AUDITORY INFORMATION PROCESSING AND MODALITY EFFECTS IN GOOD AND POOR READERS

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Auditory Information Processing and Modality Effects in Good and Poor Readers

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Abstract

Research suggests that reading disabilities result from phonological processing deficits. Penney's (1989) separate-stream hypothesis suggests that phonological deficits in poor readers may be linked to defective auditory information processing and a deficient A (auditory) code in short-term memory. The study reported here tested the hypothesis that good and poor readers, at the university level, differ in their auditory short-term memory and auditory information processing capabilities. Subtests from the Woodcock-Johnson Psycho-Educational Battery - Revised (Woodcock & Johnson, 1989) were used to measure reading and auditory processing skills. To test short-term memory recall, lists of four to nine digits were presented auditorily or visually. The usual modality effect was observed for the good readers with auditory presentation producing higher recall. In contrast, for the poor readers the modality effect was observed only for the last serial position; for the middle serial positions visual sequential recall was higher than auditory recall, producing a reverse modality effect. The results of the Woodcock-Johnson subtests indicated that the poor readers did have deficient auditory processing capabilities.

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List of Abbreviations and Symbols

M = Mean/Average

SD = Standard Deviation

r = Pearson Correlation Coefficient

p = Probability Level (Alpha)

F = F-Ratio

ns = Not statistically Significant

Introduction

To say that an individual has a learning disability implies that the individual shows unexpected difficulty in acquiring academic skills.

> "Learning disabilities" is a generic term that refers to a heterogeneous group of disorders manifested by significant difficulties in the acquisition and use of listening, speaking, reading, writing, reasoning or mathematical abilities. These disorders are intrinsic to the individual and presumed to be due to central nervous system dysfunction.
>
> Even though a learning disability may occur concomitantly with other handicapping conditions (e.g., sensory impairment, mental retardation, social and emotional disturbances) or environmental influences (e.g., cultural differences, insufficient/inappropriate instruction, psychogenic factors) it is not the direct result of those conditions and influences (Hammill, Leigh, McNutt, & Larsen, 1981, p.336).

The majority of individuals that are labelled learning-disabled receive this designation because of difficulties in learning to read (Duffy, Denckla, Bartels, & Sandini, 1980; Lyon, 1985b). Although reading is a task that most children accomplish quite readily, it does pose specific problems for some 4% to 10% of children (Mann, 1986). In order to be considered reading-disabled, the child's difficulty in learning to read must be severe, as measured by a substantial discrepancy between the individual's expected reading performance, based on intelligence, and his or her actual performance. The definition of reading disability is a definition by exclusion. In the diagnosis, several criteria are typically investigated and ruled out. According to Siegel (1988), the individual must be of normal intelligence, must have no severe emotional problems, must have no significant sensory deficits or history of neurological diseases, and he or she must have been provided with adequate educational opportunities.

Reading disability is not a homogeneous problem and any research should take into account the heterogeneity associated with this disorder. Common practice in experiments concerning reading disabilities is to compare the performance of a group of reading-disabled individuals with that of a group of normal readers. However, reading-disabled individuals can differ in the development of the specific skills that contribute to basic reading problems (Lyon, 1985). Within a sample of reading-disabled individuals, the possibility therefore exists that there will be large within-sample variance because not all individuals read poorly for the same reasons (Lyon, 1985).

Many studies have attempted to identify the specific difficulties underlying reading problems. Early studies were based on the fact that reading is a complex visual skill which places strong demands on the differentiation and recognition of visual stimuli. For this reason models of reading were developed which clarified the visual stages in reading. These models depicted reading problems as being associated with a failure in the visual domain (for a review see Mann, 1986).

Overall, the results of this line of research suggest that visual perceptual skills appear to be related to reading achievement, but only a few children are believed to suffer from reading disabilities because of a visual deficit. When it exists, this visual deficit interferes with either recognition or differentiation of memory for certain orthographic forms (Mann, 1986). Remedial programs based on visual-motor perceptual approaches generally have not been shown to result in significant reading improvement when evaluated in well-controlled studies (Kavale, Forness & Bender, 1987).

Phonological Processing

The current approach to reading disabilities assumes that for the majority of children, success in learning to read is associated with processes needed to understand speech and to comprehend phonological structures (Mann, 1986). According to Siegel (1990), Siegel and Ryan (1989b), Stanovich (1988a, 1988b), and Wagner and Torgesen (1987), difficulty with phonological processing is the central feature of reading problems. Phonological processing refers to the use of phonological information (the sounds of the language) in the processing of oral or written language (Wagner & Torgesen, 1987).

One important stage in which phonological processing is involved in reading acquisition is the learning of associations between letters and sounds. Phonological awareness is the ability to perceive a word as a sequence of individual sounds. This can be demonstrated by tasks that require tapping out the number of sounds in a word, reversing the order of sounds in a word, or blending sounds presented in isolation to form a word (Lewkowicz, 1980). To an individual with normal phonological awareness, the alphabetic system is a reasonable method of presenting the English language visually. However, to an individual unable to analyze a word into its constituent sounds, the correspondence between a letter symbol and a sound will be difficult to understand (Wagner & Torgesen, 1987).

Phonological recoding is the process of getting from the written symbol into a sound-based representational system (Crowder, 1982; Liberman & Mann, 1981). In the early stages of reading, a child learns that the symbols on a page constitute letters and these letters form clusters that represent words. Once the letter-to-sound knowledge is built up, new words can be analyzed by examining the sequences of letters and converting them into phonemes. Finally the phonemes are blended to form a word. In the more advanced stages of reading the child begins to master the word recognition process so that decoding of letters has a certain degree of automation. Tasks used to assess phonological recoding skills involve deciding whether a string of letters represents a real word or a nonword, or the rapid naming of objects, colours, and other types of stimuli (Wagner & Torgesen, 1987).

Once the written symbols have been recoded into a sound-based representational system this information must be maintained in working memory. The combination of phonological coding and memory storage may play an essential role in learning to read. According to Baddeley's (1986) model of working memory, which will be discussed later, phonological coding and phonological storage of information in memory is required for fluent reading ability. When learning to read, individuals must decode letters into sound representations, the sounds must be temporarily stored in memory, and finally the stored sounds must be blended to form words (Wagner & Torgesen, 1987). Efficient formation of phonological representations in memory allows the reader to devote maximum cognitive resources to the difficult task of blending the sounds to form the words (Wagner & Torgesen, 1987).

Stanovich (1988b) believes that phonological processing deficits are found in all disabled readers. According to Stanovich (1988a) less skilled readers have difficulty making explicit reports about sound segments at the phoneme level; they display naming difficulties; their utilization of phonological codes in short-term memory is inefficient; and their categorical perception of certain phonemes may be below average. Investigators have improved phonological processing skills through training and have demonstrated significant experimental group advantages in word recognition and spelling (Olofsson & Lundberg, 1985; Treiman & Baron, 1983). In addition, phonological processing capabilities show stronger correlations with reading skills than with general cognitive abilities as demonstrated through IQ test scores (Siegel, 1988). Researchers (Mann, 1984; Stanovich, Cunningham & Feeman, 1984; Tunmer & Nesdale, 1985) have demonstrated that measures of phonological processing account for a statistically significant proportion of the variance in reading ability after the variance associated with a variety of measures of intelligence and other cognitive processes has been partialled out.

Siegel and Ryan (1989b) have demonstrated that the type of measure used to determine reading ability will significantly influence the conclusion about individuals with reading disabilities and the profiles that emerge. It appears that the most severe form of a reading disability involves problems with phonological processing. On almost all language, memory, reading and spelling tasks, the children with a phonological or word-recognition deficit had significantly lower scores than did the normal readers (Siegel

& Ryan, 1989b). The clearest definition of reading disability appears to involve problems with reading nonwords or word-recognition. When reading disability was defined in terms of a phonological deficit, Siegel and Ryan (1989b) concluded that the population of reading-disabled children was a relatively homogeneous group in terms of reading, spelling, language and memory skills.

