disability. All subjects had IQ scores in the average range or above (80 or higher), as indicated in their current psychoeducational test records or measured by the Slosson Intelligence Test (Slosson, 1981).

Each dyslexic participant, and each compensated dyslexic participant, was assigned a specific age and a specific reading level match (matched for raw score on the WRAT) from among the normal readers. Hence, there were six groups: 1) dyslexic, 2) dyslexic age control, 3) dyslexic reading level control, 4) compensated dyslexic, 5) compensated dyslexic age control, and 6) compensated dyslexic reading level control (Table 1). Due to small numbers of students tested, some normal readers were used as both reading level matches and age matches. For the dyslexic children, there are two students in both the age control group and the dyslexic reading level control group. For the compensated dyslexic children, there are eight students in both the age control group and the reading level control group.

Students with documented attentional and behavioral problems, and those whose IQ's are below 80, as determined by testing with the Slosson Intelligence Test (Slosson, 1981), are not included in any group. Information concerning behavioral and attentional problems was obtained from classroom teachers and school records. No children with obvious visual or auditory impairments are included in any group.

The children with a history of reading disabilities that participated in this research have all been enrolled in a "multisensory" remedial phonics program for periods ranging from 1 to 4 years. In this program, the children learn phonics in a highly structured format, based on the writings of Gillingham and Stillman (1956). The program is multisensory in the sense that:

> ...our technique is based upon the close association of visual, auditory and kinesthetic elements... Each new phonogram is taught by the following processes, which are referred to as linkages and involve the association between visual (V), auditory (A) and kinesthetic (K) records to the brain. (Gillingham & Stillman, 1956, page 40).

Some of the children entered the program with pre-reading level skills, and have subsequently learned to read. This made it possible to compare the reading and memory skills of dyslexics and compensated dyslexics. It is not possible to attribute differences between these two groups to the training program specifically, as a longitudinal study was not conducted. It is possible to compare the memory profiles of dyslexics and recovered dyslexics, and to draw some tentative conclusions about how these groups differ, and how remediation may work.

Table 1 - Comparison of six reading groups: Number, mean scores, (ranges), distribution, mean scores, [standard deviations].

	Number	Mean Age (Age range)	Mean Grade (Grade range)	Gender	WRAT %ile	Woodcock %ile
Dyslexic	12	10.70 (8.60 - 13.10)	4.58 (1 - 7)	4 female 8 male	23.58 [20.17] (2.0 - 63.0)	24.58 [14.93] (4.0 - 60.0)
Normal readers (age match for dyslexics)	12	10.72 (8.10 - 12.50)	4.50 (2 - 6)	9 female 3 male	94.76 [6.56] (81.0 - 99.6)	82.17 [16.62] (44.0 - 98.0)
Normal readers (reading level match for dyslexic)	12	8.10 (6.10 - 10.30)	2.00 (1 - 4)	10 female 2 male	72.42 [17.16] (37.0 - 99.0)	72.42 [17.16] (46.0 - 96.0)
Compensated dyslexic	19	10.76 (8.11 - 12.40)	5.21 (3 - 7)	11 female 8 male	75.74 [15.94] (50.0 - 98.0)	67.79 [15.13] (41.0 - 96.0)
Normal readers (age match for compensated dyslexic)	19	10.46 (8.80 - 12.50)	4.26 (3 - 6)	13 female 6 male	94.95 [6.76] (75.0 - 99.6)	81.89 [16.86] (44.0 - 99.0)
Normal readers (reading level match for compensated dyslexic)	19	8.81 (6.10 - 12.00)	2.79 (1 - 6)	12 female 7 male	92.47 [9.24] (70.0 - 99.98)	81.81 [17.78] (44.0 - 99.8)

Experimental Tasks

Phonological Memory Test

Stimuli and Apparatus

A test of phonological memory (PM) span was used to assess the relationship of phonological memory to reading. It is based on a non-word repetition measure described by Gathercole and Adams (1993) and Gathercole and Baddeley (1989). The PM test is a test of phonological coding ability, in which subjects hear increasing lists of pronounceable syllables, and must orally reproduce them. One hundred twelve single syllable pronounceable pseudowords were used for the pretest, and 10 of these were used for the posttest (Appendices 1 and 2)

Tapes and a tape recorder were required for this test. The tape recorder was used to play the prepared tape of pseudoword lists. One hundred and twelve pseudowords were used in the pretest. The memory span task consisted of arrangements of pseudowords into sequences of 1, 2, 3, 4, 5, 6, and 7 elements. List lengths began at one, and increased. There were four lists at each list length. The stimuli for the non-word tests were tape recorded, at a speed of 1 per second. At the end of each list, a pause in the recording gave the child up to 11 seconds to reproduce the list. A high tone played on a guitar string signaled the child to begin repeating the list.

The post test consisted of sequences constructed by random selection with replacement from the 10 pseudowords used in the training intervention. Pseudoword lists were in sequences of 1, 2, 3, 4, 5, 6, and 7 elements. List lengths began at one, and increased, with four lists at each list length.

Tasks

The participants heard the tape recorded pseudoword lists, and attempted to repeat them. The responses were recorded directly onto a prepared coding sheet. Scoring reflects the summed total number of phonemes (rather than entire non-words) repeated correctly in each list up to the list length at which the child could not repeat any of the sequences correctly. Total numbers of phonemes were counted instead of total numbers of pseudowords because some children were able to reproduce most of the sounds in lists of a specific length without being able to accurately reproduce any entire list at that length. In a few cases, a child was able to reproduce three of the four lists at a specific length with only one or two phonemes mispronounced per list. In this case, half of the total obtained for that list length was added to the score obtained on the earlier lists.

To assess serial position affects, a count of correct phonemes for beginning, middle, and end positions in the four pseudoword lists was also recorded for each child. The four element lists were chosen because all but two of the participants received some score for this list length, but only two had no errors at this length. The primacy score recorded is the total number of phonemes pronounced correctly divided by the total possible number (13) for the beginning pseudowords in each of the four lists. The recorded score for the middle position is the total of correctly pronounced phonemes in the second and third pseudowords in each of the four lists divided by the total possible (26). The recency score is the total of correctly pronounced phonemes divided by the possible total (13) in the end pseudowords in each of the four lists. Total scores and serial position curves for children with reading disabilities and for chronological age and reading age matched controls were compared.

Visual Memory Tests

Iconic Memory

Stimuli and Apparatus

This test used graphic displays on a computer monitor to assess iconic visual memory and reaction time. Thirty non-meaningful simple line drawings ("pseudoletters," Dixon and Twilley, 1988) were used as visual stimuli ("invented letter forms") in this test (Figure 1). The drawings were constructed to be as similar as possible to alphabetic characters. They were composed of arrangements of curves, and horizontal, vertical, and diagonal lines. Two-by-two grids of these pseudoletters were shown on a computer screen (Figure 2). Following presentation of each grid, a new grid was presented on the computer screen, which contained only a single probe character in one of the grid positions. The participant's task was to determine whether the probe character was contained in the previous sequence. The participant pressed keys on the computer keypad marked "There" and "Not there" to indicate presence or absence of the characters.

This test was presented on a MacIntosh LC III computer, using VScope software. Four of the visual stimuli were displayed in an array of two horizontal rows with 2 pseudo letters in each row in the center the computer screen. The positions of pseudoletters in the arrays were indicated by nine small colored squares forming a partial grid pattern (Figure 2). The array appeared on the computer screen for two seconds. Then the pseudoletters disappeared, but the grid of small squares remained. A single probe character appeared in one of the grid positions. A random seed function in the Vscope software ensured that the trials were presented in the same random order for each participant (Figure 3).

A felt cover was prepared for the keypad, to help prevent accidental incorrect responses. It covered all the keys except the ones to be used as response keys, and the return key and spacebar. These were the only keys needed during the trials. The keys to be used for responses were labeled "There" and "Not there". The cover fastens with Velcro, to allow easy to access to the entire keypad for entry of student information prior to the experimental trials.

The child's choices, and the correct choices, were recorded by the Vscope computer software in an internal data file. Latency scores were also recorded by the computer in this data file. This is the time elapsed from onset of the probe character to the child's keypress response. The data file was retrieved from VScope as a formatted file using Microsoft Word software, and transferred to a PC computer for analysis by SPSS software.

For the posttest, the four element arrays were constructed by selection from the 10 pseudoletters designated for the test. Post testing was also conducted in blocks of twenty trials each (Figures 3 and 4).

Tasks

The iconic memory test preceded the visual memory span test (described in the next section) for all children. Students were told, "You will see a four-box grid pattern on the computer screen with four 'invented letters' in it, one in each box. The invented letters are simple black line drawings. The grid will appear for a short time on the computer screen. Then the grid and the letters will disappear. Right away, a new four-box grid will appear, with a made-up letter in one of the boxes. All of the other boxes will be empty. Your job is to decide whether this letter is the same as the one that was in that position in the first grid. If it is, you have to press the 'There' key. If not, then press the 'Not there' key."

Students were allowed to practice the procedure for two trials before beginning the experimental block of trials, to ensure that they understood the procedure. The target array was displayed on the computer screen for 2 seconds. Immediately after offset of the display, the grid reappeared with a single probe character in it. Participants were asked to indicate whether the probe character was in that position in the original array by pressing the *present* or *not present* key. The participant's exact responses and response latency were recorded by the Vscope software. Participants had 8 seconds to respond. Then they initiated the next trial by pressing the spacebar. A block of twenty trials was used for each participant. The number of correct choices out of 20 trials was the score recorded.

Visual Memory Span

Stimuli and Apparatus

The visual span test is based on a visual span test used by Katz, Shankweiler, and Liberman (1981). Thirty non-meaningful simple line drawings ("pseudoletters," Dixon and Twilley, 1988) were used as visual stimuli ("invented letter forms") in this test. Sequences of these pseudoletters were shown on a computer screen at a speed of about 1 per second. Sequences began with three elements, and increased to six elements. Following presentation of each sequence, a colored probe character was presented. The participant's task was to determine whether the probe character was contained in the sequence. The participant pressed marked keys on the computer keypad to indicate presence or absence of the characters.

This test were presented on a MacIntosh LC III computer, using Vscope software. The stimuli for this memory span test consisted of a set of 30 line drawings or "pseudoletters." All 30 of these were used for the pretest, but only 10 for the posttest. The pseudoletters were drawn for the computer using MacPaint software.

Pseudoletters were arranged into sequences of 2, 4, and 6 elements (Figure 5). Elements in the sequences were paired, so that two pseudoletters appeared at a time, each pair appearing in the same location on the screen. Each trial consisted of a sequence, followed by a colored probe character. Each participant completed a block of twenty trials, randomly drawn from a set of 6 two element lists, 10 four element lists, and 6 six element lists. The trials actually presented to the subjects included 5 two element lists, 10 four element lists, and 5 six element lists for the both the pretest and posttest. The sequences for the pretest were composed by selection by random drawing without replacement from the set of 30 "invented letters". Sequences of pseudoletters were shown at a rate of 1 per second per pair. The paired pseudoletters appeared in the center of the monitor screen. A random seed function in the Vscope software ensured that the sequences were presented in the same random order for each participant.

The felt cover was again used for the keypad, to help prevent accidental incorrect responses. The child's exact choices, and the correct choices, were recorded by the Vscope computer software in an internal data file. Latency scores are also recorded by the computer in this data file. The data file was retrieved from VScope as a formatted file using Microsoft Word software, and transferred to a PC computer for analysis by SPSS software. The number of correct choices out of 20 trials was the score recorded.

For the posttest, the sequences were constructed by selection from the 10 pseudoletters designated for the test. Post testing was also in blocks of twenty trials each (Figures 5 and 6).

Tasks

The children were tested individually in two 40 minute sessions. Students were told, "This task is similar to the one you just completed, but a bit different. Instead of seeing the 'invented letters' in a grid, you'll see them in sequences or lists, two at a time. The sequence might have two invented letters in it, or four, or six. If it's a sequence of two invented letters, there will be only one pair. For sequences of four invented letters, you'll see two pairs. For sequences of six invented letters, you'll see three pairs. Each pair will appear in the middle of the computer screen for a short time, and then disappear. You'll know when the sequence is over because a single green invented letter will appear in the middle of the screen. Your job is to decide whether the green letter is the same as one of the ones in the sequence. If it is, you have to press the 'Present' key. If not, then press the 'Not present' key." Students were allowed to practice the procedure for two trials before beginning the experimental trial.

The sequences of black line drawings were displayed two symbols at a time, in the middle of a white computer screen. The probe character was presented after termination of the sequence. This character is green, to aid in its identification as the probe. Participants were asked to determine whether the probe character was in the target sequence. If it was present, they indicated this by pressing a *present* key. If it was not present, they indicated this by pressing a *not present* key. The subjects had 8 seconds to respond.

The child's exact choices, and the correct choices, were recorded by the computer in an internal data file. Latency scores were also recorded by the computer. The data file was retrieved from VScope as a formatted file using Microsoft Word software, and transferred to a PC computer for analysis by SPSS software. The total number correct in twenty trials was recorded.

To calculate serial position scores, only trials in which the probe character was present in the target sequence (Class 1) could be used. Additionally, only target sequences of 4 and 6 elements permit determination of primacy and recency scores. For the 4 and 6 element list, the number of correct responses to probes corresponding to pseudoletters in the beginning, middle, and end of the sequence were recorded. These scores were then converted according to the equation:

$$\frac{\text{\# of correct responses}}{\text{maximum possible correct}} \times 10 = \text{serial position score recorded.}$$

These converted scores were recorded in the data file. Scores were whole numbers ranging from 0 to 10.

This allowed recording of five dependent measures for each temporal test: total number correct, number of primacy items (first shown stimuli in each sequence) correct, number of middle items correct, number of recency items (last shown stimuli in each sequence) correct, and response latency.

Training Intervention

A training intervention followed the three tasks. Ten of the pseudoletters and 10 of the pseudowords were selected for this test. Children were taught to associate each visual element with a specific phonological element; that is, the "invented letters" used in the visual memory test were assigned names from the list of non-words used in the non-word repetition test. Items were presented in the same order for all subjects

Pictures of shapes on cards were presented and names supplied in iterative cycles until the subject was able to name all of the stimuli in two complete presentations of the deck of 10 symbols, or until the entire deck had been presented twenty times. The experimenter presented the stimuli on 3 x 5 inch index cards, in the first two presentations supplying the name ("This one is called ..."). After the first two presentations, the experimenter waited a few seconds to allow the child to supply the name, and then requested the name of the stimulus ("What sound goes with this shape?"). The experimenter provided the name it if the child is unable to do so after five seconds ("This is...").

The number of cycles necessary to achieve the criterion level of mastery, or the number of names mastered in twenty repetitions of the deck, was recorded on the phonological memory coding sheets. The training score recorded in the SPSS data file represents the average number of names learned per one repetition of the deck.

total number of names learned / total number of repetitions of deck =

average number of names learned per repetition

Visual and Phonological Posttests

Following the successful completion of sound-symbol training, modified versions of the iconic memory test, the visual memory span test, and the phonological span test were administered. The modified tests used the same procedures as the pretests, but the only visual and phonological stimuli used were the ones used in the training intervention. Since only ten pseudoletters and ten pseudowords were used in the training intervention, the visual and phonological posttests used only these stimuli. This resulted in more frequent repetition of the visual and phonological elements in tests. The tests were designed so that each of the stimuli would be used approximately the same number of times, and would never be repeated in a single sequence or grid.

Students were told, " Now we'll try the tape recorder test again. It's the same as the one that you already tried, except this time the only invented words that you'll hear are the ones that you learned to use for the pictures on the flash cards."

or, " Now we'll try the computer tests again. These tests will be the same as the ones that you already tried, except this time the only invented letters that you'll see are the ones that you learned names for with the flash cards."

The testing and scoring procedures were identical to those for the pretests.

Figure 1: Pseudoletters Used in the Visual Memory Tests (Dixon and Twilley, 1988)

