Do phonological deficits in reading-disabled children stem from imprecise phonological representations?

by

DIANE SLONIM

A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

2002

This manuscript has been read and accepted for the Graduate Faculty in Speech and Hearing Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

04-23-02
Date

Linnea C. Ehri
Chair of Examining Committee

4/23/02
Date

Executive Officer

Helen Cairns

Winifred Strange

Maria Mody
Supervisory Committee

CITY UNIVERSITY OF NEW YORK

Abstract

DO PHONOLOGICAL DEFICITS IN READING-DISABLED CHILDREN STEM FROM IMPRECISE PHONOLOGICAL REPRESENTATIONS?

by

Diane Slonim

Adviser: Professor Linnea Ehri

This study addressed the theory that phonological deficits in reading-impaired children stem from imprecise phonological representations. An audio-visual paradigm was used to test this theory with children reading at the second grade-equivalent level. Eighteen children with a reading disability (RD) were compared to 17 non-RD, reading-level matched children on a task requiring them to judge whether an auditorily presented real word matched a visually presented real word. The word pairs differed by a single stop consonant phoneme occurring either at the beginning or at the end of the word. In addition to making a same/different judgment, the children were required to verbally report either the word that they heard, or the word that they saw. The same experimental paradigm was used with nonword pairs.

The reading impaired children did not differ statistically from the typically developing children in their ability to judge word pairs as the same or different. Similarly, the two groups did not differ significantly in their latencies to make these judgments.

Both groups were significantly more accurate in judging real and nonword pairs that contrasted the place feature in the phoneme pair (e.g., cook-took) than in the voice feature (e.g., coat-goat). In the nonword pairs only, more errors were made on word pair judgments when the contrasting consonant phoneme appeared at the end of the word than at the beginning of the word. An analysis of the children's verbal productions of the words showed that the reading-impaired children made significantly more vowel errors in reporting the real and nonwords that they saw or heard than the control group. Moreover, the reading-impaired children were more likely to mistake the vowel in the word pair when asked to report the word seen than when asked to report the word heard.

The results suggest that reading -impaired children possess a selective impairment in vowel representation, and that deficits in vowel identification are a hallmark of their early reading deficiency.

Acknowledgments

To my parents, Jack and Etta Grodinsky, for your love and support

To my dear husband Michael, without you, it couldn't have been done

To my mentor and friend, Cathy Constable, for your friendship, insights, and help all along the way

To my adviser, Linnea Ehri, whose standards for excellence and passion for research were a source of inspiration

Table of Contents

Lists of Tables

Lists of Illustrations

Introduction

According to the simple view (Gough & Tumner, 1986), reading is composed of two basic processes, decoding and linguistic comprehension. The process of decoding has been a major focus of reading research for the reason that, whereas linguistic comprehension can be acquired through experience with spoken language, decoding skills typically cannot. Rather, decoding is a skill that most children need to be taught. Learning to decode involves learning grapheme-phoneme associations and how to use these to sound and blend words to read them. This is a complex skill because phoneme-sized units are not transparent in speech. Speech sounds are perceived and produced in relation to their coarticulated neighboring sounds. In the process of acquiring decoding skills, children must create phonological representations of words that link letters with speech sounds. Given that decoding is dependent on phonological processing skills, and given that disabled readers show impairment in phonological tasks, some researchers have concluded that phonological deficits are at the root of most reading disabilities.

The past twenty years of research have repeatedly shown that phonological deficits play a causal role in reading difficulties (Frith, 1981, Wagner and Torgesen, 1987, Stanovich, 1999). Highlighting the dominant role that phonology plays in reading is the fact that the term, "phonological recoding", is now synonymously used with the term, decoding. Within the phonological domain, many different skills and processes have been studied, and correlated with reading achievement. One skill that has been extensively studied is phonological awareness, the knowledge of and ability to manipulate phonological segments in words. Preliterate measures of phonological

awareness have been shown to be predictive of beginning reading achievement (Bradley & Bryant, 1983; Lundberg, Olofsson, & Wall, 1980; Share, Jorm, McClean,, Matthews, 1984). Additionally, training studies have shown that children's phonological awareness can be improved to benefit their spelling and decoding skills. (Bradley & Bryant, 1985; Bus & van Ijzendoorn, 1999; Lundberg, Frost, & Peterson, 1988).

Phonological recoding (or decoding) is another skill that has been extensively studied and has been shown to play a causal role in reading deficits (Rack, Snowling, & Olson, 1992). Studies have shown that reading-disabled children are impaired on reading nonwords (Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996), and that this disability continues into adulthood (Elbro, 1994).

Phonological deficits have also been suggested as the underlying cause of object naming difficulties observed in reading-impaired children. Poor readers make more errors than good readers in naming objects that they can recognize. Their errors involve producing forms phonologically related to the target, for example, *glub* for *globe* (Fowler, 1991). Furthermore, the object naming difficulties observed cannot be accounted for by low levels of vocabulary knowledge (Snowling, Van Wagtendonk, & Stafford, 1988). One interpretation of this finding is that poor readers have less precisely defined phonological representations of the spoken words they know.

Other research has suggested that reading-impaired children have difficulty with the categorical perception of certain speech contrasts. It has been shown that reading-impaired children have difficulty with close phonetic judgments across a variety of speech contrasts (Brandt and Rosen, 1980; Reed, 1989).

A large question that remains is, how are these various phonological skills related? Is there one underlying cause for these deficits, or are they multi-determined? Some researchers (Elbro, 1996, Swan & Goswami, 1997) have suggested that there is one unifying cause underlying these various phonological deficits. It has been proposed that reading-impaired children have difficulty establishing "complete", "full", "clear" or "precise" phonological representations in long-term memory. Accordingly, poor performance on phonological awareness tasks may be attributable *not* to a lack of skill (for example, decoding), but to poor underlying representations of the words that are to be segmented.