Nonword Reading Ability

Phonological processing may be examined through the reading of pseudowords, which are pronounceable combinations of letters that are not real words (for example feap). As these "words" have not been seen before, the individual cannot rely on a visual or a whole-word recognition approach. Therefore the individual must rely on phonemic recoding which involves the application of pronunciation rules of English. Siegel and Ryan (1989b), Siegel and Heaven (1986) and Vellutino (1978, 1979) argue that single word or nonword reading is the best measure of reading for identifying individuals with reading problems. When an individual reads a word in a sentence correctly, it is unclear whether the word is actually being decoded or whether the individual is relying on prior exposure to the word or is using the sentence context to read the word. Using nonwords with regularized spellings eliminates the problems associated with irregular or unpredictable letter-sound relationships that occur in real English words. The use of isolated nonwords ensures that the individual is actually reading the word by decoding the sound of the letters.

In general, it has been shown that reading-disabled children have significantly more difficulty reading pseudowords than real words with the same phonological features (Siegel & Faux, 1989; Snowling, 1980). Studies such as those of Snowling (1980), Siegel and Ryan (1989b) and Walters, Bruck, and Seidenberg (1985) have shown that individuals with reading problems have greater difficulty reading pseudowords than do normal readers matched by chronological age and reading level. Siegel and Ryan (1989b) found that 13- and 14-year-old individuals with reading problems read pseudowords at the same level as 7- and 8-year-old normal readers. Baron (1979) found that the ability to read nonwords was more highly correlated with the ability to read phonologically or orthographically regular words than with the ability to read irregular words that violate letter-sound correspondence rules. This is an indication that reading nonwords is a measure of how much has been learned by an individual about letter-sound correspondence rules.

Short-Term Memory Ability

Recently, researchers have suggested an important role for memory processes in the attainment of fluent reading. Although reading-disabled children frequently perform poorly on tests such as digit span, the direction of causation is not clearly understood. Farnham-Diggory and Gregg (1975) outlined a general model of reading that demonstrates the importance of short-term memory in reading. The reader must attend to the first visual portion of a word and retrieve an auditory and articulatory association from long-term memory. This retrieved information must be held in memory while the reader attends to the next visual portion of the word. This process will continue until the entire word has been completed. Then all of the auditory pieces must be integrated so that the word can be identified.

Lyon (1985) found that 13% of a sample of 10- to 12-year-old children with learning disabilities showed difficulties on span tasks, while an additional 23% of the students displayed span difficulties in combination with other cognitive limitations. Speece (1987) found that 15% of the sample of reading-disabled children exhibited isolated difficulties on the digit-span task, and an additional 20% showed difficulties on both span and rapid naming tasks. In a series of studies, Torgesen (1988) demonstrated that 15% to

20% of school-identified children with learning disabilities performed in the mentally delayed range on immediate verbatim recall of sequences of verbal stimuli.

The poor performance of reading-disabled individuals on memory span tasks appears to be related to difficulties in phonological coding. Previous studies have indicated that short-term memory retention is accomplished by relying on phonological encoding of the stimuli (Baddeley, 1986). Brady (1986), in a series of studies, examined the role of phonological processes in short-term memory in children with reading problems. A relationship was found between phonological processes and verbal short-term memory, but not between phonological processes and nonverbal memory. The results indicated that poor readers were slower at phonological encoding and had poorer performance on the memory span tasks. These findings indicated that verbal memory span is related to the efficiency of phonological processes. In addition, Torgesen, Rashotte, Greenstein, Houck and Portes (1987) identified reading-disabled children who had short-term memory difficulties. These children had poor performance on memory span tasks as well as on tasks that depended on phonological coding such as reading, spelling or sound blending.

Shankweiler and Liberman (1976) studied immediate memory in good and poor readers for auditorily presented sequences of consonants that were either phonologically similar (rhyming) or dissimilar (non-rhyming). It was expected that the use of similar items would maximize phonetic confusability and lower recall in subjects that were using a phonological code in short-term memory. They found that the good readers were superior to the poor readers with the dissimilar set, but were much more impaired by the introduction of phonologically similar consonants. The good readers were clearly better at recall of dissimilar items than the poor readers, while, at the same time, the good readers failed to show a clear advantage on recall of similar items.

Shankweiler and Liberman (1976) argued that the results reflected differences between good and poor readers in their use of a phonological code. The poor readers were not affected by the phonological similarity because they were not using phonological codes to retain the information. Shankweiler and Liberman also made the point that the availability of a "phonetically organized" short-term memory is necessary but not sufficient for good reading ability. The individual must also have the ability to make explicit decisions concerning segmentation, especially at the phoneme level. Shankweiler and Liberman (1976) suggested that poor readers are deficient in forming a phonological representation and that this absence of phonological coding may be crucial to their reading difficulty.

In subsequent experiments, Liberman, Shankweiler, Liberman, Fowler and Fischer, (1977) and Mann, Liberman and Shankweiler (1980) investigated phonological similarity. In both studies the good readers remembered more with dissimilar information but were more impaired with the phonologically similar material than poor readers. Torgesen (1988) found a subgroup of reading-disabled children who had serious performance problems on span tasks that required short-term retention of sequences of familiar verbal items. The results of Torgesen's studies indicated that these deficits were extremely stable and were associated with difficulties in learning to code phonological information effectively.

If short-term memory difficulties are a result of inadequate or incomplete phonological representations, reading-disabled individuals should perform well on memory tasks that do not require the use of phonological coding. Liberman, Mann, Shankweiler and Werfelman (1982) tested recognition memory with stimuli that could not be easily labelled such as unfamiliar faces and abstract non-representational line drawings. Their results indicated that the good and poor readers had similar retention of information that did not involve phonological codes. In fact, the poor readers' retention was slightly better than that of good readers although this difference was not statistically significant. Torgesen et al. (1987) also found that a subgroup of reading-disabled children who performed poorly on verbatim recall of verbal items showed no impairments on recognition memory tasks or on certain tasks requiring the immediate recall of abstract visual information that allowed for semantic encoding of items.

The finding, that children do not show a performance deficit when asked to retain sequences of visual figures that are difficult to label verbally provides strong evidence for a specific verbal phonological code deficit. The difficulties are not the result of general limitations in storage, but are specifically related to tasks that require verbal or phonological processing. It is not memory in general that demonstrates the deficit, but rather the deficit lies in the phonological coding of information.

Baddeley's Model

Baddeley's (1986) model of short-term memory is extensively cited in the literature to describe the relationship between short-term memory, phonological coding, and normal reading processes. This model of short-term working memory describes a system for temporarily holding and manipulating information in a range of cognitive tasks. The model includes a supervisory system, called the central executive, which is aided by two slave systems, the articulatory loop, responsible for the temporary storage of phonological information, and the visuo-spatial scratch pad concerned with visuo-spatial memory.

The articulatory loop consists of an articulatory control process and phonological store. Information is registered in this phonological store either by auditory presentation or subvocal rehearsal. The phonological representation will fade within two seconds unless rehearsal occurs (Baddeley, 1986).

Evidence for an articulatory loop arises from experiments on the phonological similarity and word-length effects. The phonological similarity effect refers to the finding that in letter-memorization tasks, more intrusion errors are found for similar-sounding letters such as b, v, p, c, or t than for dissimilar letters (Baddeley, 1986). This phonological similarity effect is thought to result from confusion among items that have similar phonological codes (Shankweiler & Liberman, 1976). The word-length effect refers to the finding that memory span for short words is greater than that for longer words, a finding which is explained by assuming that shorter words are better remembered simply because they can be spoken more rapidly. With silent articulation, longer words take longer to say, reducing the rate at which an item can be rehearsed, and increasing the opportunity for decay (Baddeley, 1986; Baddeley, Thomson & Buchanan, 1975).