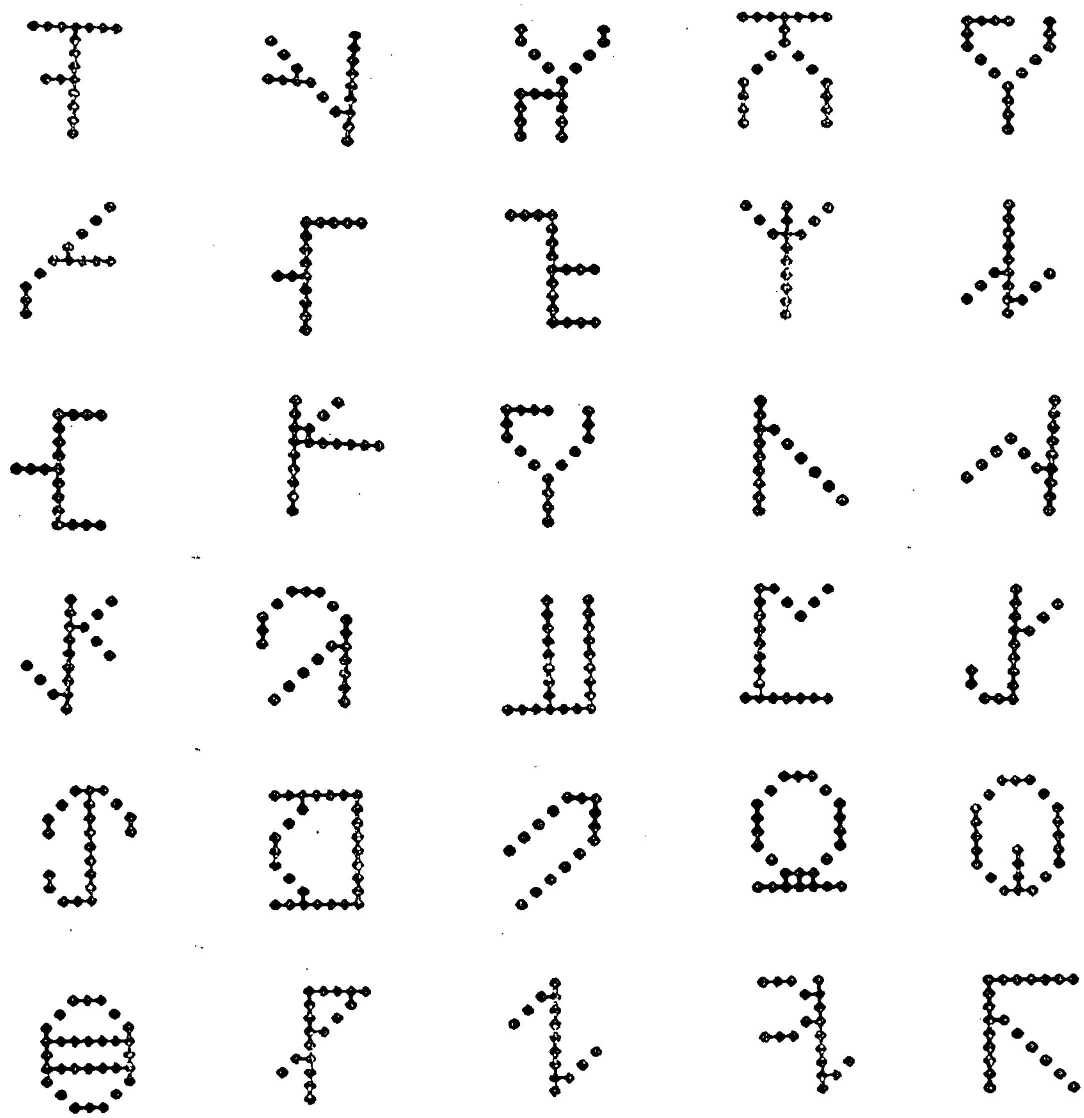


Figure 2: A sample array as shown on the computer screen

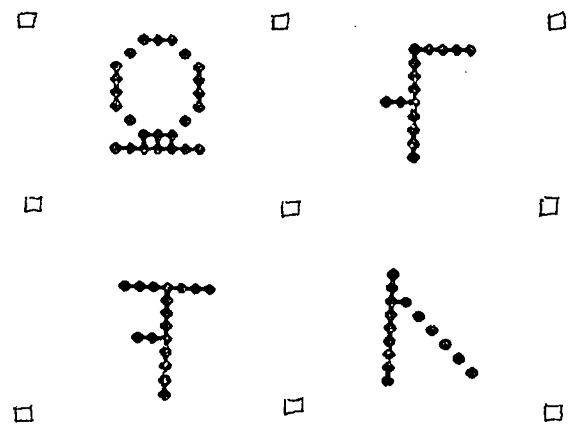


Figure 3: Iconic Memory Pretest Grids and Probes

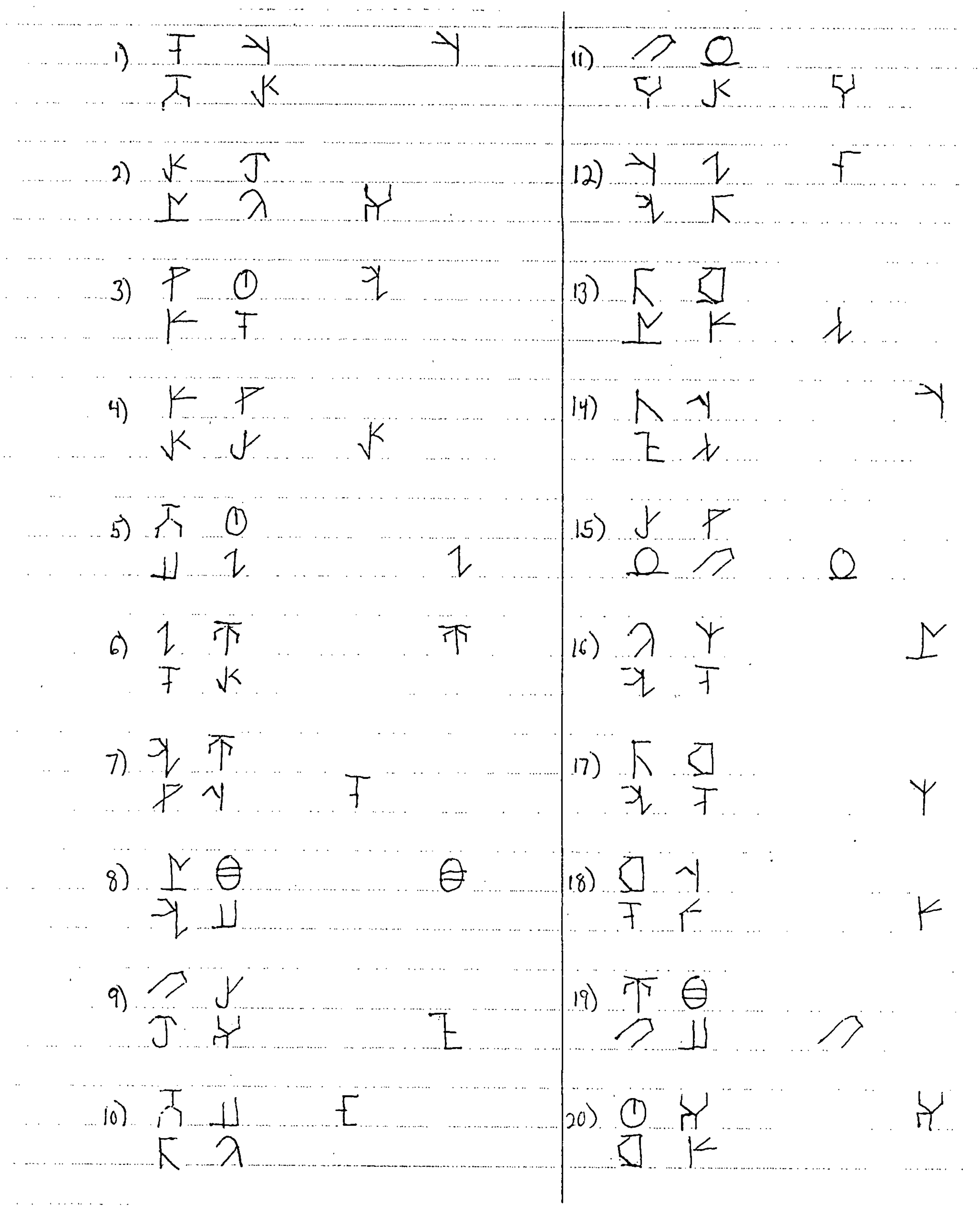


Figure 4: Iconic Memory Posttest Grids and Probes

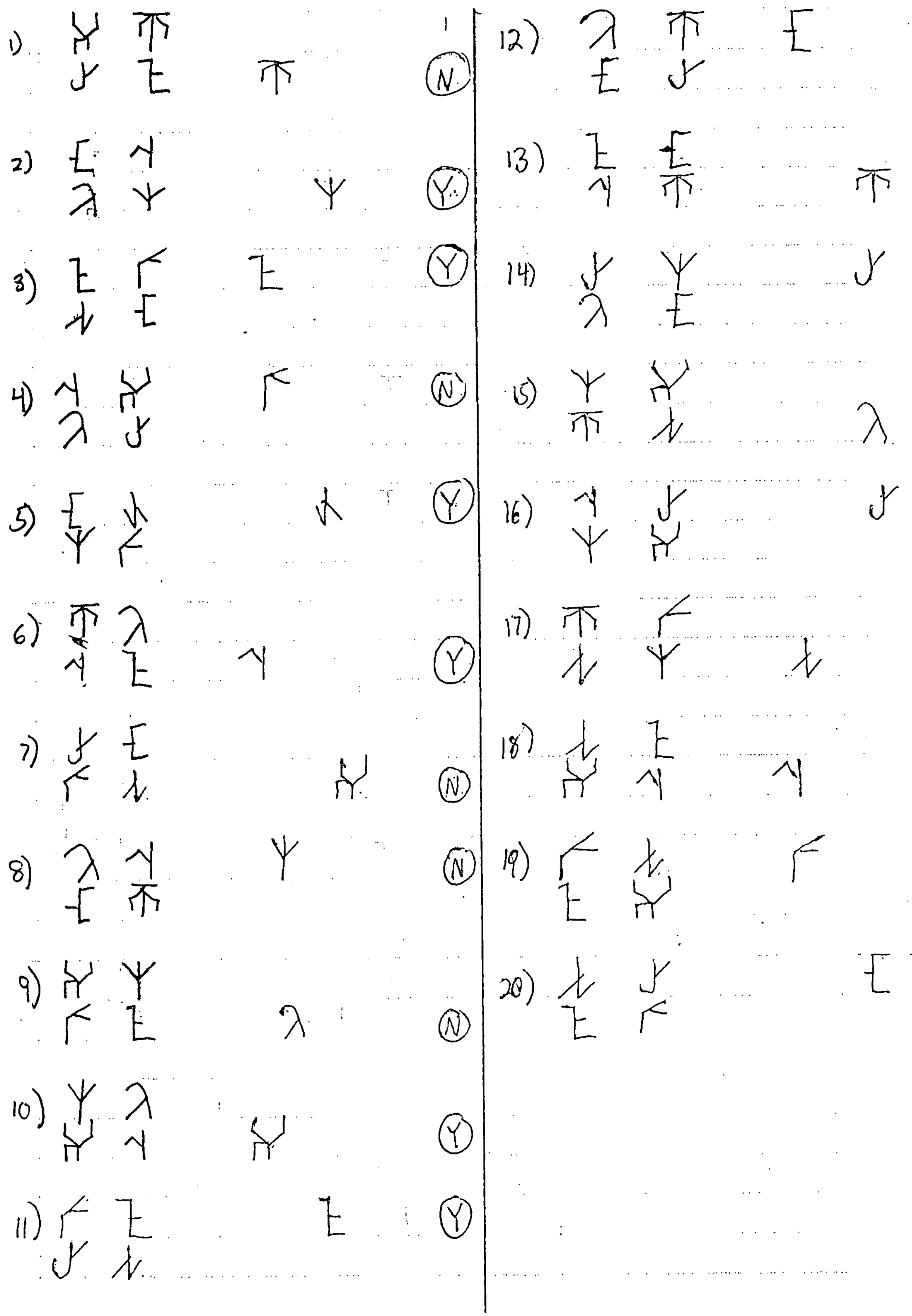


Figure 5: Sequential Memory Pretest Grids and Probes

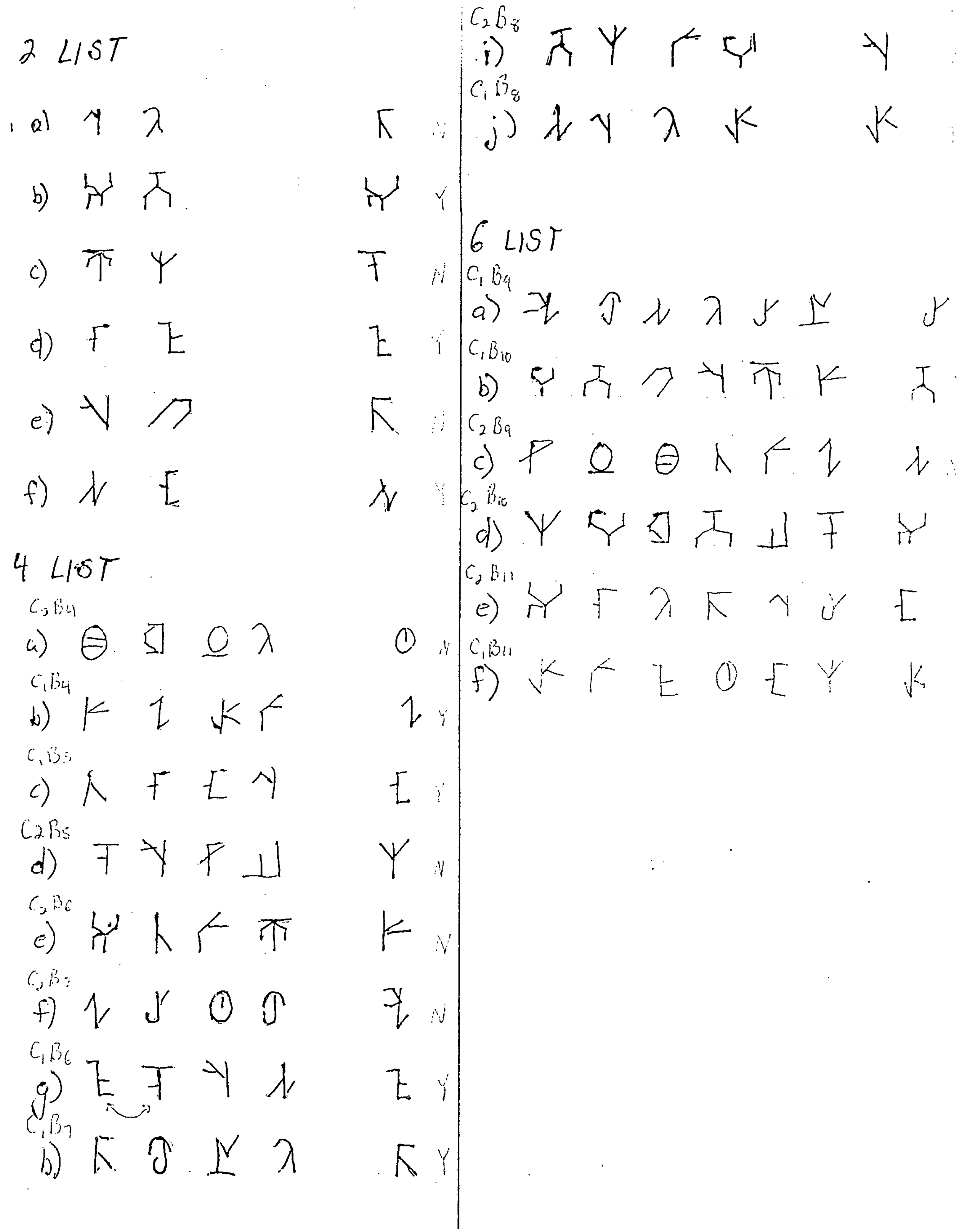


Figure 6: Sequential Memory Posttest Grids and Probes

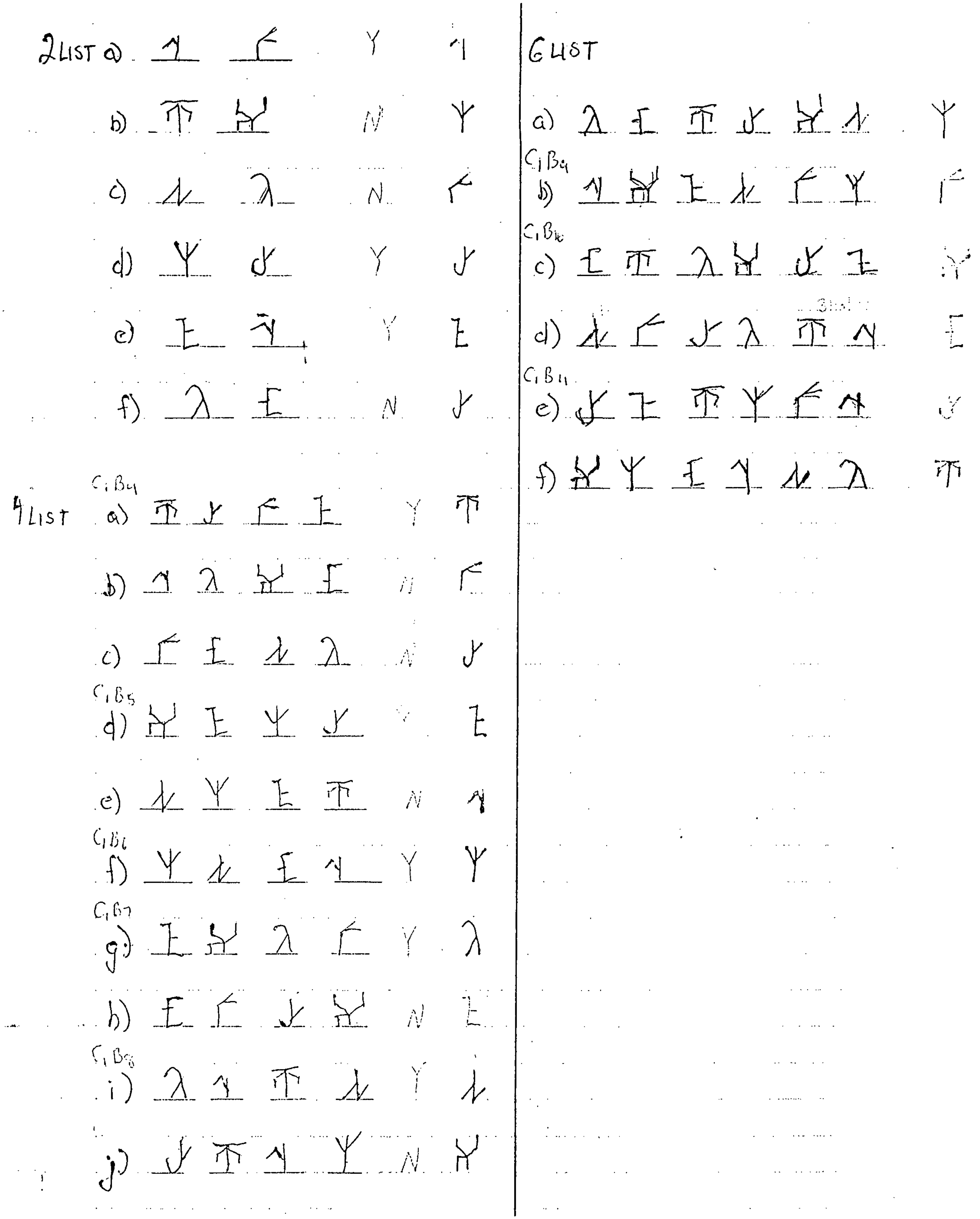
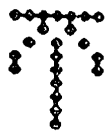
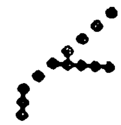


Figure 7: Symbols Used in the Training Intervention and Posttests

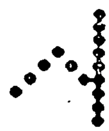
1) prin



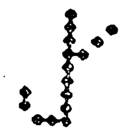
2) fen



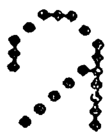
3) jix



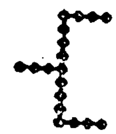
4) pag



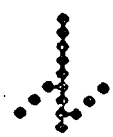
5) lish



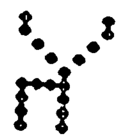
6) lote



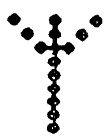
7) tweg



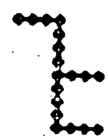
8) kirp



9) larp



10) vun



CHAPTER 4: RESULTS

Questions:

1) Do children with reading disabilities have deficits in phonological or visual memory relative to chronologically and reading age matched children with normal reading skills?

Children with reading disabilities had deficits in some measures of phonological and visual memory in comparison to both age and reading level comparison students. For each of the memory measures, mean scores of dyslexic, compensated dyslexic, and age level or reading level comparison normal readers were computed (Table 2). Group mean scores on memory measures for dyslexics and compensated dyslexics were compared to the group mean scores of the matched age and reading level comparison groups by the SPSS repeated measures ANOVA procedure.

Six of these repeated measures analyses were used: for dyslexics, age controls, and reading level controls, and then for compensated dyslexics, age controls, and reading level controls, the comparisons were computed for the phonological tests, the visual iconic tests, and then the visual temporal tests. Post hoc Tukey HSD tests were used for the two group comparisons.

Performance differences on the phonological measures will be considered first. Repeated measures 3 x 2 ANOVA of phonological pretest and posttest scores for dyslexics with age and reading level comparisons showed a significant main effect for group, $F(1, 33) = 6.22$, $p = .005$. The post hoc Tukey HSD test showed that the mean phonological pretest score of the dyslexic group was not significantly lower than the corresponding scores for either the age-matched or reading level-matched normal readers (Table 2). However, relative to normal readers of matched age, dyslexic readers scored significantly lower on the phonological posttest, $\underline{p}=.001$ (Table 2), and on some of the serial position variables (Table 3, discussed in later sections). Therefore, in this investigation, children in the dyslexic group did demonstrate significant deficits in phonological memory relative to chronological age matched children with normal reading skills on the phonological posttest, although not on the pretest.

In comparison, by 3 x 2 repeated measures ANOVA, to younger students matched for reading ability, students with reading disabilities did not have significantly lower mean scores on either the phonological pretest or the phonological posttest (Table 2). There were significant differences between the dyslexic group and the reading level comparison group on all of the phonological posttest serial position variables in a 3 x 2 repeated measures comparison (Table 3, discussed in a later section). Children in the dyslexic group did show significant deficits in phonological memory relative to reading age-matched normal readers with respect to individual serial position scores, although not on the phonological pretest and posttest.

Repeated measures 3 x 2 ANOVA of phonological pretest and posttest scores for compensated dyslexics with age and reading level comparisons did not show a significant main effect for group (Table 2). Additionally, the recovered dyslexic group did not show significant deficits at any of the phonological serial positions (Table 3). Children who have recovered from reading disability did not demonstrate significant deficits in phonological memory relative to chronologically or reading level matched children with normal reading skills.

Although the dyslexic group had lower mean scores on all of the visual tests than either of the comparison groups, significant differences in mean visual memory scores were evident only between children with reading disability and their age controls on the iconic memory pretest (Table 2). For dyslexics and comparison groups, repeated measures ANOVA of iconic pretest and posttest scores showed a significant main effect for group, $F(2, 35)=4.37$, $p=.021$. According to Tukey post hoc analysis, dyslexic readers scored significantly lower than their age peers on the iconic pretest, $p=.021$. The temporal pretest and posttest 3 x 2 analysis did not show a significant main effect for reading group.

If a more conservation 1% significance criterion is maintained because of the large number of variables in this study, these differences are not statistically significant. However, a multivariate 3 x 2 ANOVA for the dyslexic group and both of its comparison groups also showed a significant differences between the dyslexic group and the age matched group on the iconic pretest, $F(2, 34)= 3.47$, $p= .035$ and the temporal pretest, $F(2, 34)= 3.28$. $p= .049$, according to post hoc Tukey analysis. In summary, children with reading disability demonstrated visual iconic memory deficits relative to age peers with normal reading skills, but not relative to younger normal readers matched for reading level. They did not show statistically significant deficits on temporal memory relative to either comparison group, as defined in this study.

There was a significant main group effect on mean visual response latency, $F(2, 35)=3.32$, $p=.048$. However, post hoc Tukey analysis did not show any significant two-group differences. Younger children are generally slower to respond manually to the visual probes than older ones, regardless of reading ability. Children with dyslexia scored similarly to their age peers on visual response latency.