The present study addressed this theory. Do reading-impaired children possess imprecise representations of the spoken words they know compared to non-disabled readers reading at the same grade level? An audio-visual paradigm was used to test this hypothesis.

The children were simultaneously presented with a spoken word and a phonetically identical or similar written word (e.g., BIG/BIG or BIG/PIG). They were asked to judge whether the two words were the same or different, and then to report which word they heard or saw. In order to do this task, the children needed to compare the phonological forms of the written and the spoken word. If reading disabled children (RD) have poorer phonological representations of familiar real words than non-disabled readers (non-RD), then they should be less accurate and take longer in judging whether words heard match words seen than non-RD children. Moreover, when the words seen and heard differ, RD children should be more accurate in reporting the words seen than the words heard. In contrast, non-RD children should not show any difference. The

explanation is that for RD students, the word heard is phonologically imprecise and hence is less accessible and more easily overridden by the written word.

In a second task, the children were asked to judge whether two phonetically similar nonwords are the same or different. Again, one word was presented visually, and the other auditorily. The purpose of including nonwords was to assess the influence of nonword reading deficiencies. In the real word task, the children may be able to bypass the grapheme-phoneme translation process, and read the words by sight. Nonwords, by definition, have no lexical representations in memory and thus, grapheme-phoneme translation is required to do the task. If the difficulties that RD children exhibit in the nonword matching task arise from nonword reading deficiencies, then RD children should be less accurate and take longer in judging whether nonwords heard match nonwords seen than non-RD children. Moreover, when the nonwords seen and heard differ, RD children should be more accurate in reporting the nonwords heard than the nonwords seen. In contrast, non-RD children should not show any difference.

A reading-level match design was chosen for this study. The children selected for the study were reading between the second and third grade-equivalent level, as measured by a standardized reading test (Woodcock Reading Mastery Test-Revised, 1987, word identification and non-word identification subtests). A reading-level match design was selected in order to rule out reading ability as the cause of performance differences between reading disabled and normal readers.

There are several areas of research that bear upon both the theoretical and experimental/procedural aspects of this study. These areas of research are outlined below and are discussed in detail in subsequent sections of this proposal.

1. What theories have been proposed concerning the nature of phonological representations in RD and non-RD students? How do phonological representations relate to reading development? How have research studies assessed phonological representations?

2. How have audio-visual experiments been used to study phonological processes, including phonological recoding?

3. What are the linguistic factors involved in phonological processing tasks?

4. What is the relationship between orthographic processing and phonological recoding?

5. What is the relationship between speech discrimination and reading impairment?

Phonological Representations

Definitions and theories of phonological representations are still somewhat vague, and the research is still in the beginning stages. Elbro (1996, 1998b) and Fowler (1991) both offer hypotheses concerning how phonological representations provide the foundation for the development of phonological processing skills.

Elbro's Theory: Elbro (1996, 1998b) proposes that phonological representations refer to actual "phonological material", and thus are different from phonological skills/processes (such as phonological awareness, phonological working memory). Generally speaking, he maintains that phonological representations may be a common factor underlying many phonological skills. Children who have difficulties in learning to read possess relatively indistinct representations of words, or have difficulty accessing their distinct representations. He maintains no clear position as to whether the

phonological representation of the word is indistinct, or whether the children have difficulty accessing distinct representations.

Elbro (1996) defines distinctness as the degree of difference between a lexical representation and its neighbors. The greater the number of distinctive (i.e., phonetic) features that distinguish a word from its neighbors, the more distinct is its lexical representation. Words exist and can be pronounced at varying levels of distinctness. For example, the word "and" can be pronounced as [aend] or [ən]; in the former case, the word is stressed, and in the latter case the word is pronounced without stress. The unstressed pronunciation [ən] is less distinct because it can be confused with other words such as "an". Elbro hypothesizes that phonological representations of words at a low level of distinctness impair an individual's access to phoneme-size lexical segments (Elbro, 1998b). In turn, these indistinct representations impair a wide range of phonemic processing skills that are critical to reading development.

Fowler's Theory: Fowler (1991) proposes a developmental theory concerning phonological representations. The segmentation hypothesis (Fowler, 1991) states that phonological representations of words are gradually restructured from holistic units to increasingly smaller segments, and ultimately phonemes. This restructuring process occurs during the first one to eight years of language acquisition. The degree to which this restructuring process has taken place dictates the child's level of phonological awareness. Thus, if a child has not achieved a sufficient amount of restructuring of the lexicon, his/her phonemic awareness skills may be seriously impaired.

In addition, Fowler (1991) implies that phonological representations can be altered with training. She states that highly familiar (and early acquired) words will have

more highly segmented/specified representations than newly acquired, less familiar words. This theoretical position has also been supported by other researchers (see Metsala & Walley (1998)).

Studies of Phonological Representations

Elbro (1994, 1998a) conducted a few studies exploring the hypothesis that the quality or distinctness of a child's phonological representations provides the foundation for phonological processing skills. In one longitudinal study (Elbro, Borstrom, & Petersen,1998a), a group of children were followed from the beginning of kindergarten through the second grade, and given a series of language tests including phonemic awareness, phonemic discrimination and verbal short-term memory. One of the purposes of the study was to test whether the distinctness of phonological representations contributes to the prediction of reading development, when differences in phonemic awareness and other prereading skills have been accounted for. Phonological distinctness was measured, as follows: the kindergarten children were given the task of acting as a speech therapist to a puppet who had difficulty pronouncing words; the experimenter would name a word at a low level of distinctness, (e.g., "crodi" for "crocodile") and the child's job was to pronounce the word correctly. The children's responses were scored for distinctness based on production of selected vowel segments in the words. In second-grade, the children were divided into two groups based on a series of reading test scores. A logistic regression analysis showed that phonemic awareness, letter knowledge and phonological distinctness (measured in kindergarten) all made significant contributions to the prediction of reading disability in second grade.