As both phonological similarity and word-length effects appear to be due to subvocal articulation, the effects should disappear when articulation is prevented. Articulatory suppression is achieved by having subjects utter an irrelevant word or phrase at the time when silent articulation of the memory item would otherwise occur. According to the model, articulatory suppression should prevent silent articulation and create difficulties with phonological encoding and the maintenance of items in memory. Indeed, experiments have shown that interference with the articulatory loop by articulatory suppression impairs retention of visually presented words and eliminates the phonological similarity and word-length effects (Baddeley, 1986; Murray, 1968).

It is believed that the articulatory loop is involved in acquisition of complex verbal skills such as reading. During reading, the executive may be conceptualized as coordinating information about syntax, word meaning and phonological rules. Meanwhile the articulatory loop retains the phonemes, syllables, words or phrases that have been decoded in order that longer units of text, phases or sentences can be comprehended (Siegel & Ryan, 1989a). If the articulatory loop were not used, the central executive would have the additional burden of retaining the sound of letters and words already decoded while simultaneously attempting to decode the remaining letters hence overloading the executive.

Auditory Processing Deficits and Modality Effects

The possibility that auditory factors may be contributing to reading difficulties has received little attention. In 1960, Goetzinger, Dirks and Baer reported evidence indicating that poor readers are significantly inferior to good readers on auditory discrimination tasks. These results led Goetzinger et al. (1960) to suggest that a primary auditory-cortical dysfunction may be occurring in the poor readers. Tallal (1980) hypothesized that some reading disabilities are related to a low-level auditory perceptual dysfunction that affects the ability to learn to use phonics skills adequately. Her 1980 study found that a subgroup of children with reading disorders demonstrated impaired performance on auditory processing tasks, similar to the impairment found in language-delayed children.

Godfrey, Syrdal-Lasky, Millay and Knox (1981) investigated the performance of children with reading difficulties on auditory-phonetic tasks. Significant differences were found between the performance of good and poor readers on identification and discrimination of consonant-vowel stimuli. The good readers passed all criterion tests whereas 47% of the poor readers were unable to pass one or more criterion tests. As a result Godfrey et al.

(1981) concluded that auditory-phonetic difficulties may underlie reading disabilities.

Studies by Godfrey et al. (1981), Goetzinger et al. (1960) and Tallal (1980) suggest that auditory or acoustic factors may be involved in reading problems. Most models of short-term memory, including Baddeley's model of working memory, have not taken into account the importance of acoustic information even though it is well known that auditory presentation invariably produces large effects in short-term memory studies. When visual and auditory items are presented for immediate serial recall, auditory presentation consistently produces higher recall levels than does visual presentation for two or three items presented at the end of a list. The term "modality effect" refers to the finding that auditory presentation provides superior recall levels when compared to visual recall for items at the end of a list (Penney, 1989).

To account for the modality effects, Penney (1980, 1989) proposed a separate-stream hypothesis in which auditory and visual items are processed differently in short-term memory. With visual presentation, a visually based code (V code) is produced, however this type of code is relatively ineffective for use with verbal information. Typically, when verbal information is presented, an individual silently articulates or rehearses the verbal items and this rehearsal activates the

P or phonological code. The P code in the separate-stream hypothesis is similar to Baddeley's (1986) phonological code produced as a result of activity within the articulatory loop.

In contrast to visual presentation, when an item is presented auditorily, an A (acoustic) code is produced as a result of perceptual processing. The A code is produced only for items that are heard. Individuals cannot prevent an auditory item from entering the auditory stream and being encoded in the A code. If no interference is present, the A code can last for up to 1 minute (Penney, 1989). It is the availability and durability of the A code that is responsible for the documented superiority of auditory presentation and it is the displacement of this information that underlies the auditory suffix effect (Penney, 1989).

Penney (1989) presented evidence that when a subject silently articulates or imagines the sound of visually presented items, the trace in memory is different from the trace of an item that is presented auditorily. While the P code is common to both visual and auditory items, the A code is produced only for items that are heard. When verbal information is presented visually, phonological codes are normally activated from long-term memory in a process of subvocal rehearsal or articulation. However, when information is presented aurally the phonological codes appear to be activated directly by the acoustic stimuli without the need of articulatory processes.

To summarize, an individual with deficient auditory processing skills will have difficulty perceiving differences between phonemes and making judgements concerning sound representations. Consequently, because of ineffective auditory processing capabilities, the individual will have difficulty in retaining phonological information in short-term memory. The short-term phonological store is necessary as an intermediate stage, holding information and allowing it to be transferred to some form of long-term phonological store. Without proper maintenance of phonological material in short-term memory, inadequate phonological representations will be formed in long-term memory. These inadequate representations may be difficult to retrieve or manipulate, leading to the documented problems in word retrieval, rehearsal, and phonemic segmentation. As previous research has indicated, phonological ability is necessary for fluent reading ability to develop (Siegel, 1990; Stanovich, 1988a, 1988b; Wagner & Torgesen, 1987). Thus problems with auditory processing may be responsible for phonological deficits associated with reading difficulties.

College Students with Reading Difficulties

The research literature on reading difficulties focuses, for obvious reasons, on school-aged children. There exists an expectation that if students are high achievers and eventually reach a college level, they could not have learning or reading difficulties. Since the late 1970s there has been interest in college students who have learning difficulties including reading problems (Aaron & Phillips, 1986; Hughes & Osgood Smith, 1990). Often bright individuals can compensate for their reading difficulties with or without the benefit of remediation training (Cohen, 1983), but these individuals are generally slow readers and do not read for pleasure.

Aaron and Phillips (1986) presented a summary of ten years of research on developmental dyslexia in college students. The overall results from their review suggested that developmental dyslexia is a syndrome, the common factor with all their subjects appearing to be poor mastery of grapheme-phoneme conversion rules. Aaron and Phillips' (1986) results also suggested that the college students possessed compensatory skills; for example, the subjects compensated for their decoding deficits by developing a strong sight vocabulary. In addition, the college students tended to be highly motivated and tenacious; nevertheless they remained slow readers. Aaron and Phillips (1986) suggest that reading skills develop in stages and that these college students have passed the critical stage and have all reached a similar level. The college level dyslexic subjects they studied may belong to a homogenous group in the sense they have crossed the initial stage of reading acquisition but have failed to reach the higher stages (Aaron & Phillips, 1986).

Hughes and Osgood Smith (1990) completed a literature review of college students with learning disabilities. They reported that nc studies have been conducted to confirm that reading difficulties comprise the primary characteristic of learning disabilities with college students. Generally reading measures were included in studies for the purpose of collecting demographic information or to compare scores across tests and were not used to analyze reading ability in the college population (see Hughes & Osgood Smith 1990 for a review of the studies).

Hughes and Osgood Smith (1990) found that college students with learning difficulties do not read as well as students that have no learning problems. They have comprehension problems and are slow readers. While learning-disabled college students appear to be functioning well, evidence indicates a variety of problems that could adversely affect academic performance. Hughes and Osgood Smith (1990) also noted that college students are very adept at understanding and pinpointing their specific strengths and weaknesses.

Although limited research on learning or reading difficulties with college students has been conducted, anecdotal evidence indicates that there is a substantial proportion of college students with poor reading skills. It can be assumed that college students are bright individuals, functioning in many ways at an adequate level but with specific deficits. It is also assumed that college students have well developed memory and rehearsal strategies. College students with reading difficulties have successfully completed high school thanks to motivation, use of rehearsal and memory strategies. The present study uses subjects at the college level as a pilot study to investigate reading ability, memory and modality effects.

The Present Study

The purpose of the study reported here was to investigate auditory short-term memory and auditory information processing in good and poor readers at a university level. Past research suggests that reading disabilities result from phonological processing deficits; Penney's (1989) separate-stream hypothesis suggests that these phonological deficits may be linked to defective auditory processing and a deficient A code.