Compensated dyslexic children did not demonstrate significant iconic memory deficits relative to either of the normally reading comparison groups (age or reading level matches). The compensated dyslexic group did not score significantly lower than either their age or reading level matched peers on the temporal memory tests. There was a significant difference between the compensated dyslexic group and the younger reading level matches on visual response latency, $F(2, 56)= 4.45$, $p=.016$. The mean visual response speed of the older children was higher than that of the younger reading level comparison group.

In some of the comparisons, visual memory scores were significantly correlated with age. In the normal readers, the iconic pretest score was significantly associated with age, $r(30)=.65$, $p<.001$; as was the iconic posttest score, $r(30)=.41$, $p=.025$ and the temporal pretest score, $r(30)=.38$, $p=.039$.

For compensated dyslexics, the iconic pretest was significantly associated with age, r(19)=.58, p=.009. The SPSS ANCOVA procedure was also used for the visual memory data, using age as a covariate. This increased the level of significance of group differences in the groups that were matched by age only slightly. For the dyslexic students and matched reading level comparison students, use of the covariate resulted in some group mean differences that were significant at the 5% level. Significant differences were noted for the iconic pretest, $F(1, 23) = 5.15$, $p=.034$, and the iconic posttest, $F(1, 23) = 4.65$, $p=.043$.

The mean memory scores of the dyslexic readers were compared to those of compensated dyslexic readers by 3 x 2 repeated measures ANOVA of dyslexics, compensated dyslexic, and all normal readers participating in the study (Table 6). Children who have recovered from a reading disability had higher mean scores than dyslexic children on all the visual tests, but only on the iconic pretest was the difference significant. Repeated measures ANOVA showed a significant group effect, $F(2, 58)= 3.80$, $p= .028$. The score of the dyslexic group was significantly lower than that of the compensated dyslexic group, $p= .014$ by post hoc Tukey test.

The dyslexic group also had a lower mean score on the phonological memory posttest than the compensated dyslexic group. The main effect for group was $F(2, 58) = 3.11$, $p=.052$. According to post hoc Tukey analysis, the dyslexic and compensated dyslexic groups were significantly different, $p=.039$. Compensated dyslexics scored significantly lower than dyslexics on phonological primacy on both the pretest and posttest, F(2, 58)= 7.33, p= .023, and F(2, 58)= 8.57, p= .001 respectively.

Phonological posttest scores were not correlated with the visual memory scores in normal readers. There were significant associations between phonological pretest middle position scores and temporal posttest primacy, r(27)=.38, p=.042, and temporal posttest middle position scores, r(27)=.37, p=.050. There was a significant association between phonological posttest recency and iconic pretest, r(8)=.67, p=.035, and between phonological posttest recency and temporal pretest recency, r(7)=.75, p=.020 in the dyslexic group. In the compensated dyslexic group, the relationship between phonological posttest and sequential pretest primacy was significant, r(15)=.59, p=.012. Possibly a child who has facility in sustaining an iconic image can also sustain an echoic one. Phonological memory span scores were not significantly associated with age in the groups tested.

Table 2: Comparison of normal and disabled readers on memory variables by ANOVA and ANCOVA: Age as Covariate. Mean scores and (standard deviations).

	Iconic memory pretest	Iconic memory posttest	Temporal memory pretest	Temporal memory posttest	Phonological memory pretest	Phonological memory posttest	Visual response latency
Dyslexic n=12	12.17 (2.79)	11.67 (3.11)	12.91 (1.45)	13.33 (2.50)	72.83 (27.89)	90.58 (29.73)	1819.42 (498.72)
Normal readers (age match for dyslexics) n=12	15.08 (1.89)	13.50 (1.51)	14.67 (1.56)	14.50 (2.43)	89.75 (17.16)	143.25 (44,59)	1805.45 (427.88)
Significance by ANOVA/Tukey	$F(1, 33)$= 4.37, p= .021	ns	ns	ns	ns	$F(1, 33)$= 6.95, p= .001	$F(2, 33)$= 3.32, p=.048 / ns
Normal readers (reading level match for dyslexics) n=12	13.75 (2.80)	12.75 (2.09)	14.25 (2.14)	13.25 (1.82)	78.17 (13.74)	118.25 (14.67)	2198.64 (327.26)
Significance by ANOVA/Tukey	ns	ns	ns	ns	ns	ns	ns
Significance by ANCOVA (age as covariate)	$F(1, 23)$= 5.15, p=.034	$F(1, 23)$= 4.65, p=.043	$F(1, 22)$= 4.89, p=.039	ns	ns	ns	ns
Compensated dyslexic n=19	14.74 (1.88)	13.00 (3.40)	13.68 (2.47)	14.26 (2.56)	83.84 (16.91)	112.58 (35.55)	1742.5 (392.0)
Significance by ANOVA/Tukey (comp. to dyslexics)	$F(2, 58)$= 3.80, p=.014	ns	ns	ns	ns	ns	ns
Significance by ANCOVA	F(1, 30)= 9.12, p=.005	ns	ns	ns	ns	ns	ns
Normal readers (age match for compensated dyslexics) n=19	15.26 (1.88)	13.68 (1.77)	15.11 (1.63)	13.63 (2.11)	90.89 (17.10)	131.11 (40.99)	1835.8 (381.3)
Significance by ANOVA/Tukey	ns	ns	ns	ns	ns	ns	$F(1, 56)$= 4.45, p=.016
Normal readers (reading level match for compensated dyslexics) n=19	13.95 (2.70)	13.32 (2.14)	14.68 (1.77)	13.58 (2.19)	83.74 (14.51)	112.58 (20.59)	2099.4 (373.3)
Significance by ANOVA/Tukey	ns	ns	ns	ns	ns	ns	ns
Significance by ANCOVA (age as covariate)	ns	ns	$F(1,37)$= 8.47, p=.006	ns	ns	ns	ns

Table 3 - Comparison of normal and disabled readers on memory variables by ANOVA and ANCOVA: Age as Covariate. Mean scores and (standard deviations).

	phonological pretest primacy	phonological pretest middle	phonological pretest recency	phonological posttest primacy	phonological posttest middle	phonological posttest recency
Dyslexic n=12	.52 (.39)	.45 (.33)	.64 (.36)	.71 (.25)	.55 (.33)	.60 (.27)
Normal readers (age match for dyslexics) n=12	.81 (.176)	.65 (.17)	.69 (.15)	.89 (.16)	.87 (.18)	.80 (.13)
Significance by ANOVA/Tukey	ns	ns	ns	$F(1, 33)=3.38$, $p=.002$	$F(1, 33)=4.55$, $p=.005$	$F(1, 33)=1.27$, $p=.032$
Normal readers (reading level match for dyslexics) n=12	.57 (.35)	.40 (.27)	.52 (.33)	.98 (.05)	.79 (.16)	.87 (.12)
Significance by ANOVA/Tukey	ns	ns	ns	$F(1, 33)=3.38$, $p=.05$	$F(1, 33)=4.55$, $p=.040$	$F(1, 33)=1.27$, $p=.003$
Significance by ANCOVA (age as covariate)	ns	ns	ns	$F(1, 23)=9.84$, $p=.005$	$F(1, 23)=4.61$, $p=.044$	$F(1, 23)=5.81$, $p=.025$

Table 4 - Comparison of normal and disabled readers on phonological memory variables by ANOVA and ANCOVA: Age as Covariate. Mean scores and (standard deviations).

	phonological pretest primacy	phonological pretest middle	phonological pretest recency	phonological posttest primacy	phonological posttest middle	phonological posttest recency
Compensated dyslexic n=19	.79 (.17)	.59 (.15)	.71 (.19)	.94 (.10)	.74 (.22)	.72 (.23)
Significance by ANOVA/Tukey (comp. to dyslexics)	$F(2, 58)=7.33$ $p=.023$	ns	ns	$F(2, 58)=8.57$ $p=.001$	ns	ns
Significance by ANCOVA (comp. to dyslexics)	$F(1, 30)=7.56$ $p=.010$	ns	ns	$F(1, 29)=12.10$ $p=.002$	$F(1, 30)=4.02$, $p=.055$	ns
Normal readers (age match for compensated dyslexics) n=19	.79 (.15)	.64 (.17)	.72 (.19)	.92 (.13)	.80 (.20)	.81 (.16)
Significance by ANOVA/Tukey	ns	ns	ns	ns	ns	ns
Normal readers (reading level match for compensated dyslexics) n=19	.76 (.17)	.55 (.18)	.64 (.19)	.89 (.16)	.73 (.24)	.79 (.17)
Significance by ANOVA/Tukey	ns	ns	ns	ns	ns	ns
Significance by ANCOVA (age as covariate)	ns	ns	ns	ns	ns	ns

Table 5 - Comparison of normal and disabled readers on visual temporal memory variables by ANOVA and ANCOVA: Age as Covariate. Mean scores and (standard deviations).

	Sequential pretest primacy	Sequential pretest recency	Sequential posttest primacy	Sequential posttest middle	Sequential posttest recency	Training
Dyslexic n=12	5.27 (2.41)	9.09 (3.02)	4.77 (2.36)	6.36 (5.04)	8.18 (3.37)	.43 (.26)
Normal readers (age match for dyslexics) n=12	6.83 (1.80)	9.16 (1.95)	5.83 (3.26)	9.17 (2.89)	9.17 (1.95)	.93 (.29)
Significance by ANOVA/Tukey	ns	ns	ns	ns	ns	F(2, 35)= .8.76, p=.001
Normal readers (reading level match for dyslexics) n=12	6.83 (2.17)	8.33 (2.46)	4.79 (3.10)	5.83 (5.15)	7.08 (3.34)	.77 (.34)
Significance by ANOVA/Tukey	ns	ns	ns	ns	ns	F(2, 35)= 8.76, p=.025
Significance by ANCOVA (age as covariate)	ns	ns	ns	ns	ns	F(1, 23)= 13.77, p=.001
Compensated dyslexic n=19	6.00 (2.83)	8.33 (2.43)	5.92 (2.66)	5.79 (5.06)	7.89 (3.03)	.66 (.22)
Significance by ANOVA/Tukey (comp. to dyslexics)	ns	ns	ns	ns	ns	F(2, 56)= 5.04, p=.01
Significance by ANCOVA (comp. to dyslexics)	ns	ns	ns	ns	ns	F(1, 37)=9.54, p=.005
Normal readers (age match for compensated dyslexics) n=19	7.16 (1.80)	9.21 (1.87)	6.05 (2.68)	6.84 (4.78)	8.16 (2.99)	1.01 (.39)
Significance by ANOVA/Tukey	ns	ns	ns	ns	ns	F(1, 56)=5.04, p=.008
Normal readers (reading level match for compensated dyslexics) n=19	7.37 (2.0)	9.21 (1.87)	5.79 (2.89)	7.37 (4.52)	8.16 (2.99)	.89 (.39)
Significance by ANOVA/Tukey	ns	ns	ns	ns	ns	ns
Significance by ANCOVA (age as covariate)	ns	ns	ns	ns	ns	F(1, 37)= 7.52, p=.010

Table 6 - Comparison of dyslexic, compensated dyslexic, and normal readers on memory variables by ANOVA: Mean scores and (standard deviations).

	Iconic memory pretest	Iconic memory posttest	Temporal memory pretest	Temporal memory posttest	Phonological memory pretest	Phonological memory posttest	Visual response latency
Dyslexic n=12	12.17 (2.79)	11.67 (3.11)	12.91 (1.45)	13.33 (2.50)	72.83 (27.89)	90.58 (29.73)	1819.42 (498.72)
Recovered dyslexic n=19	14.74 (1.88)	13.00 (3.40)	13.68 (2.47)	14.26 (2.56)	83.84 (16.91)	112.58 (35.55)	1742.5 (392.0)
Significance (dyslexic and compensated dyslexic)	F(2, 58)= 3.80, p=.014	ns	ns	ns	ns	F(2, 58)= 3.11, p=.039	ns
All normal readers n=30	14.17 ((2.51)	13.20 (1.92)	14.53 (1.85)	13.67 (2.02)	86.33 (18.11)	122.97 (41.71)	2019.50 (421.93)
Significance (dyslexic and normal)	F(2, 58)= 3.80, p=.045	ns	ns	ns	ns	ns	ns

2) Are scores on the measures of phonological and / or visual memory significantly associated with reading skills in children with reading disabilities or in chronologically and reading age matched children with normal reading skills?

Some of the visual and phonological scores, especially phonological primacy and the phonological posttest score, were related to reading in normal readers and compensated dyslexics, but none of these scores were related to reading in the dyslexic group. Pearson partial correlations, controlling for age, indicated that the phonological pre- and posttest scores were significantly associated: for all children tested $\underline{r}(58)=.72$, $\underline{p}<.001$, for normal readers only $\underline{r}(27)=.62$, $\underline{p}<.001$, for dyslexic readers only $\underline{r}(9)=.83$, $\underline{p}=.001$, suggesting that a common cognitive skill, referred to here as phonological memory span, was required for the two measures. It should be noted that these scores were not significantly associated for compensated dyslexic readers.

Partial correlation matrices (controlling for age) of the visual, phonological, and reading measures were used to determine whether significant relationships existed between the memory measures and reading ability. Significant correlations for some of the measures and the reading scores were obtained, as listed in Tables 7A and 7B:

Table 7A - Significant Pearson Correlations of Memory Variables and Reading Scores				
Group	**Test**	**Correlate**	**r**	**sig r**
All Participants	WRAT	Woodcock	.87	<.001
(n=60)		Phonological Pretest	.28	.033
		Phonological Posttest	.42	.001
		Phonological Pretest Primacy	.42	.001
		Pretest Middle Position	.36	.005
		Phonol. Pretest Recency	ns	
		Phonol. Posttest Primacy	.34	.007
		Posttest Middle Position	.35	.006
		Phonol. Posttest Recency	ns	
		Visual Pretest Primacy	ns	
		Visual Pretest Recency	ns	
		Visual Posttest Primacy	.33	.01
		Middle Position	ns	
		Visual Posttest Recency	ns	
		Iconic Pretest	.37	.003
	Woodcock	Phonological Pretest	.36	.005
		Phonological Posttest	.38	.003
		Phonological Pretest Primacy	.42	.001
		Pretest Middle Position	.38	.003
		Phonol. Pretest Recency	ns	
		Phonol. Posttest Primacy	.33	.009
		Posttest Middle Position	.38	.003
		Phonol. Posttest Recency	ns	
		Visual Pretest Primacy	ns	
		Visual Pretest Recency	ns	
		Visual Posttest Primacy	ns	
		Middle Position	ns	
		Visual Posttest Recency	ns	

Table 7B - Pearson Correlations of Memory Variables and Reading Scores

Group	Test	Correlate	r	sig r
Normal readers	WRAT	Woodcock	.79	<.001
(n=30)		Phonological Pretest	.37	.05
		Phonological Posttest	ns	
		Phonological Pretest Primacy	.57	.001
		Pretest Middle Position	.55	.002
		Phonol. Pretest Recency	.63	.001
		Phonol. Posttest Primacy	ns	
		Posttest Middle Position	ns	
		Phonol. Posttest Recency	ns	
		Visual Pretest Primacy	ns	
		Visual Pretest Recency	ns	
		Visual Posttest Primacy	.48	.008
		Middle Position	.44	.017
		Visual Posttest Recency	ns	
	Woodcock	Phonological Pretest	.44	.018
		Phonological Posttest	ns	
		Phonological Pretest Primacy	.46	.012
		Pretest Middle Position	.46	.013
		Phonol. Pretest Recency	.58	.001
		Phonol. Posttest Primacy	ns	
		Posttest Middle Position	ns	
		Phonol. Posttest Recency	ns	
		Visual Pretest Primacy	ns	
		Visual Pretest Recency	ns	
		Visual Posttest Primacy	.ns	
		Middle Position	.41	.029
		Visual Posttest Recency	ns	

For children with reading disabilities, WRAT word reading and Woodcock pseudoword reading scores were not significantly correlated with any of the memory variables. For compensated dyslexics, WRAT and Woodcock scores were significantly correlated, $r(16)=.88$, $p<.001$. When data for dyslexics and compensated dyslexics were combined, more significant correlations were obtained:

WRAT and iconic memory pretest, $r(28)=.46$, $p=.013$,
WRAT and phonological posttest primacy, $r(28)=.45$, $p=.014$,
WRAT and phonological posttest middle, $r(28)=.38$, $p=.038$.

Woodcock and iconic memory pretest, $r(28)=.40$, $p=.028$,
Woodcock and phonological posttest primacy, $r(28)=.38$, $p=.036$,
Woodcock and phonological posttest middle, $r(28)=.38$, $p=.040$,
Woodcock and temporal posttest primacy, $r(25)=.39$, $p=.045$.

For the entire test population, word reading scores were significantly correlated with mean scores on the iconic pretest, and the phonological pretest and phonological posttest. They are also significantly correlated with mean scores for specific serial positions on these tests. The iconic pretest and phonological posttest were measures for which dyslexic children showed significant deficits. Word reading scores were also significantly correlated with phonological and temporal primacy, both measures of temporal processing. Pseudoword reading scores were significantly correlated with the phonological pretest and posttest. [As correlations between reading and memory measures are strongest in the areas of greatest deficit for the dyslexic group, it is possible that phonological and visual memory deficits among reading disabled children constrain their ability to perform the reading tasks.]

For the youngest normal beginning readers in this study (the reading level comparison group for the dyslexics), the mean word reading score was significantly correlated with phonological pretest primacy and middle position scores, $r(7)=.68$, $p=.041$, and $r(7)=.82$, $p=.006$ respectively. Pseudoword reading was significantly correlated with phonological pretest primacy and middle position scores, $r(7)=.76$, $p=.017$, and $r(7)=.79$, $p=.012$ respectively. Word and pseudoword reading scores were not significantly correlated with phonological posttest primacy for this group.

3) Do children with reading disabilities have deficits in memory span for letter-sound correspondences relative to chronologically and reading age matched children with normal reading skills?

Children with reading disabilities did have deficits in memory span for letter-sound correspondences relative to both comparison groups. Children in the compensated dyslexic group had a significantly lower mean training score than the normally reading participants in this study, despite their higher mean age. The scores for the sound-symbol training are used here to represent memory span for sound symbol correspondences (Table 5). Repeated measures 3 x 2 ANOVA showed a significant main effect for group, $F(2, 35) = 8.76$, $p= .001$. Dyslexic participants had significantly lower training scores than either age matched children, $p= .001$, or reading level matched children with normal reading skills, $p= .025$ by post hoc Tukey analysis. Children with reading disability had deficits in memory span for novel letter-sound correspondences relative to chronologically and reading age matched children with normal reading skills.

Repeated measures ANOVA of sound symbol training scores of recovered dyslexics and comparison groups showed a significant main effect for group, $F(2, 56) = 5.04$, $p = .01$. The compensated dyslexic group's training score was significantly lower than that of their age comparison group by Tukey test, $p = .008$. Children with dyslexia, even after recovery, had deficits in memory span for novel letter-sound correspondences relative to chronologically matched children with normal reading skills. The compensated dyslexic group did not score significantly below the reading level matched group on this variable.

Compensated dyslexic participants did score significantly lower on sound symbol training than a group of all the normally reading participants in the study, $F(2, 60) = 10.54$, $p < .001$, by 3 x 2 repeated measures ANOVA. The mean training score for the compensated dyslexic group was not significantly different from that of the dyslexic group. However, in a two group comparison of dyslexics and compensated dyslexics, there was a significant difference in mean training scores when age was used as a covariate, $F(1, 37) = 7.52$, $p = .01$.

Training scores were related to word and pseudoword reading ability for some groups. In a Pearson partial correlation analysis, controlling for age, training scores were significantly related to the reading measures: for all children tested:

WRAT %ile and sound-symbol training score, $r(58) = .60$, $p < .001$,
Woodcock %ile and sound-symbol training score, $r(58) = .66$, $p < .001$.

For children with normal reading ability:

WRAT %ile and sound-symbol training score, $r(27)=.36$, $p=.055$,
Woodcock %ile and sound-symbol training score, $r(27)=.41$, $p=.026$.