In another study (Elbro, 1998b), children who were identified as at-risk for reading difficulties were given a 17-week training program in phonemic awareness. A correlational analysis showed that phonological distinctness predicted gains in phonemic awareness in the trained children and also in the normal comparison group.

Snowling, van Wagtendonk, & Stafford (1988) conducted an object naming study with dyslexic children (nine to eleven years of age) and age-matched and reading-level matched controls. The children were screened for receptive vocabulary, so that there were no significant differences among the groups in this skill. The children were asked to name objects from pictured objects and from spoken definitions of the objects. Six weeks later, the children were also asked to give definitions for each of the object names in the study. The results showed that the dyslexic children named objects (from pictures and definitions) only as well as children two years their junior (the reading-level matched controls). Their conclusion from this study was that dyslexic children have difficulty retrieving the phonological representations of words that they know (i.e., can define), and this deficit is not accounted for by poor vocabulary knowledge.

The results of these studies raise many questions. What remains unclear is whether reading-impaired/dyslexic children have a phonological accessing problem, a phonological storage problem, or both. Furthermore, Snowling et al.(1988) and Elbro used two different types of verbal production measures to assess phonological representation. Snowling et al. (1988) infers weak phonological representations from object naming and Elbro uses precise articulation as an index of phonological representation. It is unclear how word pronunciation provides an index of underlying phonological representation. Furthermore, it would be valuable to know whether these

two measures are highly correlated, and whether they are indeed measures of the same underlying problem.

Another issue regarding these studies is whether the methods used are valid means of assessing phonological representations. This dissertation proposes an alternative method for assessing phonological representations. It contrasts with studies cited above in that it is a receptive judgment task, and does not require production of the target words to make a judgment.

Audio-Visual Experiments

Audio-visual experiments have been conducted to address a variety of questions concerning the phonological processing of printed words. One of the early experiments (Snowling, 1980) was designed to assess phonological recoding skills in disabled readers. Disabled readers, matched on reading level to younger, typically developing readers, were presented with 4-letter nonsense word pairs that were constructed by changing the order of the middle two letters (e.g., snod, sond). The pairs were presented in four conditions: spoken word, followed immediately by the paired spoken word; the written word, followed by the paired written word; the spoken word followed by the written word; and the written word followed by the spoken word. The word pairs differed on 50% of the trials. The children's task was to (verbally) report whether the two words were the same or different. The results showed that the disabled readers were significantly more accurate on the written to written word match than on either spoken – written conditions. Furthermore, the normal readers showed improvement on the spoken-written conditions with increasing age, whereas the disabled readers did not. The author hypothesized that the disabled readers were using a letter by letter matching

approach in the written – written condition, whereas phonological recoding was required in the written – spoken conditions. This study had several limitations. First, no information was given regarding the length of presentation of the written words, or how much time elapsed between the presentation of the paired words. Therefore, verbal memory or visual memory for letter patterns could have also explained variations in performance. Furthermore, reaction-time for the responses was not measured. Additional information regarding word reading strategies could have been obtained by having the children pronounce the words. For example, did the children have more difficulty with vowel identification or blending? Oral reading would have also provided an index of the children's nonword reading abilities.

A follow-up to Snowling's study was conducted by Fox (1994). The question addressed was whether disabled readers could tell the difference between real-word pairs when the contrasting letter was at the beginning versus the end of the word. Dyslexic readers (nine to twelve years) were matched to two groups of normal readers: age-matched and reading-level matched. The children were presented with the words in the same four conditions used by Snowling (1980). However in this study, presentation length of the visual words was standardized. The visual word was presented for five seconds, followed immediately by the auditory word. If the spoken word was presented first, the visual word was presented immediately following the spoken word. Reaction time was recorded from the onset of the first word by activation of a millisecond timer. The results showed that the disabled readers had slower reaction times than the age-matched group, greater difficulty with the cross-modal conditions, and greater difficulty judging words when the ends were different but not when the beginnings of words were

different. Comparison of the disabled readers with reading level matched readers showed no differences in error judgments between the groups when words were presented in the same modality (auditory-audiory, visual-visual). Similarly, there were no significant reaction-time differences between the groups. However the disabled readers had significantly more errors than the reading level matched children on judgments of words in the cross-modality conditions (auditory-visual, visual-auditory). Moreover, the reading disabled children's performance was strikingly deficient (close to chance) in the cross-modality judgments when the phoneme change occurred at the end of the word.

There were some significant limitations to this study as well. The author did not control for the degree of phonetic contrast between the paired words. She simply changed one letter. As such, some pairs may have been more phonetically similar than others, and this could have accounted for some of the differences in performance. Furthermore, the children were not required to read the words, so that decoding problems could have explained the results, rather than the issue of whether the contrast was in the beginning or the end of the word. Finally, there was no information concerning the manner in which the words were spoken. Final stops are often unreleased , thus reducing the acoustic salience of the final sound in a word. The experimenter read the words aloud to the children, and thus pronunciation variance could have been a factor. Thus pronunciation manner could have also accounted for some of the difficulties with the judgments of final phonemes.

In contrast to Fox's study, Reed (1989) used phonetically-controlled stimuli in a study where children were asked to match pictures to spoken words. The children were

presented with two pictures, corresponding to two spoken words that differed in the place of articulation of the initial stop consonants (e.g., bowl –goal, top- cop). The children's task was to identify the picture (two-item forced choice) that corresponded to the word spoken by the examiner. The participants were second and third-grade disabled and average readers, matched on age and grade. The reading-disabled children made significantly more errors than the average readers did on this task. The conclusion from these results was that reading-disabled children have difficulty processing brief stop consonant cues. However, an alternative explanation may be that the children have poorly defined phonological representations of words.