The Woodcock-Johnson Psycho-Educational Battery - Revised (Woodcock & Johnson, 1989) is a standardized battery of subtests with adult norms. Specific subtests were chosen from the battery in order to measure reading and auditory processing capabilities. It was anticipated that subjects identified as poor readers would have problems with the auditory processing subtests due to deficient auditory processing skills and a deficient A code.

To test short-term memory, immediate recall for digits was required under different presentation modalities. In short-term memory tasks, auditory and visual sequential presentations are normally compared to examine the modality effect. If poor readers have a deficient A code, the modality effect should be eliminated or should be less extensive than for good readers. Because oral recall is known to reduce the size of the modality effect compared to written report (Penney, 1979), subjects always used written recall for the digit-span tests.

Both sequential and simultaneous visual presentation were included in this study to determine if simultaneous visual presentation influenced the modality effect. It was anticipated that visual simultaneous presentation would provide the best recall regardless of the subjects' reading ability (Crowder, 1966; Penney, 1975, 1989).

Method

Subjects

A total of 40 first- or second-year university students, 20 males and 20 females, participated in the study. The ages ranged from 18 to 28 years. The subjects were recruited from advertisements posted in the academic buildings and Thompson Student Centre of Memorial University seeking individuals to participate in a study on reading ability. Some posters indicated an interest in individuals that had reading difficulties. All subjects signed an informed consent form (See Appendix A) and were paid for their participation. All subjects who began the study completed both sessions and no subjects were excluded from the study.

Measures

Woodcock-Johnson Psycho-Educational Battery - Revised (Woodcock & Johnson, 1989). Three subtests from this battery were used to provide a measure of subjects' basic reading skills and their level of reading achievement. The Word Attack subtest is used to measure the ability to apply phonic skills and structural analysis to the pronunciation of unfamiliar printed words. Subjects read aloud letter combinations that are permissable in English but do not form actual words. The Reading Vocabulary subtest is used to measure the ability to read and comprehend words. In Part A:

Synonyms, the subjects read aloud the word and produce a word similar in meaning to the word presented. In Part B: Antonyms, the subjects read aloud the presented word and produce another word opposite in meaning to the word presented. Only one-word responses are acceptable. The Letter-Word Identification subtest measures skill in reading aloud words that appear in large type on the subject's side of the test book. The subject is asked to respond to words that he or she may or may not be familiar with. In this test it is not necessary that subjects know the meaning of any word correctly read.

Three further subtests from the battery were used to measure auditory processing. A pre-recorded tape was used to present the stimuli for all three of these subtests. The Incomplete Words subtest measures auditory closure. After hearing a recorded word with one or more phonemes missing, the subjects try to identify the complete word. The Sound Blending subtest measures a subject's ability to say whole words after hearing syllables or phoneme parts of the words pronounced at a slow rate. These are actual words in which the word parts are presented in the proper order with brief pauses between each word part. The Sound Patterns subtest measures the ability to detect differences between pairs of complex sound patterns. The ound patterns may differ in pitch, rhythm, or sound content and the subjects indicate whether the patterns are the same or different.

Peabody Picture Vocabulary Test - Revised (Dunn & Dunn, 1981) This test is designed to measure receptive vocabulary and does not require the subject to read. The examiner reads words aloud, one at a time, and for each word the subject is required to select one picture from a set of four that best represents the meaning of a particular stimulus word. The test was used to provide an estimate of verbal ability and vocabulary knowledge for all subjects. Comparisons of the Peabody standard scores with WAIS Verbal Scale scores produced correlations that ranged from .21 to .91 with a median of .71 (Dunn & Dunn, 1981).

Digit-Span Tests These tests were used to determine short-term memory capacity for auditory and visual materials. The tests started with four-digit strings and progressed in increments of one to nine-digit strings. At each list length there were ten trials. The digits used in each trial were random permutations of digits from one to nine and there was no trial where any digit was presented more than once. The word "ready" was seen and heard before each digit string. Subjects were told to concentrate on the digits while they were being presented as written recall would be required after each digit span trial. The subjects were told that once the entire digit string had been presented they should write what they recalled on the response sheet beginning with the first digit presented.

For the auditory span trials, auditory stimuli were presented via an IBM-AT compatible computer that had a Soundblaster card and software. The digits were recorded in a male voice, and the computer controlled playback of the recorded digits. For the visual span trials there were two conditions, simultaneous presentation and sequential presentation of digits. The visual stimuli were white on a black computer screen. The digits were centered and the column width was set to 40 columns. Sequentially presented digits, whether auditory or visual, were presented at a rate of 1 digit/.8 sec; for simultaneous visual presentation, all digits were presented for a period equal to .8 sec times the number of digits.

Procedure

Each subject was tested individually and was asked to participate in all tests. For the Woodcock-Johnson subtests and the Peabody Picture Vocabulary Test - Revised, the examiner followed all instructions and procedures outlined in the test manuals. In the first session, which took approximately 2 hours to complete, subjects were randomly assigned to one of two test orders. In order 1, subjects first completed the Woodcock-Johnson Reading Vocabulary subtest; this was followed by the Woodcock-Johnson Word Attack subtest, Simultaneous Visual Digit Span test, Woodcock-Johnson Letter-Word Identification subtest, Auditory Digit Span test, Peabody Picture Vocabulary Test - Revised and the Visual Sequential Digit Span test. For order 2 the tests were presented in the reverse order except that the Woodcock-Johnson Reading Vocabulary subtest was given first. This was followed by the Visual Sequential Digit Span test, Peabody Picture Vocabulary Test - Revised, Auditory Digit Span test, Woodcock-Johnson Letter-Word Identification subtest, Visual Simultaneous Digit Span test and the Woodcock-Johnson Word Attack subtest. In a second session, which took approximately 1/2 hour to complete, subjects were given the Incomplete Words, Sound Patterns and Sound Blending subtests. This order was the same for all subjects. Once both sessions were completed the subjects were debriefed on the nature of the study and all questions were answered. Subjects were also paid for their participation.

Results

Reading ability was determined from the raw scores of the Word Attack subtest. Seventeen subjects had a raw score of 25 or above which is equivalent to a grade level of 14.4, and 23 subjects had scores 24 or below. As the groups (N=17 and N=23) were close to a 50 - 50 split it was decided to take a median split of the Word Attack results to achieve equal-sized groups for statistical analyses. Twenty subjects (9 females, 11 males) obtained a raw score of 24 or better for a grade level of 11.9 and were classified as good readers. The remaining 20 subjects (11 females, 9 males) were performing below this level with a raw scores less than 24 and a grade equivalent of 9.8 or below. The poor readers on the Word Attack had a mean grade equivalent of 7.8 with a standard deviation of .88 compared to a mean of 14.4 and a standard deviation of 1.52 for the good readers.