Significant relationships of training and reading scores did not exist in the dyslexic group. For compensated dyslexics, the relationship between Woodcock scores and training scores was significant, $r(16)=.54$, $p=.022$, but WRAT scores are not significantly related to training scores. When data for dyslexics and compensated dyslexics were combined, both relationships became significant:

WRAT and training score, $r(28)=.66$, $p<.001$,
Woodcock and training score, $r(28)=.56$, $p=.001$.

4) In children with reading disabilities, are memory spans for letter-sound correspondences related to visual and phonological memory scores?

Memory spans for letter-sound correspondences were related to some of the visual and phonological memory scores in normal readers and recovered dyslexics, but to very few of these scores in the dyslexic group. Partial correlations (controlling for age) between the phonological measures and training scores were not significant in the dyslexic group. Training scores were also not significantly associated with any of the visual measures in the dyslexic group. For compensated dyslexics, training scores were significantly positively associated with phonological posttest recency, $r(15)=.50$, $p=.041$, and significantly negatively associated with mean temporal pretest score, $r(15)=-.62$, $p=.007$. For normally reading students in grade 1 only, training scores were significantly associated with phonological posttest primacy, $r(10)=.85$, $p=.002$, and phonological posttest recency, $r(10)=.79$, $p=.006$.

Among normal readers, the training scores were significantly associated with iconic posttest scores, $r(27)=.44$, $p=.016$, but not with the phonological measures. In the total test population, there were significant relationships between phonological posttest scores and training scores, $r(58)=.30$, $p=.018$; phonological posttest middle position scores and training scores, $r(58)=.27$, $p=.040$; and phonological posttest recency and training scores, $r(58)=.25$, $p=.054$. There were also significant associations between the iconic pretest and mean training score, $r(58)=.27$, $p=.038$, and the iconic posttest score and mean training score

$r(58)=.26$, $p=.044$.

5a) Do learned sound-symbol associations increase visual and phonological memory for the sounds or the symbols (facilitative effect of labeling)?

Learned sound-symbol associations did increase phonological memory, but not visual memory, for the sounds and the symbols. The differential effects of the sound-symbol training were analyzed by 3 x 2 repeated measures ANOVA. The two levels of test were the pretest and the posttest. The dyslexic group with its two comparison groups was analyzed separately from the compensated dyslexic group with its comparison groups, forming 2 three-group comparisons.

All groups had higher mean phonological posttest scores than mean phonological pretest scores. The main effects for pretest-posttest were significant: for dyslexics and comparison groups, $F(1, 33)= 88.02$, $p< .001$; for compensated dyslexics and comparison groups, $F(1, 54)=91.33$, $p<.001$. The phonological posttest was presumably easier for the children than the pretest because the pseudowords were familiar, and there were fewer of them (only 10, as opposed to 112 for the pretest). There may also have been a facilitative effect of multiple coding among normal readers, since phonological posttest scores are significantly associated with training scores for this group. The association of phonological posttest and training scores was not significant in the dyslexic group.

Following the sound-symbol training, mean iconic memory scores decreased slightly for most groups. The main pretest-posttest effects for iconic memory were significant by 3 x 2 repeated measures ANOVA: for dyslexics and comparison groups, $F(1, 33)=4.68$, $p=.038$; for compensated dyslexics and comparison groups, $F(1, 54)= 13.10$, $p= .001$. A significant pretest-posttest change was not observed in the dyslexic group when the scores were compared by ANOVA, ANCOVA, or t-test.

Following the sound-symbol training, ANOVA of visual temporal memory pretest and posttest scores did not show a significant mean score change for dyslexic and comparison groups or for compensated dyslexics and comparison groups. Mean scores in the compensated dyslexic group were somewhat lower on the visual temporal posttest than on the pretest (Figure 9). Mean pretest and posttest scores of the other groups were quite similar.

5b) Is the influence of sound-symbol training different for reading disabled children and either control group?

The influence of sound-symbol training was different for reading disabled children and the comparison groups. It was also significantly greater in recovered dyslexics than in dyslexics. Differential effects of the sound-symbol training on memory scores for the six reading groups were represented as 3 x 2 pretest-posttest x group interactions. The 3 levels of group represented comparisons of dyslexics to each comparison group, and then compensated dyslexics to each comparison group. Interaction effects were analyzed by repeated measures ANOVA and ANCOVA. Significant interaction effects were obtained for the phonological tests in comparisons involving the dyslexic group, $F(1, 33)= 6.22$, p=.005. Phonological pretest-posttest interaction effects were not significant in comparisons involving the compensated dyslexics. There were no significant interaction effects for iconic or temporal memory, although there were significant group effects for iconic memory.

6) Are serial position curves for visual and phonological spans significantly different for children with reading disabilities and normally reading comparison groups?

Serial position curves for visual and phonological spans were in some respects significantly different for children with reading disabilities and normally reading comparison groups. Phonological serial position curves are typically U-shaped, higher at the beginning and end, and depressed in the middle. All groups showed phonological pretest serial position effects (Tables 3, 4, 8A, Figure 8), with some variations. Phonological primacy scores theoretically reflect the use of cumulative rehearsal of beginning and middle list items. Recency scores represent the superiority of immediate auditory memory in the absence of interference.

Repeated measures 3 x 2 ANOVA of phonological pretest and posttest primacy scores showed a significant main effect for group, $F(2, 33) = 3.38$, $p = .046$, and a significant interaction effect, $F(2, 33) = 5.17$, $p = .011$. Children with dyslexia showed a significant deficit in phonological posttest primacy scores representing pseudowords in the beginning of posttest memory lists in comparison to both their age peers, $p = .05$, and their reading level peers, $p = .002$ according to Tukey post hoc analysis (Table 8B). Scores for pretest primacy did not differ significantly among these groups.

Similarly, repeated measures ANOVA of phonological pretest and posttest middle position scores showed a significant main effect for group, $F(2, 33) = 4.55$, $p= .018$, and a significant interaction effect, $F(2, 33)= 4.40$, $p=.02$. Children with dyslexia showed a significant deficit in phonological posttest middle position scores in comparison to both their age peers, $p= .005$, and their reading level peers, $p= .04$ according to Tukey post hoc analysis. Pretest middle position scores showed no significant group differences (Table 8A).

Repeated measures ANOVA of phonological pretest and posttest recency scores showed a significant interaction effect, $F(2, 33)= 4.66$, $p= .016$, but no significant group main effect. In the compensated dyslexic and normal reading groups, the recency effect which was evident on the pretest was reduced or eliminated on the posttest. This did not occur in the dyslexic group. Children with dyslexia showed a significant deficit in phonological posttest recency scores in comparison to both their age peers, $p= .032$, and their reading level peers, $p= .003$, according to Tukey post hoc analysis (Table 8B). The mean phonological pretest recency scores show no significant group differences.

The children in the dyslexic group scored lower at all phonological posttest serial positions than children in either comparison group. This suggests that the observed phonological memory deficit is not only related to deficits in phonological encoding and rehearsal, although rehearsal deficits are suggested. The dyslexic group also gained less as a result of the sound symbol training than children in comparison groups.

Children who have recovered from dyslexia scored similarly to their age and reading level peers at all phonological pretest serial positions. The reading level comparison group had lower mean scores than the age comparison group at all phonological serial positions (Table 4), but the differences were not statistically significant. Phonological serial position curves of children who have recovered from dyslexia therefore were not significantly different from those of age or reading level matched normal readers.

Repeated measures 3 x 2 ANOVA of phonological primacy scores of dyslexics, compensated dyslexics, and all normally reading participants showed a significant main effect for reading group, $F(2, 58) = 7.33$, $p = .001$. Dyslexics scored significantly below compensated dyslexics on phonological pretest primacy, $p = .023$, and posttest primacy, $p = .001$, by post hoc Tukey analysis. The dyslexic group also scored significantly below compensated dyslexics at the phonological pretest middle position, $F(2, 58) = 3.72$, $p = .03$. Tukey analysis showed the difference between dyslexics and compensated dyslexics at this position to be significant, $p = .023$. Phonological recency scores of dyslexics and recovered dyslexics were not significantly different.

Phonological primacy scores were significantly higher on the posttest than the pretest for all comparisons. In comparison of dyslexics, compensated dyslexics, and all normally reading participants, repeated measures 3 x 2 ANOVA showed a significant phonological primacy score increase from pretest to posttest, $F(1, 58)= 28.26$, $p< 001$, with no significant interaction. Phonological middle position scores were also higher on the posttest than on the pretest, $F(1, 33)= 36.30$, $p< .001$. In this case, the interaction was significant. The pretest to posttest gain at this position was less for dyslexics than for the other groups, again suggesting rehearsal and encoding deficits. Phonological recency scores did not show a significant main effect for pretest to posttest change, but the interaction effect approached significance, $F(2, 58)=3.06$, $p= .055$, due to the significantly higher posttest recency score of normal readers as compared to children with dyslexia, $p= .02$.

Phonological pretest primacy scores were higher than pretest recency scores only for normal readers, and the main effect for phonological pretest primacy to recency was not significant for any of the groups. Phonological posttest primacy scores were higher than posttest recency scores for all groups, and the main effect was significant, $F(1, 58)= 26.01$, $p<.001$. The interaction was significant as well, $F(2, 58)= 8.57$, $p= .001$. Dyslexics scored significantly below recovered dyslexics and normal readers at the pretest primacy position, but only below the normally reading group at the recency position (Figure 8). There was a reduced but still evident recency effect in the dyslexic group on the phonological posttest, as compared to the phonological pretest. For the compensated dyslexics and the normal readers, there was no recency effect on the phonological posttest, although there was one on the pretest, $F(1, 58)=22.86$, $p< .001$, with no significant group x middle-position-to-recency position interaction.

Phonological primacy effects, represented by score comparisons of mean scores in the primacy and middle positions, were significant on both the pretest, $F(1, 58)= 25,80$, $p<.001$, and posttest, $F(1, 58)= 36.85$, $p< .001$. The pretest primacy effect had an interaction which did not reach conventional levels of significance, but approached significance, $F(2, 58)=3.03$. $p= .056$, due to the smaller primacy effect showed by the dyslexic group on the phonological pretest, $p= .023$, as compared to the compensated dyslexic group. It is striking that most normal and recovered readers received highest mean scores for items at the beginning of the lists, reflecting the use and efficiency of phonological rehearsal.

Table 8A: Mean Phonological Pretest Serial Position Scores and (Standard Deviations) for Dyslexics, Compensated dyslexics, and Normal Readers Matched for Age and Reading Level

Data File	Serial Position	Disabled Readers	Normal Readers	Significance by t-test
Dyslexic	Phonological Primacy	.52 (.39)	.81 (.16)	
and Age	Middle Position	.45 (.33)	.65 (.17)	
Control	Phonological Recency	.64 (.36)	.69 (.15)	ns
Dyslexic &	Phonological Primacy	.52 (.39)	.57 (.35)	ns
Reading	Middle Position	.45 (.33)	.40 (.27)	ns
Control	Phonological Recency	.64 (.36)	.52 (.33)	ns
Recovered	Phonological Primacy	.79 (.17)	.79 (.15)	ns
and Age	Middle Position	.59 (.15)	.64 (.17)	ns
Control	Phonological Recency	.71 (.19)	.72 (.19)	ns
Recovered &	Phonological Primacy	.79 (.17)	.76 (.17)	ns
Reading	Middle Position	.59 (.15)	.55 (.18)	ns
Control	Phonological Recency	.71 (.19)	.64 (.19)	ns

Table 8B: Mean Phonological Posttest Serial Position Scores and (Standard Deviations) for Dyslexics, Compensated dyslexics, and Normal Readers Matched for Age and Reading Level

Data File	Serial Position	Disabled Readers	Normal Readers	Significance by t-test
Dyslexic	Phonological Primacy	.71 (.25)	.89 (.16)	(p=.054)
and Age	Middle Position	.55 (.33)	.87 (.18)	p=.007
Control	Phonological Recency	.60 (.27)	.80 (.13)	p=.029
Dyslexic &	Phonological Primacy	.71 (.25)	.98 (.05)	p=.004
Reading	Middle Position	.55 (.33)	.79 (.16)	p=.033
Control	Phonological Recency	.60 (.27)	.87 (.12)	p=.006
Recovered	Phonological Primacy	.94 (.10)	.92 (.13)	ns
and Age	Middle Position	.74 (.22)	.80 (.20)	ns
Control	Phonological Recency	.72 (.23)	.81 (.16)	ns
Recovered &	Phonological Primacy	.94 (.10)	.89 (.16)	ns
Reading	Middle Position	.74 (.22)	.73 (.24)	ns
Control	Phonological Recency	.72 (.23)	.79 (.17)	ns

Among normal readers, all phonological pretest serial position scores were significantly correlated with both word and pseudoword reading scores (page119). Correlations between the phonological pretest serial position scores and the reading measures were of higher magnitude than correlations between the phonological pre- and posttests and the reading scores. Among dyslexic readers, no significant correlations of phonological pretest serial position scores and reading scores were obtained.

Visual serial position curves are generally different in form from phonological curves. They do not show a primacy effect (Table 5A, 5B), suggesting that visual cumulative rehearsal does not occur. In this study, lowest mean visual serial position scores were obtained for the earliest list items, increasing to highest scores for the recency items. This was true for all groups tested. Dyslexic readers obtained the lowest mean visual serial position scores, for items in the primacy and middle positions. None of the group differences at individual serial positions were significant at the 5% level by t-test.

Temporal primacy scores were significantly higher on the pretest than posttest for some of the group comparisons. Repeated measures ANOVA for dyslexics and comparison groups showed a significant main effect for test time, $\underline{F}(1, 31)= 4.53$, $\underline{p}=.041$. For compensated dyslexics and comparison groups, there was also a significant main effect of test time, $\underline{F}(1, 53)= 4.80$, $\underline{p}=.033$. Temporal recency scores were significantly lower on the posttest than on the pretest for recovered dyslexics and comparison groups, $\underline{F}(1, 53)= 5.80$, $\underline{p}=.02$, but not for dyslexics and comparison groups. Temporal recency effects, represented by significant main effects in 3 x 2 ANOVA comparison of reading group x primacy-to-recency scores, were significant for both the temporal pretest, $\underline{F}(1, 56)= 35.68$, $\underline{p}< .001$, and the posttest, $F(1, 57)=26.61$, $p< .001$, for dyslexics, compensated dyslexics, and normal readers.

The temporal posttest primacy score, and posttest middle position score, representing visual recall of a newly learned visual character with visual retroactive interference, were significantly correlated with WRAT word reading scores in normal readers, $\underline{r}(27)=48$, $\underline{p}=.008$ and $\underline{r}(27)=44$, p=.017 respectively. The temporal posttest primacy score was also significantly correlated with word reading in the entire sample, r(58)=.33, p=.010. Temporal posttest middle position scores were significantly correlated with pseudoword reading in the children with normal reading skills, r(27)=.41, p=.029. None of the visual serial position scores were significantly correlated with reading scores in the dyslexic group. [In the compensated dyslexic group, a significant negative correlation between temporal pretest primacy and word reading, r(15)=-.54, p=.025, and a significant positive correlation between temporal posttest primacy and non-word reading, r(15)=-.54, p=.026, were obtained.]

Among dyslexic children, there was a significant negative correlation between the phonological pretest and training score, phonological pretest primacy and training score, phonological pretest middle position and training score, and phonological pretest recency and training score, r(7)=-.78, p=.014; r(7)=-.81, p=.008; r(7)=-.73, p=.024; r(7)=-.68, p=.044 respectively.

Among dyslexic children, there were significant negative correlations between visual posttest recency and WRAT scores, r(7)=-.93, p<.001 but a significant positive correlation between visual posttest recency and phonological posttest recency, r(7)=.75, p=.020.

Among compensated dyslexic children, there were significant negative correlations between sequential pretest scores and sound symbol training scores, [sequential pretest scores and WRAT scores, and sequential pretest scores Woodcock scores, r(15)=-.63, p=.007; r(15)=-.62, p=.008; r(15)=-.65, p=.005)].

Figure 8: Phonological Pretest and Posttest Serial Position Curves for Dyslexic, Recovered Dyslexic, and Normal Readers

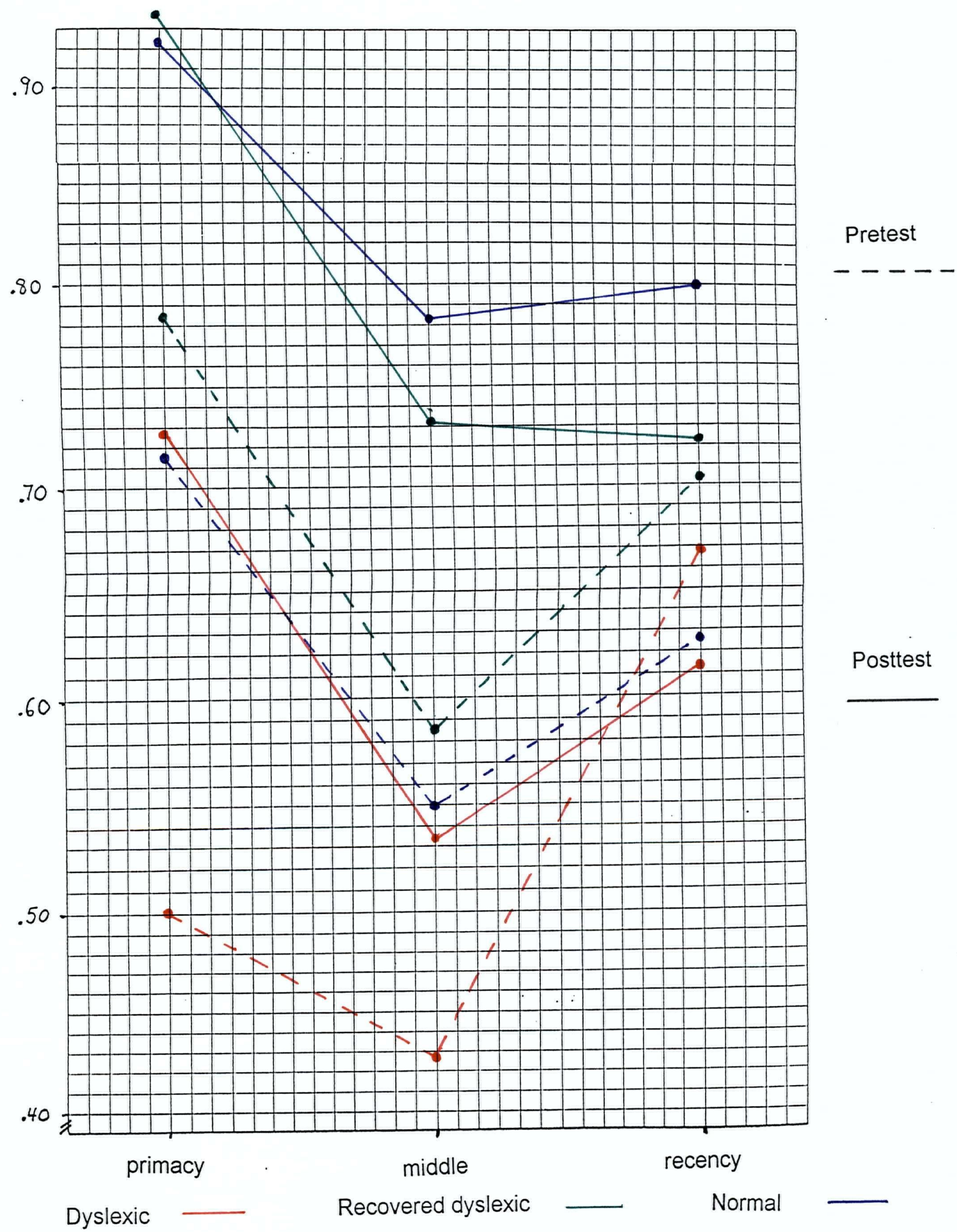
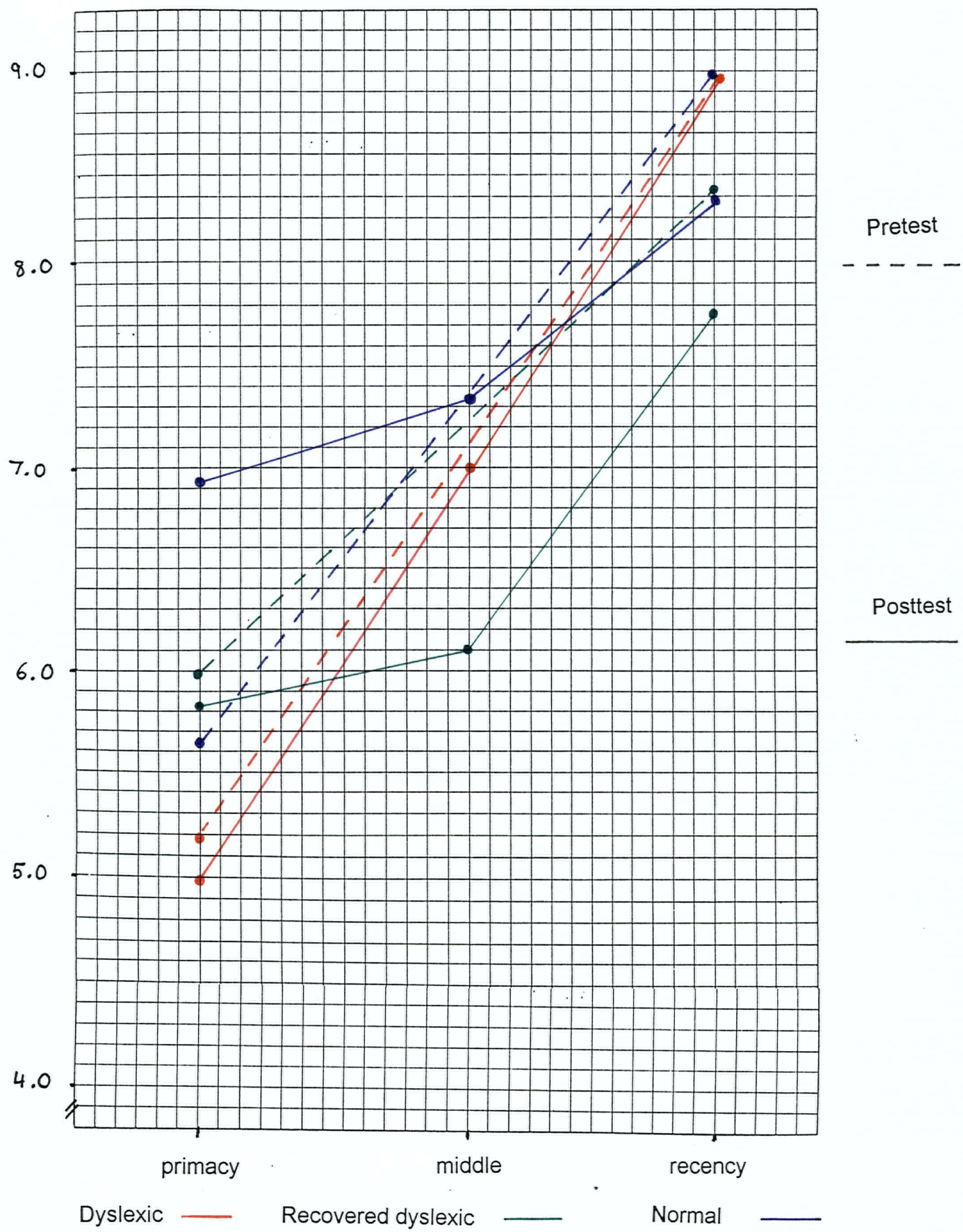