Frost and his colleagues conducted a series of audio-visual experiments with different questions in mind. Frost, Repp & Katz (1988) addressed the question of whether speech perception can be influenced by the simultaneous presentation of a written word. In this experiment, adults were presented with either speech + noise, or noise alone, and simultaneously saw a matching word, a nonmatching word or a random letter pattern (e.g., XXXX). The noise was amplitude-modulated, so that it followed the contour of each spoken word. The adults were told that sometimes the word presented on the screen was similar to the speech or noise presented, and sometimes it was not. The task was to press a key to indicate whether or not a word was detected in the auditory signal. The adults were instructed to pay attention to the words on the screen, although their task was auditory. The expectation was that the adults would be more likely to detect speech in the speech + noise condition, than in the noise only condition because the spectral features of speech hidden in the noise would facilitate the word detection.

The researchers' hypothesis was disconfirmed. The adults were as likely to detect speech in the matching print- noise only condition, as they were when speech and noise were presented. Nonetheless, this study strongly suggests that printed words are immediately coded into a detailed phonological representation, and that this representation has speech-like characteristics.

Frost (1991) conducted another study with adults to examine whether word-frequency contributed to the likelihood of detecting speech in noise. The stimuli were high and low-frequency Hebrew words, which were unpointed (no diacritic marking for vowels) or pointed (diacritic marking for vowels). Nonwords were also included. Once again, the adults were presented with speech + noise trials and noise-only trials where the printed word matched the speech on some trials and did not match the speech on other trials. The results again showed that adults detected speech in noise when the written word matched the amplitude-modulated noise. This result was observed for both high and low frequency words, and for pointed and unpointed Hebrew. This effect was not observed for the nonwords, suggesting that nonwords are processed differently than real words.

Frost and his colleagues' research was conducted exclusively with adults. An extension of his studies with children, from a developmental perspective, would address some interesting questions. For example, at what reading age/level does the detection of speech (given simultaneous presentation of printed word) in amplitude-modulated noise occur? Additionally, do we see different responses in children with reading disabilities versus normally developing readers?

Orthographic Processing

Phonological skills are of central importance to the development of beginning reading. However, orthographic processing/knowledge also contributes to the variance in reading skills. Orthographic processing can be defined as the ability to access visual-orthographic codes for words (Manis, Custodio & Szeszulski, 1993). There have been some studies to suggest that orthographic processing/knowledge is superior relative to phonological processing in reading-disabled readers and that this relationship remains constant into adulthood (Greenberg, Ehri, & Perin, 1997).

Manis and his colleagues (Manis et al., 1993) conducted a two-year longitudinal study of phonological and orthographic skill development in reading-impaired and normally developing readers in grades two through eight. The children were given two phonological processing tasks (phoneme deletion and pseudo-word pronunciation) and two orthographic processing measures. The orthographic measures included a verification task, in which the child heard the pronunciation of a word and, at the same time, saw a written word on the screen. The written and spoken words were phonetic equivalents (e.g., street (spoken) – streat (written)). The child's task was to decide if the written word had the correct spelling. The second task was a homonym verification task. In this task, the experimenter read a homonym aloud and used it in a sentence (e.g, "week- Monday is the first day of the week."). Simultaneously, the children saw a printed homonym on a computer screen that sometimes matched the spoken homonym. The children's task was to press a yes or no button indicating whether the spoken and written homonyms matched. The results showed that progress in orthographic knowledge exceeded progress in phonemic analysis skills in the reading-impaired

children. In fact, the reading-impaired children showed little or no progress in the phoneme deletion task with increasing age.

Rack (1985) examined the degree to which reading-impaired and normal readers use phonological versus orthographic coding. The underlying question was whether reading-impaired children make more use of orthographic coding as a product of poor phonological coding skills. The participants were reading-impaired children and a reading-age-matched control group. The children were presented with pairs of words and were asked to judge whether the word pairs rhymed. Four types of rhyming word-pairs were presented: rhyming and orthographically similar (e.g., bird-third), rhyming only (bird-word), orthographically similar only (cash-wash), and no relationship (farm-sand). Half of the children were administered the task visually, and half auditorily. Upon either seeing or hearing the paired words, the children were given a cued recall task in which one word in the pair was provided and the second was to be recalled.

The reading-impaired children did not differ from the normal controls in the total number of words recalled. However, the reading-impaired children remembered more words from the orthographically similar only cues and fewer from the rhyming only cues than the normal controls. This result was obtained only in the visual condition. In contrast, the control group remembered more words from the rhyming only cues in both the auditory and visual conditions, relative to the reading-impaired children. The results suggest that the reading-impaired children make more use of orthographic coding than do normally developing readers.

The results of these studies suggest that orthographic skills are relatively stronger than phonological skills in reading-disabled children. Consequently, when reading

words, they may rely more heavily on letter patterns in words than average readers. As such, the following prediction is made in this study: when reading-disabled children judge a word-pair containing minimally different words as the same, they will be more accurate in reporting the words *seen* than the words *heard*. There are however, two explanations for this prediction. One is that the children's orthographic skills are superior to their phonological skills. The other is that they possess imprecise phonological representations of familiar words.

Linguistic Factors

There are several linguistic factors that may influence performance on phonological processing tasks. The linguistic complexity of the words/syllables, and the phonological contrasts between the words that are to be judged, have a direct impact on the difficulty level of a task.

The impact of linguistic factors on phonemic awareness tasks (Byrne & Fielding-Barnsley, 1990; Buck & Treiman, 1990; Treiman, Broderic, Tincoff, & Rodriguez, 1998) has received some attention. In a recent study (Treiman et al., 1998), preschoolers and kindergarteners were shown a puppet and were told that the puppet only liked "words" that began with a certain sound. The "words", in this case, were meaningless CVs. The child's task was to say whether the puppet would like the "word" spoken by the examiner. For example, the experimenter explained to the children that the puppet only liked "words" that started with /pə/ (pronounced with a schwa). On a given test block, the children were asked whether nine CV pairs started with the target sound. The stimuli differed from the target in initial voicing, initial place, and place and voice. The results

showed that the children had more difficulty classifying the words when the target word contrasted with the spoken word in the voicing feature only (e.g., /t/ vs. /d/). Place of articulation contrasts were easier for the children to detect (e.g., /b/ vs. /d/). Furthermore, fricatives (/z/, /s/) were no more difficult to contrast than stop consonants in this task.