In Table 1 the performance of good and poor readers on the 10 measurement tests is compared. All analyses of the Woodcock-Johnson subtests were based on the raw scores. On all the Woodcock-Johnson reading subtests the poor readers had lower raw scores than the good readers but the difference on the Reading Vocabulary subtest was not statistically significant ($\underline{t}_{(38)} = 1.68$, $\underline{p} > .05$). For the Reading Vocabulary subtest the raw scores for the poor readers ranged from 42 to 51 whereas for the good readers the range of raw

Table 1

Means, Standard Deviations, and t-Test Results for Good and Poor Readers on all Measurement Tests

MEASURES	MEANS GOOD	MEANS POOR	STANDARD DEVIATIONS GOOD	STANDARD DEVIATIONS POOR	t-TEST
WORD ATTACK	25.9	22.4	1.52	.88	t=8.91***
LETTER-WORD	54.40	52.50	1.19	1.47	t=4.50***
READING VOCABULARY	47.60	46.25	2.70	2.38	ns
PEABODY PICTURE	115.4	104.2	12.79	10.46	t=3.03**
INCOMPLETE WORDS	29.40	27.15	2.70	1.84	t=3.08**
SOUND BLENDING	27.25	23.10	2.05	2.69	t=5.48***
SOUND PATTERNS	29.50	23.55	2.84	4.45	t=5.04***
VISUAL SIMULTANEOUS	368	351.25	15.21	25.91	t=2.49*
VISUAL SEQUENTIAL	339.9	327.25	33.88	39.64	ns
AUDITORY	347.1	311.05	28.70	38.91	t=3.33**

NOTE. p<.001 = ***, p<.01 = **, p<.05 = *

scores was 43 to 55. The poor readers had a mean grade equivalent of 13.2 on the Reading Vocabulary subtest while the mean for the good readers was 13.9. The subjects' performance on the Reading Vocabulary subtest is about average for first- or second-year university students. On the Letter-Word Identification subtest the mean score for the poor readers was 52.5 with raw scores ranging from 49 to 55, while for the good readers the mean score was 54.4 with raw scores ranging from 52 to 57. The difference in mean raw scores is only about two items, but the mean grade equivalents were 11.9 for the poor readers and 16.8 for the good readers. Standard scores were used for the analysis of the scores on the Peabody Picture Vocabulary Test - Revised. The mean score was 104.2 with a range of 83 to 117 for the poor readers compared with a mean of 115.4 with a range of 92 to 143 for the good readers. While the poor readers were below the average expected for university students on these two measures, they did not demonstrate severe deficits.

The results of the three auditory processing subtests were critical to the hypothesis of this study. It was anticipated that the poor readers would perform more poorly on these tests than would the good readers. On the Incomplete Words subtest, the poor readers scored at a mean grade level of 4.2 with raw scores ranging from 23 to 30, compared with a mean grade level of 7.1 with raw scores ranging from 23 to 33 for the good readers. The raw scores on the Incomplete Words subtest were much lower than expected for both groups, but there were more poor readers with very low scores. The mean grade equivalent on the Sound Blending subtest was 4.6 for the poor readers, whereas the good readers scored a mean grade equivalent of 16.8. The range of raw scores on the Sound Blending subtest was 19 to 31 for the poor readers and 24 to 31 for the good readers. Some of the poor readers did have high scores but there were more poor readers that had very low scores. Finally on the Sound Patterns subtest the poor readers had a mean grade equivalent of 5.1 with raw scores ranging from 8 to 28, and the good readers had a mean grade equivalent of 16.9 with a range of raw scores from 23 to 34. The results on the Incomplete Words, Sound Blending, and Sound Patterns subtests indicated that the poor readers did have auditory processing deficits.

The digit span tests were scored giving a point for each digit in its correct position. There were 10 trials at each list length and the points were added to provide a score for each list length. Finally the scores at each list length were summed to give a total score which represented the number correct out of a possible total of 390. On the digit span test, regardless of presentation modality, the poor readers had lower mean recall levels than the good readers (see Table 1). For visual simultaneous presentation, the poor readers had a mean recall of 351.25 with a range of scores from 290 to 390. The mean recall for visual simultaneous presentation was 368 for the good readers with a range from 331 to 390. With auditory presentation, the poor readers had a mean recall of 311.05 and a range from 216 to 390 while the good readers had a mean of 339.9 with a range from 291 to 390. The mean recall score for visual sequential presentation was 327.25 for the poor readers and 339.9 for good readers but the difference was not significant ($t_{(38)} = 1.09$, $p > .05$). The range of scores for the poor readers on the visual sequential digit span was from 226 to 372, while for the good readers the range was from 268 to 388.

Table 2 gives the significant correlation coefficients between the measurement tests. The largest correlations were between the Auditory, Visual Sequential and Visual Simultaneous Digit Span tests. The obtained correlations between the digit span tests are consistent with the view that all the digit span tests measure a common short-term memory component. The reading measures from the Woodcock-Johnson (Word Attack, Reading Vocabulary and Letter-Word Identification) were all intercorrelated with one another. In addition the Peabody Picture Vocabulary Test - Revised was correlated with all the reading measures. These significant correlations indicated that the reading subtests and the Peabody Picture Vocabulary test were measuring related aspects

Table 2

Correlation Coefficients for all Measurements Tests

					CORRELATIONS					
TESTS	1	2	3	4	5	6	7	8	9	10
1. WORD ATTACK	*	.607	.427	.342	.534	.567	.525	.428	ns	.539
2. LETTER-WORD	-	*	.557	.570	.375	.541	.381	.406	.370	.447
3. READING VOCABULARY	-	-	*	.425	ns	ns	ns	.356	ns	ns
4. PEABODY PICTURE	-	-	-	*	ns	.639	ns	ns	ns	ns
5. INCOMPLETE WORDS	-	-	-	-	*	ns	.342	.414	ns	.486
6. SOUND BLENDING	-	-	-	-	-	*	.445	ns	ns	ns
7. SOUND PATTERNS	-	-	-	-	-	-	*	.516	.436	.654
8. VISUAL SIMULTANEOUS	-	-	-	-	-	-	-	*	.793	.854
9. VISUAL SEQUENTIAL	-	-	-	-	-	-	-	-	*	.811
10. AUDITORY	-	-	-	-	-	-	-	-	-	*

NOTE. $p < .01$ for correlations = .418, $p < .05$ for correlations = .325

of verbal ability. The significant correlations between the Word Attack and Letter-Word Identification subtests suggest that phonological analysis is important in word identification tasks. The Word Attack was less related to the Peabody and Reading Vocabulary subtest than to the Letter-Word Identification subtest. This is consistent with the notion that both types of vocabulary measures are more dependent on word identification skills than phonological analysis skills.

The Incomplete Words, Sound Blending and Sound Patterns subtests measure auditory processing. Two of the three possible correlations were significant (see Table 2) while the third correlation between Incomplete Words and Sound Blending approached significance ($\underline{r}$=.293, $\underline{p}_{.05}$=.325). These correlations indicate that the three subtests form a cluster that represents auditory processing and that the subtests are measuring an individual's auditory processing capabilities.

There were also strong correlations between the auditory processing subtests on one hand and the Word Attack and Letter-Word subtests on the other. These correlations are as strong as the correlations that occur between the various reading measures. The significant correlations suggest that, in addition to phonological ability, good auditory processing skills may be needed for nonword and word identification tasks.

Finally the Sound Pattern subtest was correlated with the three digit span tests consistent with the idea that the Sound Patterns subtest and the digit span tests are measuring short-term memory ability. These correlations are reasonable given the fact that the Sound Patterns subtest, while primarily measuring auditory processing, does require an adequate short-term retention of the sound pattern for the subject to make the correct choice.

It was predicted that a modality effect would be observed for the good readers in that auditory presentation would lead to better recall of items from the end of the list than would the visual sequential presentation. It was expected that the poor readers would demonstrate either no modality effect or a weaker modality effect. An Analysis of Variance (ANOVA) was conducted on the total scores on the digit span tests to see whether modality interacted with reading ability. As expected, recall performance of the poor readers on the digit span tests was lower overall than that of the good readers, $\underline{F}(1,38) = 5.67$, $\underline{p} < .05$. On the digit span tests the poor readers had a mean recall of 329.9 compared to 351.7 for the good readers. A significant main effect of modality was also observed $\underline{F}(2,76) = 47.13$, $\underline{p} < .001$. As expected, visual simultaneous presentation ($\underline{M} = 359.6$) was better than both visual sequential ($\underline{M} = 333.6$) and auditory presentation ($\underline{M} = 329.1$) and this was true for both good and poor readers. Most important, the ANOVA indicated a significant interaction between modality and reading ability $F(2,76) = 6.76$, $p < .01$. The good readers showed the modality effect in that the mean recall for auditory presentation was 347.1 compared to 339.9 for visual sequential presentation. In contrast, the poor readers demonstrated a reverse modality effect; the mean recall for auditory presentation was only 311.1 compared to 327.3 for visual sequential presentation.