Figure 9: Visual Temporal Pretest and Posttest Serial Position Curves for Dyslexic, Recovered Dyslexic, and Normal Readers



CHAPTER 5: DISCUSSION

Summary

The study objectives were to identify some cognitive skills related to reading, to describe their relationship to reading disability, and to identify implications of the findings for remediation of dyslexia. Elementary aged children with dyslexia, enrolled in a private school program for remediation of reading disabilities, participated in the study. Their reading and memory scores were compared to those of normal readers in another private school. Four different types of memory significantly related to reading were identified.

These were phonological memory, visual iconic memory, visual memory span, and cross modal or associative memory. The phonological memory tests consisted of sequences of increasing length of phonetically regular non-words which the children heard and attempted to repeat; a non-word repetition span test. The visual memory tests consisted of arrays and sequences of increasing length of simple letter-like line drawings, displayed on a computer monitor, which the students attempted *to* recall when presented with a probe. The cross modal test was a training intervention, in which children learned to associate each of ten of the letter-like drawings with a unique pseudoword. The lack of consistent significant correlations between scores obtained on the measures of each type of memory suggests that different cognitive skills may be required for the four types of test.

In this study, children with a history of reading disabilities demonstrated deficits in three of the four types of memory assessed relative to the age comparison group, but only in phonological memory relative to the reading level comparison group. Dyslexic children showed deficits in phonological encoding and rehearsal on the non-word repetition test, as indicated by lower mean pretest phonological primacy performance relative to both control groups. They also had deficits in visual iconic memory relative to the age matched group, as well as to the reading level matched group when age was used as a covariate. Children whose reading disabilities had been successfully remediated did not show deficits on phonological or visual memory measures relative to either control group.

Significant associations between word and pseudoword reading and the phonological measures, especially phonological primacy, were obtained in the normal readers. The only phonological score significantly associated with reading in the dyslexic group was the primacy score, theoretically reflecting use of phonological rehearsal. Visual span serial position scores were associated with word and pseudoword reading in normal readers, and with pseudoword reading in the children with a history of reading disability. This is interpreted as reflecting the importance of sequential processing ability for the reading tasks. A significant association between iconic memory scores and reading was unique to the children with a history of reading disability. The iconic memory task had a spatial requirement, and its association with reading in the children with a history of dyslexia may suggest a spatial memory limitation affecting reading in this group. Compensated dyslexics also demonstrated superior iconic memory to those who were still dyslexic. Relatively stronger associations of visual memory scores with word than pseudoword reading in the total sample suggests a greater importance of visual processes in word reading.

Learning to associate ten visual elements from the visual tests with ten of the pseudowords from the phonological tests was significantly more difficult for children with a history of reading disability. Cross modal scores were significantly related to both reading scores for the total test population, for normal readers, and for children with a history of dyslexia. The children whose reading disability had been successfully remediated scored lower than their age peers on the sound symbol training, and also lower than their reading level matches when age was used as a covariate. Compensated dyslexics performed significantly better than dyslexics on this measure.

The sound symbol training intervention resulted in an increase in phonological memory scores, though the increase was significantly smaller for the dyslexic group than either comparison group. As a result, phonological posttest scores were significantly lower for the dyslexic group than for either control group. Phonological recency effects were significant on the pretest, but not on the posttest, for normally reading and compensated dyslexic groups, suggesting that rehearsal of early list items entails a cost in recency recall for normal readers. The dyslexic group had significant recency effects on both phonological tests.

Mean iconic memory scores decreased significantly following the sound symbol training for normal, but not for dyslexic, readers. The comparison groups had significantly higher mean scores than the dyslexic group on the pretest, but not on the posttest. This suggests possible use of a different memory strategy in the dyslexic group. Visual temporal primacy scores decreased following the sound symbol training in all groups. Visual recency scores also decreased for compensated dyslexics and comparison groups, but not for dyslexics and their comparison groups.

Serial position curves obtained from children with a history of reading disability were similar to those of both comparison groups. With respect to phonological curves, two marked differences were that, in contrast to comparison groups, dyslexic readers did not demonstrate significant primacy effects on the phonological pretest, and did demonstrate significant recency effects on the phonological pretest. Visual curves also showed a slight reading related difference in that compensated dyslexics and comparison groups showed a reduction in recency following the sound symbol training that was not observed in dyslexics and comparison groups. Otherwise, the observations made concerning these curves are true for all groups. This suggests that the memory processes used by children with reading disability may be the similar as those used by more skilled readers, but less effective.

Implications

Research has connected deficits in phonological and visual memory to reading disability (Eden, Stein, Wood & Wood, 1995; Farmer & Klein, 1995; Gathercole & Baddeley, 1989, 1990, 1993; Lovegrove, Billing & Slaghuis, 1978; Mauer & Kamhi, 1996; Morrison & Manis; 1982; Siegel, 1986, 1993; Slaghuis, Lovegrove & Davidson, 1993; Stanovich, 1986, 1988; Swanson, 1978, 1983, 1984, 1986; Torgesen, 1979; Vellutino & Scanlon, 1979; Wagner, Simmons & Laughon, 1990. Phonological deficits in dyslexia have been a particular focus of research efforts. Advances in experimental technology have made it possible to review in more detail the evidence for visual deficits. Associations between cross modal, sequential, and spatial memory deficits and reading disability have been documented (Enns, Bryson & Roes, 1995; Farmer & Klein, 1995; Mason, 1980; Snowling, 1980; Swanson, 1986; Torgesen, 1979). Efforts have been made to use the types of deficits observed in reading disabled populations in subtyping schemes (Ceci, Lea, and Ringstrom, 1980; Siegel & Heaven, 1986; Siegel & Ryan, 1988, 1989; Siegel & Linder, 1984).

However, research has also found many cognitive tasks which disabled readers perform significantly less well than skilled readers. "Mounds of correlations and significant differences have been found (Stanovich, 1986, page 361)" Stanovich (1986) cautioned that a thorough task analysis is necessary before the meaning of group performance differences can be interpreted.

Cognitive skill deficits often observed in dyslexic groups may be caused by the lack of reading development (e.g. vocabulary development, Gathercole & Baddeley, 1991), unrelated to reading (e.g. social interactions, Wagner & Kistner, 1990), related to reading but only at certain developmental stages (e.g. phonological awareness, Stanovich, 1986), associated with reading but not causally (e.g. achievement in other academic areas, Wagner & Kistner, 1990), or causally associated with reading. A reading level comparison group, as well as an age matched group, was used to help distinguish developmental delay associated with reading ability from cognitive deficits representing developmental deviance among disabled readers (Siegel & Ryan, 1988). Additionally, an effort was made in this study to select tasks that have a clear relationship to reading. No attempt is made here to draw conclusions as to the cause or specific locus of dyslexia, as was explained in the introduction. The focus here is instead on the implications of the results for the remediation of dyslexia in children.

According to Baddeley's model of memory, language is phonologically coded in short term memory, so that phonological coding is synonymous with verbal coding: "... I shall use the term 'phonological' in a purely neutral sense meaning speech-based." (Baddeley, 1986, page 75-76). Swanson (1986) defined a code as, "a descriptor that controls the ease with which stimulus properties may be placed in memory (p 204)." Reading is a working memory task, in that verbal material is continually processed, encoded and stored as new material is encountered. Functional phonological coding ability is therefore a necessary but not sufficient prerequisite for skilled reading by definition, if these models are accepted (Gathercole & Adams, 1993; Torgesen, Wagner, Simmons & Laughon, 1990; Torgesen, Wagner & Rashotte, 1994).

Phonological Memory

Phonological scores in this study were significantly intercorrelated, despite high variability in the data. This suggests that the tasks tapped a common underlying cognitive ability, although slightly different phonological skills are represented by the different tasks. The phonological pretest tested memory span for unfamiliar phoneme strings. The phonological posttest tapped memory for sounds that were partially familiar, less numerous, and possibly supported by visual images. Serial position scores reflect strategic behavior and the function of the phonological loop. Pretest to posttest phonological span changes and interaction effects of test type (pretest or posttest) with reading group reveal ways in which phonological memory processes work for normal readers, and break down for dyslexic children.

All the phonological tasks presumably reflect the function of the phonological loop, which plays an essential role in supporting types of memory required for skilled reading (Daneman & Carpenter, 1980, 1983). It allows the reader to retain material in memory while processing new material. If the phonological loop is deficient, processing of text, or even of the phonological elements in a single word to be decoded, could be extremely difficult.

Reading ability related differences in phonological memory were demonstrated in this study, although not on mean phonological pretest scores. Dyslexic children showed deficits in phonological rehearsal on the pseudoword repetition test, as indicated by lower posttest scores and lower scores at all serial positions, than either comparison group. Significant associations between word and pseudoword reading scores and the phonological measures, especially phonological primacy, were obtained in the normally reading group. The only phonological score significantly associated with reading in the dyslexic group was the primacy score, possibly reflecting a deficit in phonological encoding and rehearsal which may limit reading ability in this group. Children whose reading disabilities had been successfully remediated had lower scores at most phonological serial positions than the age matched comparison group, but the differences were not statistically significant.

Phonological encoding deficits in reading disabled children have been documented across a variety of tasks (see literature review). A phonological coding disability in reading disabled children should be most severe for sequences of unfamiliar phonological material (Farmer & Klein, 1995; Gathercole & Adams, 1993; Torgessen, 1979). Further, the deficit should distinguish dyslexic children from both age controls and reading level controls (Siegel, 1992, 1993; Stanovich, 1988; Stanovich & Siegel, 1994), and should be significantly related to reading ability (Gathercole & Baddeley, 1989, 1990, 1993; Gathercole, Willis & Baddeley, 1991; Siegel & Faux, 1989; Siegel & Ryan, 1988). The phonological memory pretest was designed to specifically illustrate this hypothesized deficit. However, comparing dyslexic children's mean phonological pretest scores to those of both age and reading level comparison children produced no significant differences.

The lack of significant weakness in the dyslexic group on the phonological pretest requires some explanation, and perhaps it can be explained in the context of Baddeley's theory. The range of phonological pretest scores was greater for dyslexic children than for normal readers. Some of the highest phonological memory pretest scores obtained were among dyslexic readers. Clearly not all of the dyslexic children tested had weaknesses in phonological memory span as measured by this test. If the dyslexic children have phonological deficits, they must have had a means to compensate for them on the phonological pretest.

According to Baddeley's model of working memory (Baddeley, 1986; Gathercole & Baddeley, 1993), a two-part phonological loop supports memory of linguistic material. One part can employ subvocal articulation (phonological rehearsal) to support memory of verbal material (Baddeley, 1986). The other component is a passive phonological storage buffer, specialized for obligatory encoding of auditory-verbal input (Salame & Baddeley, 1982). Theoretically, the passive component is directly activated by auditory-verbal input, without the necessity of active rehearsal. If this buffer were functional in some dyslexic readers, it might allow them to perform well on the pseudoword repetition task for short phonological strings (storage time is estimated at 1.5 seconds, Baddeley, Lewis & Vallar, 1984) although they had phonological rehearsal deficits. Dyslexic children who did well on the pseudoword repetition test might be using this passive mechanism, reflecting recall without encoding and rehearsal.

If high phonological span performance in some dyslexic children is based on articulatory storage without rehearsal, these children might be expected to show sharply diminished performance when the storage capacity of the buffer is exceeded. Among dyslexics and compensated dyslexics, the four highest scorers on the phonological pretest were able to correctly reproduce most of the elements of the four pseudoword lists, but only 40% of the phonological elements in the five pseudoword lists. Three of these children were not willing to attempt the six element lists, and the one who did, did not correctly repeat any of the phonological elements. Two normal readers who received similar scores on the phonological pretest continued on to the six element lists, correctly repeating 25% and 54% of the phonological elements on these lists.

Children who use passive phonological storage instead of rehearsal might also be expected to do poorly on tasks that require rehearsal. Sound-symbol training might be such a task, as it requires learning of new associations. In fact the Pearson partial correlation coefficients for the phonological pretest scores, phonological primacy scores, and phonological middle position scores to the sound-symbol training scores are all negative in the dyslexic group, although they are not significant:

phonological pretest and training, $r(8)=-.26$, $p=.49$;
phonological pretest primacy and training, $r(8)=-.48$, $p=.17$;
phonological pretest middle position and training, $r(8)=-.53$, $p=.11$.

These observations support the idea that dyslexic children may use passive articulatory storage in compensation for deficient phonological rehearsal capabilities for some verbal memory tasks.

Developmental studies have shown that the ability to read tends to develop concurrently with the ability to phonologically rehearse (Walker, Hitch, Doyle & Porter, 1994). Phonological primacy is taken to represent the role of phonological rehearsal in supporting memory for verbal material, which is essential for fluent reading (Baddeley, 1986; Hulme & McKenzie, 1992; Philips & Christie, 1977; Spring & Capps, 1977). An individual has most time to rehearse the earliest list items, so will remember them best. As young children are learning to read, their primacy performance should be improving.

Significant relationships between phonological primacy (as measured by primacy effects on the non-word repetition test) and reading scores could be taken as support for the premise that phonological rehearsal ability is necessary for reading development. Phonological pretest primacy scores in this study showed a significant relationship to word and pseudoword reading, especially in normal readers. This suggests that phonological rehearsal, as exemplified by this test, has a role in reading. Lower scores on phonological pretest primacy obtained by younger beginning readers in the reading level control group for the dyslexics reinforce this conclusion, as the grade 1 readers are at an age when rehearsal skills are thought to be developing (Hayes & Schulze, 1977; Hitch et al, 1988; Hitch et al, 1991; Walker et al, 1994). The laborious processing of text observed in dyslexic and beginning readers has been attributed to deficient rehearsal skill.

Deficits in phonological memory observed in dyslexic children were attributed to a reduced capacity for phonological storage, rather than to impaired rehearsal skills, by Gathercole and Baddeley (1990). Primacy effects noted in reading disabled children for shorter memory lists were interpreted as evidence of phonological rehearsal. Gathercole and Baddeley (1990) suggested that children may shift to a non-phonological strategy when lists exceed their phonological storage capacity. The observation that dyslexic children use rehearsal in memory tasks does not necessarily imply that they use it as effectively as skilled readers.

Phonological primacy scores were compared to phonological middle position scores, to determine whether the primacy effects (higher score for beginning list items) were significant. There were no significant primacy effects for the phonological pretest in the dyslexic group. Pretest primacy effects were significant in all other groups. Phonological posttest primacy effects were significant in all groups. Dyslexic children may have been unable to use rehearsal on the phonological pretest if encoding limitations made it difficult for them to accurately remember the novel sound combinations. Perhaps dyslexic children are able to improve their phonological rehearsal skills through their remedial phonics work. Compensated dyslexic children did not show a mean phonological primacy deficit relative to their comparison groups.

The presence of posttest phonological primacy effects in dyslexic readers suggests that they can and do use phonological rehearsal as a memory strategy (Baddeley, 1986; Gathercole & Baddeley, 1993). This strategy is less effective for them than for normal readers, as is suggested by their significantly weak performance relative to the age comparison group. It is not really possible to determine, in this case, whether dyslexic children showed deficits because the longer lists exceeded their passive storage capacity, or because their rehearsal abilities are limited.

The phonological curves for the dyslexic group most closely resemble those for the reading level control children. The phonological pretest results suggest that phonological memory in dyslexics, especially the use of phonological rehearsal, is like that of younger children reading at the same level. Based on this finding, one could conclude that the relationship of phonological memory to reading in dyslexic children can be characterized as a developmental delay (Baddeley, Ellis, Miles & Lewis, 1982; Bryant & Impey, 1986). However, examination of the sound-symbol training effects and posttest results refutes this conclusion.

The sound-symbol training did facilitate performance on the phonological task. All groups had significantly higher phonological span scores on posttest than on the pretest. Training interacted significantly with the phonological scores, resulting in significantly greater gains for normal than dyslexic readers, and significant differences in phonological posttest scores between dyslexics and the age-matched comparison group. As posttest scores were significantly correlated with the training measure in normal readers, it is possible that the visual symbols may have been used as a memory aid for the phonological posttest. Training scores were not significantly associated with the phonological posttest in the dyslexic group, so for these children the increase in the scores is probably due to familiarity with the sounds. The phonological posttest required phonological memory for sequences of somewhat familiar sounds, a simple phonological memory task for a skilled reader.

The facilitative effect of the training was less pronounced in dyslexic children. This is presumably because they had more difficulty storing, retaining, or retrieving phonological elements from memory than their normally reading peers (Siegel & Linder, 1984; Siegel & Ryan, 1988), and did not benefit from the referential coding. Fifty percent of the dyslexic children, but only 7% of the normal readers, did not master the ten sound symbol associations during the sound symbol training intervention. Mauer and Kamhi (1995) also found children with reading disabilities to be slower to learn sound symbol correspondences than normal readers. This is in contrast to Swanson's report (1986) that there was no reading related difference in number of trials to criterion on his sound symbol training procedures. However, he used meaningful common words as names, and the present study used pseudowords. The pseudowords are novel sound combinations, so were probably harder for the children to memorize that familiar combinations. Clearly, this was especially true for dyslexic children.