These results contrast with those reported by Snowling, Hulme, Smith and Thomas (1994). The researchers used a sound categorization task in which children decided which word from sequences of three, four and five words, differed from the others in the final consonant. The odd word in the sequence differed either by one phonetic feature (voice or place) or by both voice and place features. For example, in the place only trials, the children were read the words, *cap, tap, map, gap, and sack*, and asked to report the word that ended in a different sound. Six and eight-year-old normally developing readers participated in the study. Their results showed that the more phonetically similar the odd word was to the rest of the words, the more difficult was the judgement. A second experiment tested whether changes in voice (e.g., pad, had, mad, bat) or place features (rob, mob, sob, *nod*) *alone* were more difficult for children to detect. This experiment showed that changes in place of articulation were more difficult for children to detect than voicing changes.

Snowling's study differed from the Treiman study in several ways. Most importantly, Treiman's phonemic task required children to attend to the beginnings of words, whereas Snowling's task required attention to the ends of words. It is possible that the word-position of the phonetic contrast (beginning or ending of word) interacts with difficulty of the phonetic judgment. For example, when children make judgments about words involving a phonetic place contrast appearing at the end of the word (e.g.,

bad – bag), the vowel length remains relatively constant in the contrasting words and the children must rely heavily on formant transitions in making the judgment. Moreover, final consonants are often unreleased in final position and may be less intense than initial consonants. On the other hand, when children make judgments involving a voicing contrast appearing at the end of the word (e.g., bad and bat), they are cued that the next sound is voiced by the relatively longer length of the vowel. Thus the relative acoustic salience of voicing and place contrasts may vary with phonotactic context.

Another difference between the studies is that Treiman and her colleagues' stimuli were nonwords, whereas Snowling's group used real words. Making judgments about written and spoken real words is easier for beginning readers than nonwords. One obvious reason is that real words, if familiar in print, can be read by sight, whereas nonwords require some degree of phonological recoding. Furthermore, in the process of reading or listening to a real word, a phonological/orthographic representation may be accessed; nonwords, in contrast, are lexical items for which there are no lexical representations in memory. Thus, nonword processing puts an extra demand on reading-impaired children with phonological recoding deficits.

Snowling, Goulandris, Bowlby, & Howell (1986) studied nonword and real word repetition in dyslexic children, chronological age-matched controls and reading-age matched controls. The children's task was to repeat 72 items: 24 high frequency words, 24 low frequency words and 24 nonwords. The words were presented under three noise conditions: 1)no noise, 2) low noise and 3) high noise. The dyslexic children made more errors when repeating both low frequency and nonwords, when compared to their chronologically age-matched peers. A second finding was that dyslexics and reading-age

matched controls differed on nonword repetition (with dyslexics performing more poorly), but showed no difference in repeating high and low frequency words. The noise level affected the dyslexic and comparison group children to the same degree.

Rack, Snowling, & Olson (1992) reviewed the research concerning the hypothesis that reading-impaired children have a specific nonword reading deficit. Approximately two thirds of the studies reviewed found nonword reading deficits in reading-impaired children. The authors suggest several study design issues that may have influenced whether a nonword deficit was found. For instance, the linguistic complexity (i.e., the syllabic and morphological structure) of the words varied among the studies. Additionally, the age of the children studied varied. The authors point out that little research has been done on nonword reading in beginning readers. As such, this dissertation study will add to the body of knowledge concerning nonword reading in young children.

In light of the factors described above, the proposed dissertation was designed to control the phonological make-up of the word and nonword pairs. The selected pairs were contrasted for: 1) voicing in word-initial position; 2) voicing in word-final position; 3) place of articulation change in word-initial position; and 4) place of articulation change in word-final position. Additionally, the words were controlled for syllable complexity (all words were CVCs) and all words appeared on the appropriate graded word lists for the reading-age level selected (Harris & Jacobson, 1972), or appear in a published study of the oral vocabulary of first-grade children. Where possible, the nonword pairs were created by changing the initial or final phoneme of a real word, to

keep the orthographic and phonetic make-up of the nonwords comparable to the real words.

Speech Perception , Phonological Processing, and Reading

There is a body of research suggesting that poor readers manifest subtle speech discrimination deficits (Werker & Tees, 1987; Brandt & Rosen, 1980; Hurford & Sanders, 1990), although some studies have yielded mixed results (see Brady, 1997 for review of speech perception studies). Essentially two paradigms have been used to assess speech perception in reading-impaired children (Manis et al., 1997). One is the categorical perception of stop consonants in syllables, and the other is the repetition of words/nonwords with and without noise.

One major question is, by what mechanism are speech perception deficits related to reading difficulties? The prevailing view is that children who do not perceive phonemes clearly or distinctly will have difficulty laying down precise phonological representations of words in long-term memory. Without precise phonological representations to draw upon, phonological processing skills (such as phonological recoding and phonological awareness) may be compromised. This line of thought implies that speech discrimination skills provide the foundation for phonological representations, which form the basis for phonological processing skills. However, there are no studies showing that speech perception deficits play a causal role in reading difficulties. The evidence is correlational.

There may be a reciprocal relationship between speech discrimination and phonological processing skills. Fowler, Brady and Eisen (1995) showed differences in

speech perception in five year-old children as a function of their phonological awareness skills. The five-year-olds that had achieved phonological awareness of certain phonemes (fricatives) showed better speech perception skills than those children who had not achieved phonological awareness.