Serial position curves have been extensively utilized to investigate effects of auditory and visual presentation in immediate serial recall. The typical finding is that auditory presentation results in higher recall of the last two or three items, with no differences for items early in the list (Penney, 1980, 1989). To examine serial position effects separate ANOVAs for each list length were conducted with the variables of serial position (4 to 9), modality (visual sequential, visual simultaneous, and auditory) and reading ability (good and poor readers). The dependent variable was the total number of digits recalled in the correct position out of the 10 trials for each list length. Table 3 provides F ratios for the significant main effects and interactions for each of the variables included.

There was a significant main effect of serial position for all list lengths except the shortest list. With each list length except the shortest, the standard bow-shaped serial

Table 3

ANOVAs on all Digit Span Tests: Variables Included are Serial Position (S.P.), Modality (MODE) and Reading Ability (R.A.)

VARIABLES	LIST LENGTH 4	5	6	7	8	9
S.P.	ns	df(4,76) $F=7.96$ $p<.001$	df(5,95) $F=8.77$ $p<.001$	df(6,114) $F=14.82$ $p<.001$	df(7,133) $F=18.78$ $p<.001$	df(8,152) $F=26.44$ $p<.001$
MODE	df(2,38) $F=5.79$ $p<.01$	df(2,38) $F=5.07$ $p<.025$	df(2,38) $F=16.60$ $p<.001$	df(2,38) $F=24.30$ $p<.001$	df(2,38) $F=16.15$ $p<.001$	df(2,38) $F=21.65$ $p<.001$
R.A.	ns	df(1,38) $F=4.88$ $p<.05$	ns	df(1,38) $F=7.88$ $p<.01$	df(1,38) $F=8.42$ $p<.01$	ns
S.P. x MODE	ns	ns	df(10,190) $F=4.91$ $p<.001$	df(19,228) $F=4.42$ $p<.001$	df(14,266) $F=5.00$ $p<.001$	df(16,304) $F=8.71$ $p<.001$
S.P. x R.A.	ns	ns	ns	df(6,380) $F=2.80$ $p<.025$	ns	ns
MODE x R.A.	ns	ns	df(2,323) $F=14.08$ $p<.001$	df(2,380) $F=9.35$ $p<.001$	df(2,437) $F=3.82$ $p<.05$	df(2,494) $F=10.22$ $p<.001$
S.P. x MODE x R.A.	ns	ns	df(10,323) $F=1.97$ $p<.05$	ns	ns	ns

position curve was observed. A main effect of modality was observed for all list lengths with visual simultaneous presentation producing the best recall. This effect was also reflected in the significant interactions between serial position and modality for lists of six to nine digits. Figures 1 to 4 show that for the early and middle serial positions visual sequential presentation produced higher recall than did auditory presentation (see Figures 1 to 4). However, for both good and poor readers auditory presentation nearly always produced higher recall of items in the last serial positions than did visual sequential presentation.

For each list length good readers had higher recall than did the poor readers but the main effect of reading ability was significant only for lists of five, seven, and eight digits. Only lists of seven digits produced a significant interaction between serial position and reading ability, and a significant triple interaction of serial position, modality and reading ability was observed with lists of six digits. Figure 1 shows that the U shape of the auditory serial position curve is much more pronounced for the poor readers than for the good readers or the visual presentation modalities.

The interactions between modality and reading ability were significant for lists of six to nine digits. For all list lengths visual simultaneous presentation produced the

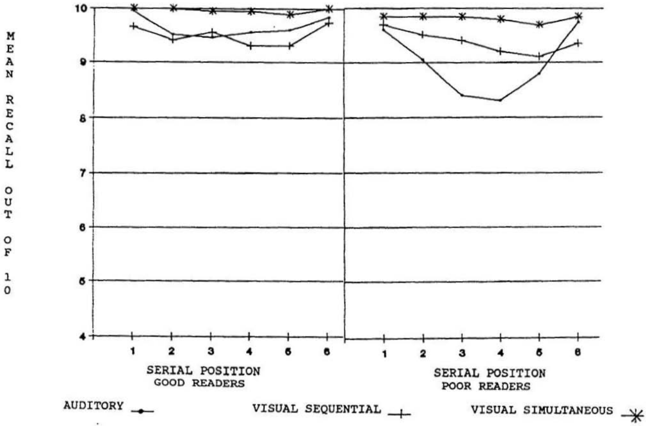

Figure 1. Mean Recall of Auditory and Visual Six- Digit Lists for Good and Poor Readers

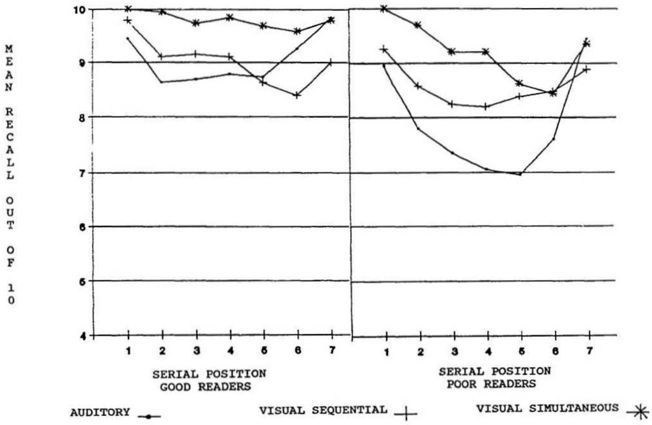

Figure 2. Mean Recall of Auditory and Visual Seven- Digit Lists for Good and Poor Readers

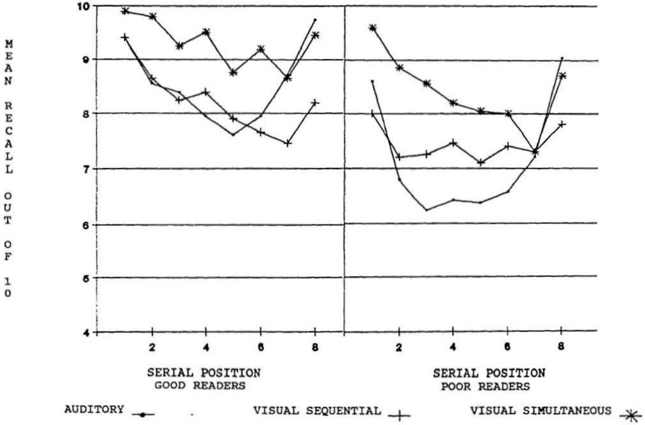

Figure 3. Mean Recall of Auditory and Visual Eight- Digit Lists for Good and Poor Readers

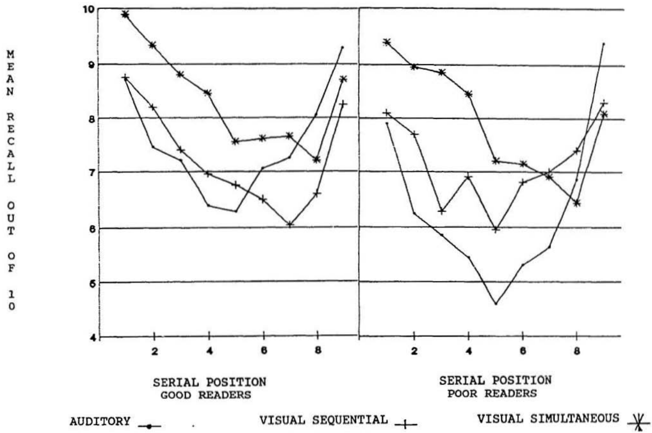

Figure 4. Mean Recall of Auditory and Visual Nine- Digit Lists for Good and Poor Readers

highest recall and this was true for both good and poor readers. For good readers remembering lists of six to nine digits, auditory presentation produced the second highest recall. The means for auditory presentation for the good readers were 9.65, 9.06, 8.54 and 7.52 (out of 10) for lists of six to nine digits respectively compared to 9.49, 9.03, 8.24 and 7.27 for visual sequential presentation. For the poor readers visual sequential presentation produced higher recall than did auditory presentation. The means for visual sequential presentation for the poor readers were 9.38, 8.59, 7.44, 7.16 for lists of six to nine digits respectively compared to 8.98, 7.88, 7.17, 6.36 for auditory presentation. The poor readers demonstrated the typical modality effect for the last serial position (see Figures 1 to 4) but for the early and middle serial positions both the good and poor readers exhibited a reverse modality effect in that the visual sequential recall tended to be higher than auditory recall, but this crossover effect was much greater for the poor readers (see Figures 1 to 4).