Cross modal memory scores, as represented by the sound-symbol training procedure used, were related to reading across all reading groups. This supports findings of Snowling (1980) that reading skill deficits of children with dyslexia are associated with extreme difficulties in learning to apply symbol-sound correspondence rules. Cross modal scores also showed significant group differences between the reading disabled group and both comparison groups, and between compensated dyslexics and the age-matched comparison group. They were strongly related to phonological posttest primacy and recency scores in the grade 1 readers forming the reading level comparison group for the dyslexics. The scores were significantly correlated with iconic memory scores in normal readers. Training scores were not significantly associated with any of the memory variables in the dyslexic group, and only weakly correlated with some of the phonological scores in the total test population.

Stanovich (1986) discussed skills that are developmentally limited with respect to their effect on reading. That is, some skills affect the acquisition of reading at certain stages, but become so automatic at later stages that they no longer are limiting factors. Most of the skilled readers tested in this study were probably able to encode the novel sound combinations sufficiently easily so that learning the pseudowords themselves was not a limitation for them in learning the sound symbol associations. Phonological encoding may reflect a skill which is normally involved in learning of sound symbol correspondences in a developmentally limited way. Developmentally persistent phonological encoding limitations may affect the ability of dyslexics to learn novel sound symbol associations.

Cross modal performance seems to represent a developmentally limited skill, that is dependent on phonological skills in very young children, and more dependent on visual skills as children get older. Deficits in this area among dyslexic children are highly significant, and seem to be separate from visual and phonological skills as represented by the tests used in this study. Cross modal deficits in the dyslexic group do not seem to merely reflect deficits in the phonological aspects of the task, as has been suggested (McDougall et al, 1994, Vellutino & Scanlon, 1982).

If the tendency to use verbal labels to support visual memory develops concurrently with beginning reading skills (Hitch et al, 1988; Hitch et al, 1989; Hitch et al, 1991; Walker et al, 1994), and its development is an essential prerequisite for cross modal performance, cross modal and phonological scores should be associated in the grade 1 children as well as in the dyslexics. A significant association of phonological posttest primacy and recency scores and training scores was observed in these beginning readers.

The phonological pre- and posttests require somewhat different phonological skills: pretest performance depends on the children's ability to encode completely novel sounds. The posttest scores reflect the ability to memorize strings of somewhat familiar sound combinations. For the grade 1 (and one grade 2) children in the reading level control group for the dyslexics, cross modal scores were not significantly related to phonological pretest scores, but only to phonological posttest serial position scores. These children were apparently not limited by their ability to encode novel sound combinations in memory, but were limited by their ability to recall longer series of the sound combinations, in keeping with the results of Walker, et al (1994). This could be attributed to limitations in rehearsal.

Children in the dyslexic group showed a reduced primacy effect approaching significance on the phonological pretest, which suggests that these children were not using phonological rehearsal as much as the skilled readers. On the phonological posttest, dyslexic children showed similar primacy effects to the other groups. Dyslexic children may have been relying on echoic memory to support phonological memory without rehearsal on the pretest, as was suggested earlier. This would suggest that the limitations of the children in the dyslexic group were more related to the encoding of the novel sound combinations than to rehearsal ability. Although the phonological pretest performances of the dyslexic children and their reading level comparison group were similar, the performances seem to reflect different types of limitations.

Among grade 1 students only (the reading level control group for dyslexics), word and pseudoword reading scores were significantly associated with phonological pretest primacy and middle position scores.

In this group, as in the dyslexic group, there were fewer significant correlations of phonological scores to reading measures than in the total test population. The group mean differences between the dyslexic group and its reading level comparison students were only significant for scores reflecting phonological rehearsal ability.

If children need to develop phonological encoding skill to a certain level before they can gain knowledge of sound symbol correspondences, this must happen before grade 1, since the encoding per se does not appear to be limitation for the children in the reading level control group for the dyslexic readers. The normal beginning readers (the reading level control group for the dyslexics) showed the greatest gain in phonological pretest-to-posttest scores of any of the six groups tested. They were significantly more able to benefit from the newly learned associations in supporting memory for pseudoword sequences than the dyslexic children, as indicated by their significantly higher mean phonological posttest score. Perhaps these young children are particularly adept in mastering novel sound combinations. This seems sensible, as the grade 1 children are at a stage when vocabulary is likely to be growing fast. This difference between the dyslexics and their reading level matched comparison group suggests a developmental deviance in the dyslexic group, as opposed to a developmental lag.

Phonological posttest serial position scores did not show recency effects (a significantly higher score at the recency position relative to the middle position score), as did the pretest scores, except for the dyslexic group. Strength in phonological recency in dyslexic readers was demonstrated in other studies (Farnham-Diggory & Gregg, 1975; Spring & Capps, 1974). In this study, what was observed was a weakness in posttest recency in skilled readers. For all comparisons, posttest primacy scores were significantly higher than posttest recency scores. Normal readers had significantly higher phonological recency scores on the posttest than on the pretest, but no significant posttest recency effect.

The reduction in recency scores following training suggests that the children are using phonological rehearsal to support memory, but that by doing so they impair their ability for immediate memory. The impairment was greatest in the dyslexic group, reducing the phonological posttest recency score to below the pretest recency level. Primacy and middle position scores were significantly higher on the phonological posttest than the pretest for normal readers and compensated dyslexics, indicating more effective rehearsal of posttest lists.

Coltheart (1980) described a mechanism which he named a "lexical monitor," which seems relevant to these observations. According to Coltheart:

> ...setting up an iconic memory consists of temporarily attaching various forms of physical information to a permanently existing entry in the internal lexicon. The attachment is a rapid, automatic process of unlimited capacity; but the attached information decays rapidly... a lexical monitor must operate on the physical information, transforming it into some more durable form (page 223).

He described the mechanism in the context of visual iconic memory, not phonological memory. Since the lexical monitor would presumably access a semantic memory trace dually coded with visual and linguistic features, a similar mechanism could be postulated for phonological icons.

Coltheart described a processing bottleneck, as "lexical entries" are accessed. When some number of lexical representations are accessed, the abilities of the lexical monitor will be taxed, and no further "stabilization" will occur. Coltheart suggests that the number may differ from individual to individual. The effort to stabilize the phonological contents of the passive storage buffer (hypothesized by Baddeley, 1986) by phonological rehearsal may be a processing bottleneck for children with low phonological rehearsal skills.

The phonological score increase for compensated dyslexics following sound symbol training was not significantly different from those of their age matched or reading level matched comparison groups. Reading group x test interaction effects were not observed in comparisons involving compensated dyslexics, suggesting that the compensated dyslexics were able to benefit from familiarity with the sounds in a manner similar to normal readers. For this group, training scores were significantly associated with phonological posttest recency. This may suggests the possibility of a facilitative effect due to the dual codes, at least for items in the recency position.

In compensated dyslexics, the sound symbol training had a facilitative effect on memory span similar to that of reading level comparison students. It could also be attributed to familiarity with the novel phoneme combinations. This group seems to have superior phonological rehearsal mechanisms to the dyslexic group. It is possible that these children entered the remedial program with superior phonological rehearsal skills which allowed them to "recover." But it is also possible that children learn phonological rehearsal skills through their remedial training. A longitudinal study would be needed to assess these two possibilities.

The extensive oral practice of individual phonemes provided by the remedial program is intended to make students familiar with the sounds of English phonemes. The increased facility of the compensated dyslexic group for learning sound symbol associations may be related to more extensive experience with sound symbol training in the remedial program.

Visual Memory

The nine visual variables representing two types of visual memory tested in this study were not consistently intercorrelated (see Appendix A). This suggests that different cognitive skills may be tapped by the measures. Although many authors claim that visual coding is intact in disabled readers (Vellutino, Steger & Kandel, 1972; Vellutino, Steger, Harding & Philips, 1975; Shankweiler, Liberman, Mark, Fowler & Fischer, 1979; Hulme, 1988; Katz, Shankweiler & Liberman, 1981; Torgesen, 1988), the dyslexic group had a significant deficit relative to age- matched comparison students on the iconic pretest. In fact, relative to both comparison groups, the dyslexic group had consistently lower mean visual scores. The possibility of a strength in iconic storage among dyslexic children was not supported in this investigation. The dyslexic children had deficits in visual iconic memory relative to the age matched group, as well as to the reading level matched group when age was used as a covariate.

The use of the covariate was intended to remove the influence of age related factors like attention, response time, and manual dexterity which might affect performance on the tests. When the effects of age are taken into account in this way, dyslexic readers scored lower on iconic memory than both chronological and reading age comparison students. This suggests that observed visual memory deficits, like phonological primacy deficits, may represent a developmental difference, and not a developmental lag as has been postulated in other research.

These results are in contrast to expectations explained in the introduction. Visual deficits observed in dyslexic readers have been attributed to blurred or overlapping images caused by visible persistence. If this is true, dyslexic children might be expected to show strength on a test of visual iconic memory, since the persistence of the image could support performance on the task. Dyslexic children could also be expected to have more difficulty with the visual temporal test, on which persistent images would probably impair performance. A deficit on the temporal test, if it were due to the overlapping of images, would likely be most pronounced in the primacy position, so a significant deficit in temporal primacy in the dyslexic group would be expected. As these predictions were not realized, either visual deficits in the dyslexic group are not due to persistent images, or persistent images do not support immediate visual memory.

Visual memory scores of compensated dyslexics were quite similar to those of their reading level matches. The compensated dyslexic group had stronger visual memory skills than the dyslexic group, especially in iconic memory. This may imply that improvement in iconic memory is related to recovery from reading disability, or that children with superior iconic memory skills have a better chance of successful remediation. Visual iconic memory was related to reading ability in children with a history of dyslexia (the dyslexics and compensated dyslexics combined).

The visual tests had a motor response requirement (pressing the correct key). It is possible to interpret observed score differences in terms of differences in motor skills. However, response latency may be considered an indication of difficulty with the motor response, and it was not related to reading ability when age was partialled out, but was significantly related to age.

Visual memory scores presented a more complex picture than phonological scores in their relationship to reading. Visual memory, especially iconic memory, was related to reading ability in the children with a history of dyslexia, and was greater in compensated dyslexics than in dyslexics. Iconic pretest scores were significantly correlated with word and pseudoword reading (using partial correlation, controlling for age), $\underline{r}$=.62, p=.001 in the entire test population. When data for dyslexic and compensated dyslexic children is combined, the iconic pretest score was significantly related to WRAT, r(28)=.46, p=.01, and Woodcock scores, r(28)=.40, p=.03. This correlation did not approach significance in the normal reading group. The iconic memory measure, not obviously like a reading task, apparently tapped some cognitive skill important for reading, especially in dyslexic readers.

The association of iconic scores with both word and pseudoword reading in children with a history of reading disability may reflect a strategic difference, or a limiting role of the visual skill tapped in reading ability. The iconic test had a spatial requirement which was not present in the visual span test. This may be the factor underlying the observed association of iconic memory and reading, which seems unique to the children with a history of dyslexia. Previous research has provided evidence of spatial memory deficits in dyslexic children (Enns, Bryson & Roes, 1995).

Visual span (temporal) posttest scores were not significantly associated with either reading measure in any group, but some of the serial positions scores were related to reading scores. Temporal posttest primacy and middle position scores were significantly related to word and pseudoword reading in the entire population, and to pseudoword reading (but not to word reading) in normal readers. Temporal posttest middle position scores were significantly associated with pseudoword reading in the normally reading group. In children with a history of dyslexia (dyslexics and compensated dyslexics combined), there was a significant association of temporal posttest primacy with pseudoword reading. Maintenance of visual images in the presence of retroactive interference is presumably a determinant factor in performance on temporal primacy, and has a logical relationship to skilled reading.

There was a significant correlation of temporal posttest primacy and the phonological posttest score in the dyslexic group. This raises the possibility that children with dyslexia were attempting to use the pseudoletters to support memory for the sounds, or the sounds to support memory of the images. The ability to do this may have been a limitation in the dyslexic group. This significant correlation was not observed in any of the other groups.

Both word and pseudoword reading were significantly associated with visual span (temporal) posttest primacy scores in the youngest group in this study (the reading level comparison group for the dyslexics). This test may tap sequential processing skills related to reading for these young children. The grade 1 children in the reading level control group for the dyslexics showed relatively stronger associations of visual span primacy scores to reading measures than the disabled or normal readers, with correlation coefficients ranging from .68 to .90.

Phonological scores were more consistently associated with both word and pseudoword reading among normal readers than were the visual scores. There were fewer significant correlations of phonological scores with reading measures in the children with a history of dyslexia, and significant correlations of scores from both visual measures with reading scores. The larger number of significant correlations between phonological measures and reading in normal readers, and of visual memory and reading in children with a history of reading disabilities, can be interpreted in two ways. Dyslexics may use a more visual strategy for reading, or may have visual limitations that affect their use of normal phonological strategies.

There is some evidence that dyslexic children, like younger children, rely more on visual reading strategies than phonological ones (Siegel, 1986; Siegel, Share & Geva, 1995; Stanovich & Siegel, 1994; Swanson, 1984). It is also possible that high memory score variability, low power of some of the tests, and a small sample make it impossible to establish a significant relationship, even though the cognitive skills used by dyslexic individuals may be the same as those used by normal readers. More data may be needed to clarify the relationship of visual memory to reading in dyslexics.

Visual memory as measured by the iconic memory task clearly plays a greater role in word reading than pseudoword reading, as it is not significantly related to Woodcock word attack scores in the total sample. This is logical, as visual memory for whole words plays an important role in fluent reading, but could not play much of a role in decoding of novel sound combinations. Stanovich (1986) asserted that in skilled readers, whole word reading occurs by a automatized visual route, as opposed to by the more laborious process of letter by letter decoding. The correlation of iconic memory scores with word reading might reflect some aspect of the role that facility of access to and maintenance of visual representations plays in use of the visual route for word reading. It is not obvious from the present data what the nature of this relationship could be, or why a task with a speeded visual recognition memory and a visual spatial component should illustrate it.

Sound-symbol training did not result in an improvement in visual memory for the visual symbols. Rather it seemed to do the opposite, more for normal readers than dyslexics. Possibly the reduction in performance from pretest to posttest, observed in normal readers and compensated dyslexics, represents ineffective efforts to use verbal coding as a memory aid on a predominantly visual task. Other research has provided examples of non-productive efforts to use a phonological strategy for a task best performed visually (Brandimonte, Hitch & Bishop, 1992a, 1992b; Schooler & Engstler-Schooler, 1990). Skilled readers are assumed to be flexible in their choice of memory strategies, but verbal coding seems to a human reflex, and is at times used even when it is not the most effective strategy for a memory task (Brandimonte, Hitch & Bishop, 1992c; Schooler & Engstler-Schooler, 1990). "It seems that, whenever possible, verbal recoding of visual stimuli is used, and this affects subsequent visual image processing... (Brandimonte, Hitch & Bishop, 1992a, page 165)." Dyslexic readers are believed to have less flexibility in their choice of strategy (Swanson, 1986).

Cross Modal Memory

Swanson (1986) claimed, based on a series of label training experiments, that disabled readers are unable to combine verbal and visual codes additively. The results here may support Swanson's claim, but with some important differences. In Swanson's studies, children learned 6 real word names for shapes. There was no reading related difference in trials to criterion. The names used by Swanson were words that even the dyslexic children knew well. In the present study, the names were pseudowords, and half of the dyslexic children never reached the mastery criterion of being able to recite all names in one complete presentation of the set.

In Swanson's study, name training reduced recall for dyslexic readers, but increased it for normal readers. In this study, name training seemed to reduce recall of the visual stimuli, more for normal than dyslexic readers. Although this seems to contradict Swanson's results, it is not necessarily inconsistent with Swanson's conclusions. In Swanson's experiments, the skilled readers mastered the codes, and used them successfully to support recall. In this study, the sound symbol task was more difficult. Skilled readers had difficulty in using the sound symbol associations successfully to support memory span, and the effort to do so resulted in a decrement in recall. This is similar to what happened to the dyslexic readers in Swanson's experiment. In this study, name training probably had less effect on recall in the dyslexic group because the children in this group were not using the names to support recall.

Obviously the novel sound-symbol relationships presented in this study were not "overlearned" to the point of mastery, and if they had been, a different pattern of results might have emerged. But in this case, visual memory (essential to word reading) was reduced after phonics training, and more for normal readers than for dyslexic ones. The visual-phonetic associations presented in a multisensory program will not, by analogy, improve visual recognition of words if the sounds and associations are not mastered to automaticity. In fact, they may interfere with whole word learning, though this could be less of a problem for children with dyslexia than for normal readers, possibly because dyslexic readers will not try to use a phonetic strategy as diligently.

Overview

In summary, dyslexic children had deficits on some of the measures of three of the four types of memory tested in this study. Phonological deficits were most evident in comparison of dyslexic readers to age matched normal readers. Only on phonological posttest serial position scores did dyslexics show deficits relative to reading level matched comparison students. Examination of the serial position data suggests that the phonological memory performance of the dyslexic group was not equivalent to that of the beginning readers in the reading level comparison group. The dyslexic children's limitations seemed to be related to encoding, whereas those of the younger children seemed to reflect rehearsal limitations.

Following the sound symbol training, phonological memory scores increased for all groups, though significantly less for the dyslexic group than for the comparison groups. Use of phonological rehearsal for the posttest lists, as indicated by significant primacy effects, seemed to entail a reduction of recency performance. It is suggested that the laborious phonological processing and encoding involved in phonological rehearsal of the pseudowords blocks further phonological processing.

Visual and cross modal scores of the dyslexic group also reflected significant differences from comparison groups. This is attributed to familiarity with the sounds on the posttest, rather than to the facilitative effect of multiple coding. Visual iconic memory deficits were demonstrated in the dyslexic group relative to the age comparison group. The dyslexic group showed deficits on both types of visual memory relative to the reading level comparison group when age was used as a covariate. The dyslexic group also showed weaker cross-modal performance than either comparison group. Visual memory scores were reduced following the sound symbol training, less for the dyslexic group than for the others. Since sound symbol training weakened visual recall in this research, the success of the remedial program is probably not due to its multisensory approach. More likely, it is due to the intensive training in phonics that the program entails.

The normal readers presumably attempted to use the learned names to support memory of the symbols, to the overall detriment of achievement. Perhaps the dyslexic group was less inclined to attempt this. This also has an important implication for remedial practice. Normal readers seem to reflexively use verbal coding when it is available, even for tasks which are best performed visually. Dyslexic readers seem less inclined to use the verbal codes, and in a remedial setting probably will not use them unless they are highly automatized. Thus "overlearning" is considered an important component of remediation.

The present data do not support the contention that dyslexic children with very weak phonological skills have compensatory high visual skills (see discussion in Stanovich & Siegel, 1994). Dyslexic children showed deficits in both visual and phonological memory. Children with relatively low scores on both phonological and visual measures have not learned to read at grade level, sometimes despite remedial language training over 3 or even 4 years. There is some evidence that dyslexic children use a more visual strategy than normal readers, as their word reading scores are only correlated with the iconic memory measures. Reading scored in normal reading groups were more strongly associated with phonological memory. Dyslexic readers may get better at using a visual strategy as they learn to read, as iconic memory scores were significantly higher in compensated dyslexics than in dyslexics.

As reading disabled children begin, through remedial training, to learn to read, they may make gains in most of the aspects of memory tested. Significantly higher scores were noted on phonological primacy, on the iconic memory test and on sound-symbol training scores. Compensated dyslexics seemed to derive more phonological memory benefit from the sound symbol training than did dyslexic readers, as indicated by higher phonological posttest serial position scores. Some improvement in the function of phonological memory may occur as the children learn to read.

Memory scores of the compensated dyslexic group were not significantly different from those of comparison groups, with a single exception. The mean sound symbol training performance of the compensated dyslexic group was weaker than that of the age comparison group. Their sound symbol training was also below that of the reading level comparison group when age was used as a covariate. The reading scores of the compensated dyslexic group were also lower than those of the age comparison group, so the sound-symbol score could be considered to be tied to reading ability. In other respects, their mean memory scores were similar to those of the comparison groups.

Compensated dyslexics have some visual and phonological skills at a higher level than dyslexics. Statistically significant differences between dyslexics and compensated dyslexics were in iconic memory and sound-symbol training score. Through remedial training, dyslexic children seemed to increase their ability to recognize and recall letter-like figures, to encode sounds in memory (phonemic awareness), and to form associations between sounds and symbols. The success of this form of remediation was noted by Torgesen, Wagner & Rashotte (1994).