Manis and his colleagues (Manis, McBride-Chang, Seidenberg, Keating, Munson & Petersen, 1997) examined the relationship between speech perception and phonological awareness in children, grades four to ten. Speech perception was measured by a categorical perception task, where the endpoint stimuli were the words, "bath" and "path". The words were presented on a thirteen-point continuum, in which the length of the voice-onset time was varied. Phonological awareness was measured by having the children identify the letter that comes before or after another given letter in a nonsense word (e.g., what comes before "l" in klat?). The reading-impaired children showed poorer categorical perception than their chronologically age-matched peers, but did not differ from the reading-level matched group. In addition, phonemic awareness was correlated with categorical perception. That is, the children who had normal or average phonemic awareness skills showed well-defined categorical perception, whether they were reading-impaired or average readers.

Research Hypotheses

Several hypotheses were tested concerning the role of phonological representations in word reading. The first set of hypotheses addressed the claim that reading-disabled children (RD) have poorer phonological representations of familiar real

words than non-disabled readers (non-RD) who are reading at the same grade-equivalent level. If true, it was reasoned that reading-disabled children should be less accurate and take longer in judging whether words heard match words seen than non-RD children. Moreover, when the words seen and heard differ, RD children will be more accurate in reporting the words seen than the words heard, provided the words are familiar and easy to read. In contrast, non-RD children will not show any difference. The explanation is that for RD students, the orthography will support a stronger phonological representation as compared to the phonological representation generated from the spoken word.

RD students are also known to have phonological recoding deficiencies. If this deficiency is influential in the word matching task, we would expect RD students to be less accurate and take longer in judging not only whether the words heard match the words seen, but also whether the nonwords heard match the nonwords seen. Moreover, when the words or nonwords seen and heard differ, RD should be more accurate in reporting the nonwords heard than the nonwords seen. In contrast, non-RD children should not show this pattern.

The third set of hypotheses concerned the influence of phonological features or properties (i.e. voicing, place of articulation and position in word) on the perception of contrasting spoken and written words. The issue of interest was whether deficiencies in phonological representations would be limited to certain phonological features or properties of words or would they be more general. That is, would RD children perform worse than non-RD children on only some phonological contrasts or would they be deficient on all contrasts? If the deficiencies are general, then RD children will judge

both types of matches less accurately and more slowly than non-RD children. If the deficiencies are specific, then differences in only some types of matches will be evident.

Overview of Study

An audio-visual paradigm was selected to test these hypotheses. The children were presented with 40 CVC minimally distinct word pairs, one presented visually, and the other auditorily. Twenty of these pairs contrasted the voicing of one stop consonant: ten pairs contrasted the voicing in the initial position and ten pairs contrasted the voicing of the consonant in the final position. Similarly, twenty word- pairs contrasted the place feature: ten pairs contrasted the place feature in the initial position and ten pairs contrasted the place feature in the final position. The study was restricted to stop consonants because 1) there is research indicating that stop consonant contrasts are particularly difficult for children (Reed, 1989); and 2) it was difficult to find contrasting fricative real-word pairs that were highly familiar to young children.

The focal task in the study included three steps. First, children were asked to press a computer key as soon as they knew whether the simultaneously presented word pairs were the same or different. In this way their reaction-time was recorded with a single key press. They were also asked to say out loud whether the words were the same or different. Accuracy was recorded manually by the examiner. Following the presentation of the word pairs, the children were shown (on the computer screen) a picture of an eye or an ear. If they saw the eye, they were asked to report the word that they saw. If they saw the picture of the ear, they were asked to report the word that they heard. The purposes of the third step were to assure that the children paid attention to the words in

both modalities and to provide some verification that the children could accurately read and hear (auditorily perceive) the two words. This assured that the children's errors were not due to the inability to read the word, or an inability to perceive the word. Finally, it enabled the exploration of several research questions, as stated above.

Following the set of real words, the children were presented with nonword pairs, designed with the same phonological contrasts as the real-word words. The rationale for this experimental set was as follows. Including nonwords allowed an alternative hypothesis to be tested, namely that the difficulties RD children have stem from poor phonological recoding skills, and not from poor phonological representations. Nonwords, by definition, have no presence in lexical memory. In order to read a nonword, phonological recoding is required. As such, this task may involve a different psycholinguistic process from that of reading real words that can be read by sight. The children were also given a nonword reading test (Woodcock, 1987) to further detect any deficiencies. It might be noted that the focal task to be used in this study was a match-to sample procedure and hence may not fully measure phonological recoding skills. The children were given a nonword that was auditorily similar to the written non -word, so full decoding of the nonword was not required.

Finally, the nonwords provided a more challenging task for the children, particularly for reading-impaired children. The results of a small pilot study showed that contrasts involving nonwords were more difficult for the reading-impaired children than contrasts involving real words (although in the pilot, the nonsense word was paired with a minimally different real word).

The selection of the second-grade reading level (at minimum) was based on pilot testing. The task was too easy for average-to-good third and fourth grader readers. Likewise, the task was too difficult for a reading-impaired child at the primer/first-grade reading level. The words were carefully selected, so that they would be within the range of the children's oral and written vocabulary. To this end, two sources were consulted, a published study of children's spoken vocabulary (first graders), and the Harris and Jacobson graded word list for reading vocabulary (Harris & Jacobson, 1972).

Method

Participants

The participants were 35 children who were native speakers of English, without any reported hearing or speech difficulties. Eighteen children were receiving remedial services for reading difficulties and 17 children were typically developing early readers, with no reported reading difficulties.

Fifteen of the children with a reading disability (RD) were recruited from two private schools in New York City, specializing in the education of children with language/reading related difficulties. With regard to the other three RD participants, one was recruited from a private school in Westchester County, also specializing in services for children with language/reading related difficulties. The other two students were recruited from public schools in Westchester, and were receiving remedial reading services in school. To qualify for the study, the RD children were required to be reading at least one year below their expected grade level in school, at the second grad-equivalent level, as measured by performance on the Woodcock Word Identification subtest of the Woodcock Reading Mastery Tests- Revised (WRMT-R; Woodcock, 1987). The RD children ranged in grade levels from the third to sixth grade (7 third-graders, 5 fourth graders, and 6 fifth graders), with a mean age of 9.8 years. The children were all Caucasian and came from upper-middle to upper class homes.