In investigations of modality effects auditory and visual sequential presentation are typically compared as sequential presentation is utilized in both conditions. To make this comparison, additional ANOVAs were performed on each list length comparing auditory and visual sequential presentation only. The independent variables included were serial position, modality and reading ability; the dependent variable was the total number of digits recalled in the correct position out of the 10 trials for each list length. Table 4 details the significant main effects and interactions. For all list lengths, except lists of four digits in which recall was at ceiling, the main effect of serial position was significant. Only for lists of seven digits was there a significant main effect of modality with visual sequential presentation producing higher recall. There were significant interactions between serial position and modality for lists of six to nine digits. Figures 1 to 4 show that visual sequential recall was higher for the midlist serial positions while auditory recall was higher for last serial positions. Only lists of nine digits produced a significant interaction of serial position and reading ability. Good readers had higher recall than did the poor readers at all serial positions except the last.

The good readers consistently produced higher levels of recall, but the main effect of reading ability was significant only for lists of eight digits. The modality and reading ability interactions were significant for list lengths of six to nine digits (see Figures 1 to 4). For the good readers recall was better with auditory presentation while for the poor readers visual sequential presentation was better. With the good readers the usual modality effect was produced but

Table 4

ANOVAs on Auditory and Visual Sequential Digit Span Tests: Variables Included are Serial Position (S.P.), Modality (MODE) and Reading Ability (R.A.)

VARIABLES	LIST LENGTH 4	5	6	7	8	9
S.P.	ns	df(4,76) F=4.47 $p<.05$	df(5,95) F=9.24 $p<.001$	df(6,114) F=9.97 $p<.001$	df(7,133) F=11.50 $p<.001$	df(8,152) F=18.77 $p<.001$
MODE	ns	ns	ns	df(1,19) F=6.38 $p<.025$	ns	ns
R.A.	ns	ns	ns	ns	df(1,38) F=6.47 $p<.025$	ns
S.P. x MODE	ns	ns	df(5,95) F=4.11 $p<.05$	df(6,114) F=5.05 $p<.001$	df(7,133) F=6.28 $p<.001$	df(8,152) F=5.23 $p<.001$
S.P. x R.A.	ns	ns	ns	ns	ns	df(1,323) F=1.99 $P<.05$
MODE x R.A.	ns	ns	df(1,209) F=18.55 $p<.001$	df(1,247) F=13.32 $p<.001$	df(1,285) F=7.26 $p<.01$	df(8,323) F=24.73 $p<.001$
S.P. x MODE x R.A.	ns	ns	df(5,209) F=2.52 $p<.05$	ns	ns	df(8,323) F=2.17 $p<.05$

for poor readers a reverse modality effect occurred, with visual sequential presentation producing higher recall levels for the midlist and preterminal serial positions. Finally there were significant triple interactions of serial position, modality and reading ability of six and nine digits. Figure 1 and 4 show that the auditory serial position curve drops lower in midlist position than does the visual curve, and this decrease is larger for the poor readers.

Figures 1 to 4 show that the visual sequential recall tended to be higher than auditory recall for the middle serial positions. Nevertheless, for the last serial positions auditory recall was higher than visual for both good and poor readers. To analyze this effect further, three separate ANOVAs were conducted on the terminal, penultimate and antepenultimate digits (see Table 5). The variables included in each ANOVA were list length (6 to 9), modality (auditory and visual sequential) and reading ability (good and poor readers). The dependent variable was the total number of digits recalled in the correct position out of the 10 trials for each list length.

For the terminal items there was a significant main effect of list length with recall decreasing for the longer list lengths. The means were 9.68, 9.30, 8.71 and 8.80 for lists of six to nine digits respectively. The main effect of

Table 5

ANOVAs on Terminal and Penultimate Items on the Digit Span Tests: Variables Included are List Length (LENG), Modality (MODE) and Reading Ability (R.A.)

VARIABLES	TERMINAL	PENULTIMATE	ANTEPENULTIMATE
LENG	df(3,57) F=12.99 p<.001	df(3,57) F=22.97 p<.001	df(3,57) F=53.44 p<.001
MODE	df(1,19) F=17.99 p<.001	ns	ns
R.A.	ns	ns	ns
LENG x MODE	df(3,57) F=4.77 p<.01	ns	ns
LENG x R.A.	ns	ns	ns
MODE x R.A.	ns	df(1,133) F=18.48 p<.001	df(1,133) F=21.83 p<.001
LENG x MODE x R.A.	ns	ns	ns

modality was also significant. The mean for auditory presentation was 9.55 compared with 8.69 for visual sequential presentation. There was a significant interaction between list length and modality for the terminal items. The mean recall for auditory presentation was 9.80, 9.65, 9.43, and 9.33 for list lengths of six to nine digits respectively. For visual sequential presentation the means were 9.55, 8.95, 8.00, and 8.27 for list lengths of six to nine digits respectively. For the last items in six- to nine- digit lists, auditory presentation consistently produced higher recall levels. As list length increased, the difference between auditory and visual recall increased. With increasing list length visual sequential presentation produced lower recall than auditory presentation for all subjects for the preterminal items.

The interaction between modality and reading ability was not significant. For the good readers the mean recall with auditory presentation was 9.69 compared to 8.80 for visual sequential presentation. For the poor readers the mean recall for auditory presentation was 9.41 and 8.59 for visual sequential presentation. For both good and poor readers auditory presentation always produced better recall, of terminal items than visual presentation.

In contrast to the results for the terminal items, there was no main effect of modality and no interactions between list length and modality for the penultimate digits. With the penultimate digits there was a significant main effect of list length with means of 9.21, 8.43, 7.66, and 7.20 for lists of six to nine digits respectively. In addition there was a significant interaction of modality and reading ability. For the good readers recall was higher with auditory presentation ($\underline{M}$ = 8.9) than with visual sequential presentation ($\underline{M}$ = 7.9). However, for the poor readers, a reverse effect was observed. Visual sequential presentation produced better recall levels ($\underline{M}$ = 8.1) than did auditory presentation ($\underline{M}$ = 7.6; see Figures 1 to 4).

The analysis of the antepenultimate digits produced results similar to that for the penultimate digits: a significant main effect of list length and a significant interaction of modality and reading ability. The means for lists six to nine digits were 9.11, 8.16, 7.40 and 6.49. As was found for the penultimate digits, for the good readers auditory presentation produced higher recall ($\underline{M}$ = 8.4) than visual sequential presentation ($\underline{M}$ = 7.9). With the poor readers the reverse was found and visual sequential recall was higher ($\underline{M}$ = 8.0) than the auditory recall ($\underline{M}$ = 6.9; see Figures 1 to 4).

The results of the ANOVAs on the terminal, penultimate and antepenultimate items show that for good and poor readers the usual modality effect was found for the last item in the list. With the preterminal serial positions, the modality effect occurred for the good readers but for the poor readers a reverse modality effect occurred in that visual sequential presentation produced higher recall levels. The poor readers did show evidence of echoic memory in that the terminal items manifested higher recall levels for auditory than visual presentation. However, the crossover effect that occurred with the penultimate and antepenultimate digits may indicate that the echoic memory of the poor readers is not as effective as that of the good readers. These results are consistent with the hypothesis that the poor readers have a smaller capacity for echoic memory or that their echoic memory is not as durable as that of the good readers.