The higher reading ability of compensated dyslexics is associated with the higher scores in visual and phonological memory. The compensated dyslexic children do not have the visual and phonological deficits associated with dyslexia, which suggest a developmental deviance rather than a lag in language development tied to reading ability. Rather, they show memory skills that are equivalent to those of reading level comparison students. The iconic memory score difference between dyslexics and compensated dyslexics may represent development of a stronger visual strategy to offset phonological encoding deficiencies.

Sound symbol training did strengthen phonological memory span in this study. This seemed to be due to familiarity with the sounds rather than to a facilitative effect of multiple coding, as phonological posttest scores were not related to visual posttest or training scores.

Future Directions and Applications

There is little or no research literature available concerning dyslexic children who have learned how to read. In fact, there is very literature available concerning the possibility that dyslexic children can learn to read, although there is some (Lovett, 1992; Torgesen & Morgan, 1990). That dyslexic children have some cognitive deficits that can be characterized as developmental differences and some that can be characterized as developmental delays has been substantiated through research (Siegel & Ryan, 1988).

Whether these deficits are remediable is an unexplored area. This study offers some weak support for the possibility that remediation is possible, even for the deficits commonly characterized as developmental deviance, because the compensated dyslexic group did not have the deficits relative to comparison groups. In order to really assess this possibility, a longitudinal study would be needed, in which cognitive and reading skills were assessed at several points during the remedial program. This would help to clarify the nature of the deficits, their accessibility to remediation, and the degree to which they are tied to reading skill development. Specific deficits connected with dyslexia in this research are phonological encoding and rehearsal, visual iconic memory, spatial memory, and associative memory. Some children who have pronounced deficits in both visual and phonological memory seem to have had great difficulty learning to read phonetically. This seemed to be predictable enough to justify using the measures similar to the ones designed for this study as screening tools. It would be worthwhile for future research to attempt to connect specific remedial practices to improvements in these cognitive areas.

This study supports the use of a structured phonics program with severely reading disabled children. The evidence seems strong enough to endorse more extensive use of this type of program with reading disabled elementary children. Possibly it is the structured direct phonics instruction that makes the program successful, more than its multisensory nature. Some suggestions to guide remedial practice are provided based on interpretation of the results.

Phonological deficits observed in the children with dyslexia in this study seem best characterized as encoding deficits. The distinction of encoding vs. rehearsal deficits in dyslexic children could be a topic for further research. These children may have difficulty in mastering sound symbol correspondences because they have difficulty in becoming familiar with the sounds. The extensive repetition and drill of the sounds provided by the remedial program is probably helpful in making the students familiar with and more aware of the sounds. This is probably one of the reasons why the program is effective. Visual deficits may be characterized as iconic or spatial. Although visual span deficits were not demonstrated here, this may be an artifact of the test design, so further study of this may be warranted. It is less clear how the remedial program supports improvement in the visual areas, but it seems important to gain more understanding of this, as this was a main difference between children with dyslexia and ones who had recovered from dyslexia. The constant cross modal training involved in remediation probably helps to produce the significant difference between dyslexics and recovered dyslexics that was noted.

Clearly use of verbal labels for visual symbols can reduce visual response accuracy. This has implications for remediation, because in a phonics program children learn to use phonological decoding skills instead of sight reading skills. This may increase their reading vocabulary to something approaching fluency, but may also reduce automaticity to the detriment of comprehension (Stanovich, 1986). It would seem important, once children have learned to read by decoding, to emphasize sight reading of more common words and speed reading in general in order to avoid a reduction in fluency due to too much decoding. Development of sight reading instruction methodology to support remedial phonics instruction would benefit the learning disabilities field.

It was observed that a reduction in recency performance can result from the effort to use phonological rehearsal to support memory. This is consistent with the idea that simple sentences and instructions work best for dyslexic children. Longer and more complicated verbal strings may not be processed accurately. Oddly, this seems more true for skilled readers and compensated dyslexics, but this may reflect the degree to which children with dyslexia attempt to process the verbal strings. Since children with dyslexia may not attempt to process verbal material unless its elements are overlearned to a point of automaticity, a great deal of repetition is probably an important element of remediation.

The literature documenting cognitive deficits in dyslexic children is extensive, perhaps too extensive for too little benefit. Documenting specific weaknesses in some of these children will not necessarily help any individuals, unless deficits can be directly related to therapeutic interventions. The literature on remediation of dyslexia is still meager, and would be a fruitful area for further work.

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APPENDIX A: Intercorrelations of Visual Memory Variables

DYSLEXIC GROUP ONLY - PHONOLOGICAL, TRAINING AND READING VARIABLES
13 May 99 SPSS for MS WINDOWS Release 6.1

--- P A R T I A L   C O R R E L A T I O N   C O E F F I C I E N T S ---

Controlling for.. AGE

	PHMPRE	PHMPOST	PHONM1A	PHONM2A	PHONM3A	PHONM1B
PHMPRE	1.0000 (0) P= .	.8331 (9) P= .001	.6908 (9) P= .019	.7777 (9) P= .005	.6425 (9) P= .033	.6124 (9) P= .045
PHMPOST	.8331 (9) P= .001	1.0000 (0) P= .	.7714 (9) P= .005	.6452 (9) P= .032	.5456 (9) P= .083	.8499 (9) P= .001
PHONM1A	.6908 (9) P= .019	.7714 (9) P= .005	1.0000 (0) P= .	.7559 (9) P= .007	.7328 (9) P= .010	.8356 (9) P= .001
PHONM2A	.7777 (9) P= .005	.6452 (9) P= .032	.7559 (9) P= .007	1.0000 (0) P= .	.6751 (9) P= .023	.5771 (9) P= .063
PHONM3A	.6425 (9) P= .033	.5456 (9) P= .083	.7328 (9) P= .010	.6751 (9) P= .023	1.0000 (0) P= .	.6486 (9) P= .031
PHONM1B	.6124 (9) P= .045	.8499 (9) P= .001	.8356 (9) P= .001	.5771 (9) P= .063	.6486 (9) P= .031	1.0000 (0) P= .
PHONM2B	.6757 (9) P= .022	.8318 (9) P= .002	.6434 (9) P= .033	.7051 (9) P= .015	.3855 (9) P= .242	.7692 (9) P= .006
PHONM3B	.5087 (9) P= .110	.7771 (9) P= .005	.5796 (9) P= .062	.3350 (9) P= .314	.1584 (9) P= .642	.6757 (9) P= .022
TRAIN	-.2438 (9) P= .470	-.2643 (9) P= .432	-.4771 (9) P= .138	-.5207 (9) P= .101	-.1985 (9) P= .558	-.0829 (9) P= .809
WRATPCTL	-.3379 (9) P= .309	-.1076 (9) P= .753	-.2045 (9) P= .546	-.1611 (9) P= .636	-.2183 (9) P= .519	.1315 (9) P= .700
WDCKPCTL	-.1261 (9) P= .712	.0358 (9) P= .917	.3001 (9) P= .370	.0507 (9) P= .882	.3620 (9) P= .274	.2787 (9) P= .407

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

--- PARTIAL CORRELATION COEFFICIENTS ---

Controlling for.. AGE

	PHONM2B	PHONM3B	TRAIN	WRATPCTL	WDCKPCTL
PHMPRE	.6757 (9) P= .022	.5087 (9) P= .110	-.2438 (9) P= .470	-.3379 (9) P= .309	-.1261 (9) P= .712
PHMPOST	.8318 (9) P= .002	.7771 (9) P= .005	-.2643 (9) P= .432	-.1076 (9) P= .753	.0358 (9) P= .917
PHONM1A	.6434 (9) P= .033	.5796 (9) P= .062	-.4771 (9) P= .138	-.2045 (9) P= .546	.3001 (9) P= .370
PHONM2A	.7051 (9) P= .015	.3350 (9) P= .314	-.5207 (9) P= .101	-.1611 (9) P= .636	.0507 (9) P= .882
PHONM3A	.3855 (9) P= .242	.1584 (9) P= .642	-.1985 (9) P= .558	-.2183 (9) P= .519	.3620 (9) P= .274
PHONM1B	.7692 (9) P= .006	.6757 (9) P= .022	-.0829 (9) P= .809	.1315 (9) P= .700	.2787 (9) P= .407
PHONM2B	1.0000 (0) P= .	.6484 (9) P= .031	-.2972 (9) P= .375	.0397 (9) P= .908	-.0834 (9) P= .807
PHONM3B	.6484 (9) P= .031	1.0000 (0) P= .	-.1370 (9) P= .688	-.2535 (9) P= .452	.2504 (9) P= .458
TRAIN	-.2972 (9) P= .375	-.1370 (9) P= .688	1.0000 (0) P= .	.2985 (9) P= .373	-.1883 (9) P= .579
WRATPCTL	.0397 (9) P= .908	-.2535 (9) P= .452	.2985 (9) P= .373	1.0000 (0) P= .	-.1812 (9) P= .594
WDCKPCTL	-.0834 (9) P= .807	.2504 (9) P= .458	-.1883 (9) P= .579	-.1812 (9) P= .594	1.0000 (0) P= .

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

- - - P A R T I A L   C O R R E L A T I O N   C O E F F I C I E N T S - - -

Controlling for.. AGE

	ICNPRESC	ICNPSTSC	SEQPRESC	SEQPSTSC	SEQM1A	SEQM3A
ICNPRESC	1.0000 (0) P= .	-.1149 (7) P= .769	.0332 (7) P= .932	-.3443 (7) P= .364	.1245 (7) P= .750	.0232 (7) P= .953
ICNPSTSC	-.1149 (7) P= .769	1.0000 (0) P= .	-.0010 (7) P= .998	.1228 (7) P= .753	.3167 (7) P= .406	-.3401 (7) P= .370
SEQPRESC	.0332 (7) P= .932	-.0010 (7) P= .998	1.0000 (0) P= .	.2987 (7) P= .435	.5154 (7) P= .156	-.1907 (7) P= .623
SEQPSTSC	-.3443 (7) P= .364	.1228 (7) P= .753	.2987 (7) P= .435	1.0000 (0) P= .	-.1621 (7) P= .677	-.3699 (7) P= .327
SEQM1A	.1245 (7) P= .750	.3167 (7) P= .406	.5154 (7) P= .156	-.1621 (7) P= .677	1.0000 (0) P= .	-.2769 (7) P= .471
SEQM3A	.0232 (7) P= .953	-.3401 (7) P= .370	-.1907 (7) P= .623	-.3699 (7) P= .327	-.2769 (7) P= .471	1.0000 (0) P= .
SEQM1B	.1095 (7) P= .779	.5912 (7) P= .094	.1631 (7) P= .675	.2049 (7) P= .597	.0735 (7) P= .851	-.1802 (7) P= .643
SEQM2B	.7793 (7) P= .013	-.0004 (7) P= .999	.4341 (7) P= .243	-.1383 (7) P= .723	.5992 (7) P= .088	-.4041 (7) P= .281
SEQM3B	-.4986 (7) P= .172	.1326 (7) P= .734	-.2279 (7) P= .555	-.2826 (7) P= .461	-.1350 (7) P= .729	-.3016 (7) P= .430
TRAIN	.2038 (7) P= .599	-.3685 (7) P= .329	.3836 (7) P= .308	.2539 (7) P= .510	-.2445 (7) P= .526	.0136 (7) P= .972
WRATPCTL	.5436 (7) P= .130	-.0161 (7) P= .967	.2817 (7) P= .463	.4414 (7) P= .234	.2040 (7) P= .598	-.0703 (7) P= .857

	ICNPRESC	ICNPSTSC	SEQPRESC	SEQPSTSC	SEQM1A	SEQM3A
WDCKPCTL	-.5338 (7) P= .139	.3719 (7) P= .324	.3503 (7) P= .355	.3280 (7) P= .389	.0868 (7) P= .824	.2318 (7) P= .548

(Coefficient / (D.F.) / 2-tailed Significance)

DYSLEXIC GROUP ONLY - VISUAL, TRAINING AND READING VARIABLES
13 May 99 SPSS for MS WINDOWS Release 6.1

--- PARTIAL CORRELATION COEFFICIENTS ---

Controlling for.. AGE

	SEQM1B	SEQM2B	SEQM3B	TRAIN	WRATPCTL	WDCKPCTL
ICNPRESC	.1095 (7) P= .779	.7793 (7) P= .013	-.4986 (7) P= .172	.2038 (7) P= .599	.5436 (7) P= .130	-.5338 (7) P= .139
ICNPSTSC	.5912 (7) P= .094	-.0004 (7) P= .999	.1326 (7) P= .734	-.3685 (7) P= .329	-.0161 (7) P= .967	.3719 (7) P= .324
SEQPRESC	.1631 (7) P= .675	.4341 (7) P= .243	-.2279 (7) P= .555	.3836 (7) P= .308	.2817 (7) P= .463	.3503 (7) P= .355
SEQPSTSC	.2049 (7) P= .597	-.1383 (7) P= .723	-.2826 (7) P= .461	.2539 (7) P= .510	.4414 (7) P= .234	.3280 (7) P= .389
SEQM1A	.0735 (7) P= .851	.5992 (7) P= .088	-.1350 (7) P= .729	-.2445 (7) P= .526	.2040 (7) P= .598	.0868 (7) P= .824
SEQM3A	-.1802 (7) P= .643	-.4041 (7) P= .281	-.3016 (7) P= .430	.0136 (7) P= .972	-.0703 (7) P= .857	.2318 (7) P= .548
SEQM1B	1.0000 (0) P= .	.0817 (7) P= .834	-.2500 (7) P= .516	.1786 (7) P= .646	.3292 (7) P= .387	-.0744 (7) P= .849
SEQM2B	.0817 (7) P= .834	1.0000 (0) P= .	-.3595 (7) P= .342	.1004 (7) P= .797	.5377 (7) P= .135	-.4066 (7) P= .278
SEQM3B	-.2500 (7) P= .516	-.3595 (7) P= .342	1.0000 (0) P= .	-.4256 (7) P= .253	-.9272 (7) P= .000	.1161 (7) P= .766
TRAIN	.1786 (7) P= .646	.1004 (7) P= .797	-.4256 (7) P= .253	1.0000 (0) P= .	.4242 (7) P= .255	-.2452 (7) P= .525
WRATPCTL	.3292 (7) P= .387	.5377 (7) P= .135	-.9272 (7) P= .000	.4242 (7) P= .255	1.0000 (0) P= .	-.2270 (7) P= .557
WDCKPCTL	-.0744 (7) P= .849	-.4066 (7) P= .278	.1161 (7) P= .766	-.2452 (7) P= .525	-.2270 (7) P= .557	1.0000 (0) P= .

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

COMPENSATED DYSLEXIC GROUP ONLY - PHONOLOGICAL, TRAINING AND READING VARIABLES

--- P A R T I A L   C O R R E L A T I O N   C O E F F I C I E N T S ---

Controlling for.. AGE

	PHMPRE	PHMPOST	PHONM1A	PHONM2A	PHONM3A	PHONM1B
PHMPRE	1.0000 (0) P= .	.7224 (16) P= .001	.4150 (16) P= .087	.5342 (16) P= .022	.4753 (16) P= .046	.2581 (16) P= .301
PHMPOST	.7224 (16) P= .001	1.0000 (0) P= .	.1699 (16) P= .500	.4124 (16) P= .089	.4141 (16) P= .088	.2388 (16) P= .340
PHONM1A	.4150 (16) P= .087	.1699 (16) P= .500	1.0000 (0) P= .	.1423 (16) P= .573	.1636 (16) P= .517	.2719 (16) P= .275
PHONM2A	.5342 (16) P= .022	.4124 (16) P= .089	.1423 (16) P= .573	1.0000 (0) P= .	.6234 (16) P= .006	.0823 (16) P= .745
PHONM3A	.4753 (16) P= .046	.4141 (16) P= .088	.1636 (16) P= .517	.6234 (16) P= .006	1.0000 (0) P= .	.1328 (16) P= .599
PHONM1B	.2581 (16) P= .301	.2388 (16) P= .340	.2719 (16) P= .275	.0823 (16) P= .745	.1328 (16) P= .599	1.0000 (0) P= .
PHONM2B	.4417 (16) P= .066	.7681 (16) P= .000	.0928 (16) P= .714	.3103 (16) P= .210	.3740 (16) P= .126	.1482 (16) P= .557
PHONM3B	.0762 (16) P= .764	.3695 (16) P= .131	.2518 (16) P= .313	.2207 (16) P= .379	.5079 (16) P= .031	-.3791 (16) P= .121
TRAIN	-.2365 (16) P= .345	-.0380 (16) P= .881	.2008 (16) P= .424	.1122 (16) P= .657	-.0025 (16) P= .992	-.0716 (16) P= .778
WRATPCTL	-.0993 (16) P= .695	.0540 (16) P= .831	.0039 (16) P= .988	-.0497 (16) P= .845	-.1025 (16) P= .686	-.2961 (16) P= .233
WDCKPCTL	.0288 (16) P= .910	.1688 (16) P= .503	.0960 (16) P= .705	-.0063 (16) P= .980	-.0055 (16) P= .983	-.3218 (16) P= .193

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

--- PARTIAL CORRELATION COEFFICIENTS ---

Controlling for.. AGE

	PHONM2B	PHONM3B	TRAIN	WRATPCTL	WDCKPCTL
PHMPRE	.4417	.0762	-.2365	-.0993	.0288
	(16)	(16)	(16)	(16)	(16)
	P= .066	P= .764	P= .345	P= .695	P= .910
PHMPOST	.7681	.3695	-.0380	.0540	.1688
	(16)	(16)	(16)	(16)	(16)
	P= .000	P= .131	P= .881	P= .831	P= .503
PHONM1A	.0928	.2518	.2008	.0039	.0960
	(16)	(16)	(16)	(16)	(16)
	P= .714	P= .313	P= .424	P= .988	P= .705
PHONM2A	.3103	.2207	.1122	-.0497	-.0063
	(16)	(16)	(16)	(16)	(16)
	P= .210	P= .379	P= .657	P= .845	P= .980
PHONM3A	.3740	.5079	-.0025	-.1025	-.0055
	(16)	(16)	(16)	(16)	(16)
	P= .126	P= .031	P= .992	P= .686	P= .983
PHONM1B	.1482	-.3791	-.0716	-.2961	-.3218
	(16)	(16)	(16)	(16)	(16)
	P= .557	P= .121	P= .778	P= .233	P= .193
PHONM2B	1.0000	.3638	.2430	.3379	.4153
	(0)	(16)	(16)	(16)	(16)
	P= .	P= .138	P= .331	P= .170	P= .087
PHONM3B	.3638	1.0000	.4255	.2142	.3885
	(16)	(0)	(16)	(16)	(16)
	P= .138	P= .	P= .078	P= .393	P= .111
TRAIN	.2430	.4255	1.0000	.2934	.5364
	(16)	(16)	(0)	(16)	(16)
	P= .331	P= .078	P= .	P= .237	P= .022
WRATPCTL	.3379	.2142	.2934	1.0000	.8760
	(16)	(16)	(16)	(0)	(16)
	P= .170	P= .393	P= .237	P= .	P= .000
WDCKPCTL	.4153	.3885	.5364	.8760	1.0000
	(16)	(16)	(16)	(16)	(0)
	P= .087	P= .111	P= .022	P= .000	P= .