A second group of typically developing readers was selected to match the reading disabled group on real-word reading level. The children were also selected to be similar to the reading disabled children in gender and socio-economic status. The typically developing readers were recruited from two school districts in Northern Westchester. They also came from upper-middle to upper class homes. To qualify, the children needed to be reading at or above grade level, as measured by performance on the Woodcock Word Identification subtest (Woodcock, 1987). Sixteen second-grade children and one third-grade child qualified for the study, with a mean age of 7.2 years. Characteristics of the reading disabled children and the typically developing readers are presented in Table 1.

With the exception of one child in the RD group, all of the children completed all pretests and experimental measures. This student completed all pretest measures, but refused to complete the experiment, complaining of fatigue. He completed both nonword blocks, but only two of the four real word blocks. As such, his data were included in the nonword data analyses (errors and reaction time) and the real word reaction time analysis, but excluded from the real word error data analysis.

Table 1
Characteristics of Reading-Disabled and Typically Developing Readers

Characteristic			
	Reading Disabled (n=18)	Typical Readers (n=17)	t-value
Age (months) M SD	 117.3 13.0	 86.1 4.3	
Gender	14 boys/ 4 girls	11 boys/ 6 girls	
Grade Level Range	3 – 6	2 –3	
Months Below Grade Level M SD	 24.8 9.9	 - -	
Word ID [1] M raw score SD raw score M GE	 45.44 8.14 2.4	 49.29 8.94 2.7	1.33 (df=33), n.s.
Word Attack [2] M raw score SD raw score M GE	 15.39 8.38 1.9	 23.88 6.47 2.9	3.34 (df=33) p < .002
PPVT [3] M standard score SD standard score M raw score SD raw score	 93.65 6.52 118.17 14.72	 112.88 8.09 111.71 10.70	7.52, (df=33), p<.0001 -1.47, (df=33), n.s.
Practiced Words M SD	 4.80 3.90	 3.12 3.20	-1.42 (df=33), n.s.

Note. [1]Word ID= Woodcock Word Identification Subtest (real words), [2]Word Attack = Woodcock Word Attack Subtest (nonwords), [3] PPVT= Peabody Picture Vocabulary Test-Revised.

Materials

Screening Measures. The Woodcock Word Identification subtest of the Woodcock Reading Mastery Tests – Revised (WRMT-R; Woodcock 1987) was given to verify each child's reading level. The Word Identification subtest measures children's proficiency at reading English words. In addition, the Woodcock Word Attack subtest (WRMT-R; Woodcock, 1987) was given to obtain a baseline measure of the children's nonword reading ability. The Word Attack subtest examines reading proficiency of phonotactically legal nonwords. The children were selected to be reading at or above the beginning second-grade level. The Peabody Picture Vocabulary Test (PPVT-III; Dunn, 1997) was given to verify that the children's reading deficits could not be explained by their poor vocabulary. Children scoring below one standard deviation of the normative mean (M=100, SD=15) of this test were excluded from the study. No child who achieved an acceptable score on the word identification test was dropped from the study because of failure to meet criterion on the PPVT-III.

Word Pairs. Forty CVC words were paired with a second CVC word, which differed from the first in one of the following ways. Twenty word pairs differed only in the voicing feature of either the initial or the final consonant (e.g. – PULL/BULL, FEED/FEET). Twenty word pairs differed only in the place feature of the initial or the final consonant (e.g., CAKE/TAKE, SHAPE/SHAKE. Furthermore, all target contrasts were stops. The words varied in grammatical class and included nouns, verbs, adjectives

and adverbs. Efforts were made to insure that the four word-pair categories (voice-initial, voice-final, place-initial and place-final) were balanced with respect to the grammatical classes of the words selected for each category. The words are listed in Appendix A.

The words were selected from a list of graded reading vocabulary words (Harris & Jacobson, 1972) ranging from a pre-primer to a second-grade reading level, and from a spoken vocabulary list generated from a sample of 329 first-graders (Moe, Hopkins. & Rush, 1982). Each word appeared on the graded vocabulary list, the spoken vocabulary list, or both sources. These procedures helped to insure that the words were in both the reading and speaking vocabularies of the children and involved high frequency terms.

Forty CVC nonwords (or very low frequency real words) were paired with a second CVC nonword. The same contrasts employed in selecting real-word pairs were used to create nonword pairs. Twenty nonwords differed only in the voicing feature of the initial or final consonant. Twenty nonword pairs differed only in the place feature of the first or ending consonant. As with the real words, all consonant contrasts were stops. The nonwords are listed in Appendix A.

The words and nonwords were recorded on digital tape, and transferred to a computer (22.05 KHz, 16-bit resolution, mono recording) using Cool-Edit Pro software (1998). The words and nonwords were spoken by an adult native speaker of English (female) using neutral prosody, with final stops released.

Procedure

Each child was individually tested in one or two sessions, between August, 2000 and January, 2001. The sessions were conducted either in the child's home or at the child's school. The screening measures were administered in the following order: 1) Word Identification subtest (WRMT-R, 1987), 2) Word Attack subtest (WRMT-R, 1987), 3) PPVT-III. Next, children practiced reading the words to be presented in the word judgment task. They did not practice reading the nonwords. Then they completed the focal experimental word judgment task, first with real words, followed by nonwords.