Discussion

There is now a considerable body of evidence showing the link between phonological skills and learning to read (Siegel, 1990; Stanovich, 1988a, 1988b; Wagner & Torgesen, 1987). It is plausible that good phonological skills may be the cause of later success in reading in that good readers appear to have highly sophisticated phonological skills when they begin learning to read (Stanovich, 1988a, 1988b). But why do some individuals have poor phonological processing skills to begin with? The hypothesis tested in this study was that phonological deficits arise from auditory processing difficulties.

Only a few articles have suggested a link between reading ability and auditory processing skills (Godfrey et al. 1981; Goetzinger et al. 1960; Tallal, 1980). Tallal (1980) found a highly significant correlation between poor nonword reading skills and difficulty in processing rapidly presented nonverbal auditory information. Tallal's results suggested that perceptual difficulties with auditory processing may be related to phonological difficulties. She believed that the ability to process rapidly changing auditory information plays a role in analyzing the phonetic codes involved in speech perception and phoneme identification. Therefore a deficit in analyzing rapidly changing auditory information may result in less sharply defined phonological categories for reading disabled individuals.

When a child begins learning to read, auditory perceptual deficits would be related primarily to difficulty learning the sound-symbol relations (Tallal, 1980). An individual with deficient auditory processing skills would have difficulty perceiving subtle differences between phonemes and making judgements concerning sound representations. Auditory perceptual difficulties would likely cause deficiencies in short-term memory, as an individual would have difficulty retaining complete phonological information. In the absence of proper processing and storage of phonological material in short-term memory, impoverished phonological representations will be laid down in long-term memory. Deficiencies in the memory representations may be responsible for the phonological recoding and retrieval problems that poor readers demonstrate. Because the impoverished memory representations do not support phonemic analysis, a child learning to read would have difficulty associating letters and sounds. Thus problems with auditory information processing may be responsible for the phonological deficits associated with reading difficulties.

The university students used in this study were not extremely poor readers; nevertheless, the poor readers in this sample performed below average on most of the reading measures. The inferior performance on the nonword reading subtest indicated that the poor readers in the present study did have deficits in their phonological processing. Previous studies (Siegel & Ryan, 1989b; Siegel & Heaven, 1986; Vellutino, 1978, 1979) have shown a robust relationship to exist between nonword reading and other reading measures, and this relationship was replicated in the present study. The highly significant correlation between the Word Attack and Letter-Word Identification subtests suggests that phonological analysis skill is related to word identification performance. The Word Attack subtest also significantly correlated with the two vocabulary measures although these correlations were not as high as the correlation with the Letter-Word Identification subtest. This suggests that vocabulary knowledge is directly dependent on word identification skills but only indirectly related to phonological analysis skills.

The present study was conducted to test the hypothesis that poor readers have deficits in auditory information processing and short-term memory. Although both good and poor readers had poor performance on the Incomplete Words subtest, the poor readers were more likely to have very low scores than were good readers. On the Sound Blending subtest, which measures the ability to combine isolated phonemes and syllables into words, there were large differences in the mean raw scores for the good and poor readers. The Sound Patterns subtest, which relies on distinguishing differences between auditory patterns, also produced major differences between the good and poor readers. All three auditory processing subtests proved to be difficult for the poor readers consistent with the hypothesis that the poor readers have deficits in auditory processing capabilities.

Strong correlations were found between the various auditory processing subtests and the auditory digit span on one hand and with the nonword reading subtest on the other. Interestingly enough, these correlations were as high as or higher than the correlations among the different reading measures. Tallal (1980) also found that nonword reading was highly correlated with ability to process rapidly presented auditory stimuli. This is further evidence of a connection between phonological and auditory processing skills. Despite the fact that the nonword reading subtest is not intended to measure auditory processing, the correlations with the different auditory tests indicate that auditory processing is a critical component for phonological processing.

Finally it was anticipated that the modality effect would be of weaker magnitude or eliminated for the poor readers. The usual modality effect was observed for the good readers in that auditory presentation produced higher recall levels for the terminal and preterminal serial positions. In contrast, with the poor readers, the modality effect was observed for the last serial position only. For the preterminal serial positions visual sequential recall was higher than auditory recall, producing a reverse modality effect. The reverse modality effect is consistent with the hypothesis that poor readers have a deficit in auditory processing capabilities and a problem with auditory short-term memory. The poor readers did show evidence that echoic memory is operative but the results indicate that the echoic memory for the poor readers may not be as efficacious as that of the good readers.

An alternative explanation for the relatively inadequate performance of poor readers with the preterminal serial positions is that they have less effective rehearsal and coding strategies. Sipe and Engle (1986) conducted a series of experiments, using a suffix procedure, to determine whether echoic memory was related to reading ability. The poor readers, relative to good readers, demonstrated a larger terminal position suffix effect and a faster loss over time for digits presented to the unattended ear in a dichotic listening task. However, in a gap-detection task devised to measure the duration of aural persistence the good and poor readers demonstrated no differences.

Sipe and Engle (1986) proposed three explanations for the results they observed. One explanation was that the poor reader's echoic memory had a smaller capacity or that the echoic memory trace decayed faster. A second explanation consistent with the data was that the poor readers were more affected by interference from the suffix. The third explanation suggested that good readers are capable of quickly creating a phonological code that is more durable than echoic memory whereas the poor readers either do not construct a phonological code or the code they create is ineffective.

Sipe and Engle (1986) felt that inferences concerning the capacity of echoic memory were difficult to justify on the basis of their data. If good readers can rely on strong phonological coding, their recall will be good despite the suffix interference on echoic memory. The poor readers have to rely heavily on echoic memory because of their ineffective phonological coding ability and therefore suffix interference will further lower their recall.

When Sipe and Engle's (1986) logic is applied to the results in the present study, inconsistencies occur. The lower recall of the preterminal items for the poor readers could be explained by relatively ineffective rehearsal and coding strategies related to the poor phonological coding ability. But this does not explain why the bigger differences exist between good and poor for auditory than for visual recall. The alternative explanation that echoic memory capacity is deficient in the poor readers is more consistent with the results of the present study.

A second possible problem with Sipe and Engle's argument is that their studies were conducted on school-aged children.

The present study used university subjects who are probably quite proficient at using rehearsal techniques and other methods to compensate for their reading difficulties. In fact, if rehearsal and coding strategies were responsible for influencing the modality effect, lower recall would be expected with visual rather than auditory presentation (Penney, 1989). It is probable that the results in the present study reflect more of a problem with the poor reader's echoic memory ability and the duration of the memory trace.

New Directions

The hypothesis that auditory processing deficits contribute to reading disability may bring a new perspective to the difficulty that poor readers experience. The findings in this study support the hypothesis that poor readers have less effective auditory information processing capabilities and auditory memory than do good readers. The present study's results cannot infer a causal relationship between auditory information processing deficits and poor reading ability. However, the results do suggest the need for future research to investigate the possibility that auditory information processing deficits are responsible for reading difficulties.

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Appendix A

I understand that the experiment I will be doing will investigate short-term memory in students with different reading abilities. Digit-span tasks will be used to measure short-term memory and auditory and visual presentation will be compared.

I will be asked to participate in a number of tests of reading abilities. These tests will require me to read words and provide synonyms or antonyms, to read some words, to read nonwords, to match pictures to words and to identify words heard on auditory tapes. The digit-span tasks will require written recall of a string of digits that I will either see or hear. The entire study will take approximately 2 1/2 hours to complete over two days.

I understand that participation in this study is completely voluntary, that all my results will be strictly confidential, and that I can withdraw from this study at any time. I will be paid for participating in this study, but I understand that payment is conditional on completing the entire study.

Signed

Date