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

COMPENSATED DYSLEXIC GROUP ONLY - VISUAL, TRAINING AND READING VARIABLES - - - P A R T I A L

Controlling for.. AGE

	ICNPRESC	ICNPSTSC	SEQPRESC	SEQPSTSC	SEQM1A	SEQM3A
ICNPRESC	1.0000 (0) P= .	.4740 (15) P= .055	.2801 (15) P= .276	.4485 (15) P= .071	.0530 (15) P= .840	.5124 (15) P= .035
ICNPSTSC	.4740 (15) P= .055	1.0000 (0) P= .	.2182 (15) P= .400	.3069 (15) P= .231	.0775 (15) P= .767	.1915 (15) P= .462
SEQPRESC	.2801 (15) P= .276	.2182 (15) P= .400	1.0000 (0) P= .	-.1043 (15) P= .690	.6334 (15) P= .006	.2504 (15) P= .332
SEQPSTSC	.4485 (15) P= .071	.3069 (15) P= .231	-.1043 (15) P= .690	1.0000 (0) P= .	-.0616 (15) P= .814	-.0687 (15) P= .793
SEQM1A	.0530 (15) P= .840	.0775 (15) P= .767	.6334 (15) P= .006	-.0616 (15) P= .814	1.0000 (0) P= .	.0587 (15) P= .823
SEQM3A	.5124 (15) P= .035	.1915 (15) P= .462	.2504 (15) P= .332	-.0687 (15) P= .793	.0587 (15) P= .823	1.0000 (0) P= .
SEQM1B	-.0383 (15) P= .884	.1215 (15) P= .642	-.2252 (15) P= .385	.4351 (15) P= .081	.1208 (15) P= .644	-.2021 (15) P= .437
SEQM2B	.4239 (15) P= .090	.0271 (15) P= .918	.2015 (15) P= .438	.3946 (15) P= .117	-.0973 (15) P= .710	.1589 (15) P= .542
SEQM3B	.1319 (15) P= .614	-.1012 (15) P= .699	-.0743 (15) P= .777	.4576 (15) P= .065	.1907 (15) P= .464	.4560 (15) P= .066
TRAIN	.0496 (15) P= .850	-.1999 (15) P= .442	-.6248 (15) P= .007	.1608 (15) P= .538	-.3416 (15) P= .180	.0567 (15) P= .829
WRATPCTL	-.3945 (15) P= .117	-.2820 (15) P= .273	-.6202 (15) P= .008	.2446 (15) P= .344	-.5398 (15) P= .025	-.4027 (15) P= .109

	ICNPRESC	ICNPSTSC	SEQPRESC	SEQPSTSC	SEQM1A	SEQM3A
WDCKPCTL	-.1720 (15) P= .509	-.2945 (15) P= .251	-.6521 (15) P= .005	.3991 (15) P= .113	-.4267 (15) P= .088	-.1399 (15) P= .592

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

--- P A R T I A L   C O R R E L A T I O N   C O E F F I C I E N T S ---

Controlling for.. AGE

	SEQM1B	SEQM2B	SEQM3B	TRAIN	WRATPCTL	WDCKPCTL
ICNPRESC	-.0383 (15) P= .884	.4239 (15) P= .090	.1319 (15) P= .614	.0496 (15) P= .850	-.3945 (15) P= .117	-.1720 (15) P= .509
ICNPSTSC	.1215 (15) P= .642	.0271 (15) P= .918	-.1012 (15) P= .699	-.1999 (15) P= .442	-.2820 (15) P= .273	-.2945 (15) P= .251
SEQPRESC	-.2252 (15) P= .385	.2015 (15) P= .438	-.0743 (15) P= .777	-.6248 (15) P= .007	-.6202 (15) P= .008	-.6521 (15) P= .005
SEQPSTSC	.4351 (15) P= .081	.3946 (15) P= .117	.4576 (15) P= .065	.1608 (15) P= .538	.2446 (15) P= .344	.3991 (15) P= .113
SEQM1A	.1208 (15) P= .644	-.0973 (15) P= .710	.1907 (15) P= .464	-.3416 (15) P= .180	-.5398 (15) P= .025	-.4267 (15) P= .088
SEQM3A	-.2021 (15) P= .437	.1589 (15) P= .542	.4560 (15) P= .066	.0567 (15) P= .829	-.4027 (15) P= .109	-.1399 (15) P= .592
SEQM1B	1.0000 (0) P= .	-.3081 (15) P= .229	.4002 (15) P= .111	.3749 (15) P= .138	.3404 (15) P= .181	.5390 (15) P= .026
SEQM2B	-.3081 (15) P= .229	1.0000 (0) P= .	.1676 (15) P= .520	-.3453 (15) P= .175	-.2467 (15) P= .340	-.2157 (15) P= .406
SEQM3B	.4002 (15) P= .111	.1676 (15) P= .520	1.0000 (0) P= .	.3451 (15) P= .175	.0219 (15) P= .933	.3534 (15) P= .164
TRAIN	.3749 (15) P= .138	-.3453 (15) P= .175	.3451 (15) P= .175	1.0000 (0) P= .	.2347 (15) P= .364	.4847 (15) P= .049
WRATPCTL	.3404 (15) P= .181	-.2467 (15) P= .340	.0219 (15) P= .933	.2347 (15) P= .364	1.0000 (0) P= .	.8722 (15) P= .000
	SEQM1B	SEQM2B	SEQM3B	TRAIN	WRATPCTL	WDCKPCTL
WDCKPCTL	.5390 (15) P= .026	-.2157 (15) P= .406	.3534 (15) P= .164	.4847 (15) P= .049	.8722 (15) P= .000	1.0000 (0) P= .

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

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13 May 99 SPSS for MS WINDOWS Release 6.1

--- PARTIAL CORRELATION COEFFICIENTS ---

Controlling for.. AGE

	PHMPRE	PHMPOST	PHON1A	PHON2A	PHON3A	PHON1B
PHMPRE	1.0000 (0) P= .	.6170 (27) P= .000	.4293 (27) P= .020	.4652 (27) P= .011	.4414 (27) P= .017	.3175 (27) P= .093
PHMPOST	.6170 (27) P= .000	1.0000 (0) P= .	.1693 (27) P= .380	.3243 (27) P= .086	.2319 (27) P= .226	.4038 (27) P= .030
PHON1A	.4293 (27) P= .020	.1693 (27) P= .380	1.0000 (0) P= .	.6383 (27) P= .000	.5732 (27) P= .001	.0900 (27) P= .642
PHON2A	.4652 (27) P= .011	.3243 (27) P= .086	.6383 (27) P= .000	1.0000 (0) P= .	.6661 (27) P= .000	.1605 (27) P= .406
PHON3A	.4414 (27) P= .017	.2319 (27) P= .226	.5732 (27) P= .001	.6661 (27) P= .000	1.0000 (0) P= .	.0093 (27) P= .962
PHON1B	.3175 (27) P= .093	.4038 (27) P= .030	.0900 (27) P= .642	.1605 (27) P= .406	.0093 (27) P= .962	1.0000 (0) P= .
PHON2B	.4144 (27) P= .025	.6140 (27) P= .000	.0456 (27) P= .814	.1749 (27) P= .364	.0480 (27) P= .805	.5734 (27) P= .001
PHON3B	.0527 (27) P= .786	.3026 (27) P= .111	-.1201 (27) P= .535	.1128 (27) P= .560	.0420 (27) P= .829	.2815 (27) P= .139
TRAIN	.2223 (27) P= .246	.0624 (27) P= .748	.0788 (27) P= .684	.2722 (27) P= .153	.2031 (27) P= .291	-.0253 (27) P= .896
WRATPCTL	.3667 (27) P= .050	.1216 (27) P= .530	.5735 (27) P= .001	.5545 (27) P= .002	.6328 (27) P= .000	-.1072 (27) P= .580
WDCKPCTL	.4364 (27) P= .018	.1644 (27) P= .394	.4590 (27) P= .012	.4561 (27) P= .013	.5808 (27) P= .001	.0369 (27) P= .849

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

--- P A R T I A L   C O R R E L A T I O N   C O E F F I C I E N T S ---

Controlling for.. AGE

	PHON2B	PHON3B	TRAIN	WRATPCTL	WDCKPCTL
PHMPRE	.4144 (27) P= .025	.0527 (27) P= .786	.2223 (27) P= .246	.3667 (27) P= .050	.4364 (27) P= .018
PHMPOST	.6140 (27) P= .000	.3026 (27) P= .111	.0624 (27) P= .748	.1216 (27) P= .530	.1644 (27) P= .394
PHON1A	.0456 (27) P= .814	-.1201 (27) P= .535	.0788 (27) P= .684	.5735 (27) P= .001	.4590 (27) P= .012
PHON2A	.1749 (27) P= .364	.1128 (27) P= .560	.2722 (27) P= .153	.5545 (27) P= .002	.4561 (27) P= .013
PHON3A	.0480 (27) P= .805	.0420 (27) P= .829	.2031 (27) P= .291	.6328 (27) P= .000	.5808 (27) P= .001
PHON1B	.5734 (27) P= .001	.2815 (27) P= .139	-.0253 (27) P= .896	-.1072 (27) P= .580	.0369 (27) P= .849
PHON2B	1.0000 (0) P= .	.5139 (27) P= .004	.0477 (27) P= .806	-.1696 (27) P= .379	.0480 (27) P= .805
PHON3B	.5139 (27) P= .004	1.0000 (0) P= .	-.0182 (27) P= .925	-.2480 (27) P= .195	-.2217 (27) P= .248
TRAIN	.0477 (27) P= .806	-.0182 (27) P= .925	1.0000 (0) P= .	.3603 (27) P= .055	.4135 (27) P= .026
WRATPCTL	-.1696 (27) P= .379	-.2480 (27) P= .195	.3603 (27) P= .055	1.0000 (0) P= .	.7871 (27) P= .000
WDCKPCTL	.0480 (27) P= .805	-.2217 (27) P= .248	.4135 (27) P= .026	.7871 (27) P= .000	1.0000 (0) P= .

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

--- PARTIAL CORRELATION COEFFICIENTS ---

Controlling for.. AGE

	ICNPRESC	ICNPSTSC	SEQPRESC	SEQPSTSC	SEQM1A	SEQM3A
ICNPRESC	1.0000 (0) P= .	.1343 (27) P= .487	.4036 (27) P= .030	.1070 (27) P= .581	.3003 (27) P= .114	-.1779 (27) P= .356
ICNPSTSC	.1343 (27) P= .487	1.0000 (0) P= .	.2854 (27) P= .133	.3249 (27) P= .085	.2568 (27) P= .179	-.0600 (27) P= .757
SEQPRESC	.4036 (27) P= .030	.2854 (27) P= .133	1.0000 (0) P= .	-.1207 (27) P= .533	.5433 (27) P= .002	.1965 (27) P= .307
SEQPSTSC	.1070 (27) P= .581	.3249 (27) P= .085	-.1207 (27) P= .533	1.0000 (0) P= .	.0819 (27) P= .673	-.2435 (27) P= .203
SEQM1A	.3003 (27) P= .114	.2568 (27) P= .179	.5433 (27) P= .002	.0819 (27) P= .673	1.0000 (0) P= .	.3028 (27) P= .110
SEQM3A	-.1779 (27) P= .356	-.0600 (27) P= .757	.1965 (27) P= .307	-.2435 (27) P= .203	.3028 (27) P= .110	1.0000 (0) P= .
SEQM1B	-.0761 (27) P= .695	.1306 (27) P= .500	-.1073 (27) P= .579	.3256 (27) P= .085	.4162 (27) P= .025	.0111 (27) P= .954
SEQM2B	-.5199 (27) P= .004	.0877 (27) P= .651	-.2809 (27) P= .140	.3495 (27) P= .063	.1240 (27) P= .522	.2583 (27) P= .176
SEQM3B	-.1128 (27) P= .560	-.1074 (27) P= .579	-.1269 (27) P= .512	.2816 (27) P= .139	.0299 (27) P= .877	.2930 (27) P= .123
TRAIN	.1126 (27) P= .561	.4444 (27) P= .016	.0539 (27) P= .781	.1305 (27) P= .500	.2712 (27) P= .155	.0796 (27) P= .682
WRATPCTL	-.1967 (27) P= .306	.0743 (27) P= .702	-.0505 (27) P= .795	.1270 (27) P= .511	.2806 (27) P= .140	.1100 (27) P= .570
	ICNPRESC	ICNPSTSC	SEQPRESC	SEQPSTSC	SEQM1A	SEQM3A
WDCKPCTL	-.1748 (27) P= .364	-.0469 (27) P= .809	.1300 (27) P= .501	-.0625 (27) P= .747	.1008 (27) P= .603	.1394 (27) P= .471

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

--- P A R T I A L   C O R R E L A T I O N   C O E F F I C I E N T S ---

Controlling for.. AGE

	SEQM1B	SEQM2B	SEQM3B	TRAIN	WRATPCTL	WDCKPCTL
ICNPRESC	-.0761 (27) P= .695	-.5199 (27) P= .004	-.1128 (27) P= .560	.1126 (27) P= .561	-.1967 (27) P= .306	-.1748 (27) P= .364
ICNPSTSC	.1306 (27) P= .500	.0877 (27) P= .651	-.1074 (27) P= .579	.4444 (27) P= .016	.0743 (27) P= .702	-.0469 (27) P= .809
SEQPRESC	-.1073 (27) P= .579	-.2809 (27) P= .140	-.1269 (27) P= .512	.0539 (27) P= .781	-.0505 (27) P= .795	.1300 (27) P= .501
SEQPSTSC	.3256 (27) P= .085	.3495 (27) P= .063	.2816 (27) P= .139	.1305 (27) P= .500	.1270 (27) P= .511	-.0625 (27) P= .747
SEQM1A	.4162 (27) P= .025	.1240 (27) P= .522	.0299 (27) P= .877	.2712 (27) P= .155	.2806 (27) P= .140	.1008 (27) P= .603
SEQM3A	.0111 (27) P= .954	.2583 (27) P= .176	.2930 (27) P= .123	.0796 (27) P= .682	.1100 (27) P= .570	.1394 (27) P= .471
SEQM1B	1.0000 (0) P= .	.1923 (27) P= .318	.0573 (27) P= .768	.1649 (27) P= .393	.4807 (27) P= .008	.0942 (27) P= .627
SEQM2B	.1923 (27) P= .318	1.0000 (0) P= .	.4648 (27) P= .011	.3169 (27) P= .094	.4413 (27) P= .017	.4046 (27) P= .029
SEQM3B	.0573 (27) P= .768	.4648 (27) P= .011	1.0000 (0) P= .	.1498 (27) P= .438	.0750 (27) P= .699	.1237 (27) P= .522
TRAIN	.1649 (27) P= .393	.3169 (27) P= .094	.1498 (27) P= .438	1.0000 (0) P= .	.3603 (27) P= .055	.4135 (27) P= .026
WRATPCTL	.4807 (27) P= .008	.4413 (27) P= .017	.0750 (27) P= .699	.3603 (27) P= .055	1.0000 (0) P= .	.7871 (27) P= .000

	SEQM1B	SEQM2B	SEQM3B	TRAIN	WRATPCTL	WDCKPCTL
WDCKPCTL	.0942 (27) P= .627	.4046 (27) P= .029	.1237 (27) P= .522	.4135 (27) P= .026	.7871 (27) P= .000	1.0000 (0) P= .

(Coefficient / (D.F.) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

APPENDIX B: Phonological Memory Test Scripts

Phonological Memory Test Script - Pretest

Introduction

This is a tape of lists of non-words. I want you to try to repeat each list exactly as you heard it. When each list is finished, you'll hear a high tone. Wait for the tone, and then try to repeat the non-words you heard. You'll have a few seconds to repeat the list, and then the next list will start.

The first list is for practice. It will have two nonwords in it. Listen to the words, then wait for the tone. When you hear the tone, try to repeat the non-words you hears. Let's start. Ready?

After the practice trial...

That's good. Now you'll hear the experimental lists. The lists start short; each will be only one nonword. You'll hear four one-nonword lists, then four two-nonword ones, then four three-nonword ones, and so on. We'll try to see how long a list you can remember. If you only remember part of the list, say the part that you do remember. Let's start.

Practice Trial

sut - nad

Experimental Trials

One NonWord Lists

larp

dif

kirp

vit

Two NonWord Lists

ift - tull

gouch - plurd

trog - fent

yume - dob

Three NonWord Lists

nate - bim - satch

gat - plip - bot

rulp - fen - lote

kyme - glaf - dind

Four NonWord Lists

twem - laip - yeng - koink

vauge - wrey - gant - blos

serp - jip - gret - pag

hap - flib - pove - jik

Five NonWord Lists

vun - lish - buf - delk - gop

farl - hest - jex - zird - seng

tsar - gat - mulp - prin - nint

giph - roin - joil - girve - crat

Six NonWord Lists

cak - rube - spatch - pite - baft - fod

trope - gead - fot - thim - teg - jud

mox - blean - gake - drek - soth - parl

durg - framp - pofe - norf - brinth - rit

Seven NonWord Lists

thix - murd - noke - jate - dod - gaft - pint

raz - bim - fla - stet - chut - teg - sith

bril - mif - peng - seef - farg - toug - dut

nad - zorp - hest - reat - lats - phic - tonk

Conclusion

That's the end of the experiment. Thank you for your participation.

Phonological Memory Test Script - Posttest

Introduction

This is a tape of lists of non-words. I want you to try to repeat each list exactly as you heard it. When each list is finished, you'll hear a high tone. Wait for the tone, and then try to repeat the non-words you heard. You'll have a few seconds to repeat the list, and then the next list will start.

The first list is for practice. It will have two nonwords in it. Listen to the words, then wait for the tone. When you hear the tone, try to repeat the non-words you hears. Let's start. Ready?

After the practice trial...

That's good. Now you'll hear the experimental lists. The lists start short; each will be only one nonword. You'll hear four one-nonword lists, then four two-nonword ones, then four three-nonword ones, and so on. We'll try to see how long a list you can remember. If you only remember part of the list, say the part that you do remember. Let's start.

Practice Trial

pag - fen

Experimental Trials

One NonWord Lists

lish

vun

larp

fen

Two NonWord Lists

pag - prin

larp - vun

tweg - kirp

jix - lote

Three NonWord Lists

lish - fen - jix

vun - lote - pag

larp - tweg - lote

kirp - jix - vun

Four NonWord Lists

fen - prin - kirp - lish

lote - jix - vun - pag

larp - tweg - lish - fen

pag - lish - larp - prin

Five NonWord Lists

jix - lish - tweg - kirp - larp

tweg - fen - lote - vun - prin

lish - larp - kirp - jix - lote

prin - tweg - vun - kirp - lish

Six NonWord Lists

vun - larp - jix - lote - pag - fen

prin - fen - kirp - lish - tweg - jix

larp - vun - pag - lote - fen - prin

pag - jix - tweg - lote - kirp - larp

Seven NonWord Lists

fen - pag - lish - prin - tweg - lote - vun

jix - larp - vun - kirp - fen - lish - prin

lish - vun - prin - pag - jix - tweg - larp

lote - fen - pag - larp - vun - jix - tweg

Conclusion

That's the end of the experiment. Thank you for your participation.

APPENDIX C: Script for the Training Intervention

"Directions

"I AM GOING TO SHOW YOU SOME SHAPES AS I SAY SOME SOUNDS. EACH SHAPE DOES WITH A DIFFERENT SOUND. WHEN I SHOW YOU THE SHAPES AGAIN, I WANT YOU TO TELL ME WHICH SHAPE GOES WITH EACH. TRY TO REMEMBER WHICH SOUNDS GO WITH EACH SHAPE. LET'S START. READY?

"For the initial presentation (Learning Trial), set upthe spiral booklet in an easel format. Show the first card (with the symbol) and say the associated sound, found on the card facing the examiner. Have the child repeat the sound after the examiner by saying: NOW YOU SAY IT.

"Correct the child's pronunciation, if necessary. Proceed to the succeeding cards and repeat the procedure until all items of the trial are administered. Presentation rate duriing this Learning Trial should be a ***5 second total*** *exposure time per item.*

"After all shapes and their respective sounds have been presented on the Learning Trial, proceed to Trial 1, Card 1. Say: WHAT SOUND GOES WITH THIS SHAPE?

"Allow five seconds for the child to respond. *If correct, give positive feedback and continue with the next item.*

"When the child's response in incorrect or no response is given within the 5 second response period, ***provide the correct sound.*** *After the first error only, say: TRY TO REMEMBER THE SOUNDS THAT GO WITH THE SHAPES BECAUSE I WILL ASK YOU AGAIN. LET'S TRY THIS ONE NOW.*

"If a child spontaneously changes his/her response within the 5 second response period, ask which one answer the child wnats to give and score accordingly. If the child selects the incorrect response, state the correct response and move on to the next item.

"After the trial is completed, proceed to the next until all ... trials are completed.

"Do not give any feedback to the child after he/she responds to each of the items on trial 4. *If the child asks, give a neutral response...*

"To summarize, only on the initial presentation of the shape and sound together (Learning Trial) does the examiner administer the whole list and p-rovide the sound associated with each item. Thereafter, only the shapes are presented until the child responds. The examiner provides the corresponding sound following no