The children were given a list of the experimental words to read prior to beginning the experiment. This insured that the children could read all of the real words before beginning the experimental tasks. Any words that the child did not know were taught first by identifying letter/sound correspondences or by pointing out an orthographic spelling pattern (e.g., the word *right*). For example, if a child misread the word "BAT" as "BIT", the examiner instructed the child to look at the word "BAT" while listening to the following instruction: " The letter a in BAT makes the /æ/ sound – now you try it". Next, the children practiced the misread words by reading them from flash cards. The words were practiced until they were read correctly on two cycles through the flash cards. This procedure also minimized the potential influence of word familiarity on the children's judgments of the word pairs.

The word judgment task was presented on a laptop computer, using the E-PRIME software program (Psychology Software Tools, 1999) to present the stimuli.

Prior to beginning the focal experimental task, each participant was administered training task, in which he/she was taught how to respond in the experiment and practiced

the responses required. The purpose of the training procedure was to assure that the children understood, and could perform the task. The children were instructed that they were going to play a computer game, in which they would hear a word and see a word at the same time. The game had two parts that were performed in response to each word pair. The first part was to press the space bar on the computer keyboard as soon as they determined whether the word they heard and saw were exactly the same or different. At the same time they said out loud, SAME or DIFFERENT. In the next part of the task, they saw a picture of an eye or an ear. If they saw the picture of the eye, they reported to the examiner the word that they had just seen. If they saw the picture of the ear, they reported to the examiner the word that they had just heard. Ten word pairs were presented in the training procedure. The word pairs were five CVCs that differed by two or more letters and sounds (e.g., BALL/GET, MUD/MOP), and five CVC word pairs that were the same (e.g., BALL/BALL, MUD/MUD). The children were expected to achieve 80% accuracy on both parts of the task. If they did not achieve 80% on the first block, a second block was administered. All participants achieved criterion on this task. Instructions for the training procedure are presented in Appendix B.

Reaction times were recorded using the E-PRIME software. Reaction time was measured from the onset of the auditory/visual stimulus to the pressing of a designated key on the computer keyboard. Verbal responses were recorded on audiotape and by the examiner. The examiner blindly recorded the children's responses. That is, she did not view the computer screen during the experiment (and the spoken words were presented via headphones). Additionally, an undergraduate listened to 15% of the trials to

establish reliability of the written record. Responses from both the RD and the Non-RD children were included in the reliability sample. The criterion for reliability with the examiner was an exact match with the word recorded by the examiner (consonant and vowel phonemes). Reliability for the children's word productions was 97%, and reliability for same/different judgments was 100%. Those trials for which there was disagreement regarding the target segment were scored in favor of the examiner because the examiner had the advantage of lip reading cues in recording the words spoken.

A total of 160 trials with real words were presented in four blocks (40 trials per block). Twenty voicing contrasts (ten word-initial and ten word-final word-pairs) and twenty place contrasts (ten word-initial and ten word-final word-pairs) were assigned to each block. The presentation of the word-pairs within the blocks was randomized. The word-pairs were presented in four permutations. Specifically, each word-pair was counterbalanced, such that each word was presented both auditorily and visually. In addition each word in the pair was presented with the same word in contrasting modalities. The blocks were stratified such that only one of the four permutations. of the pairs appeared in each block. To illustrate, one or both members of the word pair, TIP/DIP, appeared in four different blocks: TIP-heard/DIP-seen; DIP-heard/TIP-seen; TIP-heard/TIP-seen; and DIP-heard/ DIP-seen.

The visual word was presented simultaneously with the auditory word. The visual word appeared on the screen for 5 seconds. Children pressed the space bar and their reaction time was recorded to indicate latency to judge whether the two words were the same or different, then a picture of an eye or an ear appeared on the screen for 2.8 seconds. Upon seeing the eye, the children reported the word that they saw. Likewise,

upon seeing the ear, they reported the word that they heard. The children had an additional five seconds to report the word that they heard or saw (after the picture was cleared from the screen), after which a signal (+) was presented, alerting the children that the next word would be presented. If the child responded before five seconds had elapsed, the experimenter or the child could press a key to issue the next pair. The purposes of the eye and the ear pictures were to assure that the children paid attention to both modalities. Additionally, it allowed for an analysis of the types of errors children made, when they reported that a word-pair containing two different words (e.g., see TEN and hear DEN) was the same. That is, when asked what they heard, would they report the word that they heard or the word that they saw?

The same procedure was followed with the nonwords, with one exception. Instead of counterbalancing the nonword pairs such that each word was presented both visually and auditorily, half of the participants (randomly assigned) received a given non-word from a pair auditorily (e.g., *gip*) and the other word, visually (e.g., *kip*). The other half of the participants received the word-pair, reversed (*kip*-auditorily and *gip*, visually). This procedure was adopted in order to limit the number of trials that needed to be presented, and thus avoided fatiguing the children. A total of 80 non-word trials were presented. The real-word trials were administered before the non-word trials.

Results

Pretests

The WRMT-R Word Identification subtest was used to match the reading-disabled children with the typically developing children on word reading level. As shown in Table 1, the word reading scores of the two groups were very similar, a t-test confirmed that there was no statistically significant difference between the groups ($p > .05$). Both groups were reading at the second grade level. Similarly, the two groups of children did not differ statistically on the number of experimental words they needed to practice/learn prior to beginning the experiment ($p > .05$). On average only 3 to 5 words out of 80 proved unfamiliar to the students. Thus, the goal of selecting familiar words was achieved.

Whereas the two reading groups performed similarly on word reading skills, the groups showed highly significant differences in nonword decoding ($p < .002$) as measured by the WRMT-R Word Attack subtest. As shown in Table 1, the mean of the typical readers was one reading grade level higher than the mean of the reading-disabled children on this measure. Poorer performance decoding nonwords by RD students is a common finding (Rack, Olson & Snowling, 1992). This is evidence that the poor readers in this study fit the profile of students with RD. The groups also differed significantly ($p < .001$) in receptive vocabulary skill, as measured by standard scores on the PPVT-R, with typical readers outperforming the reading disabled readers. However, an analysis of

raw scores on this test showed no statistically significant differences between the groups. Thus, although the reading disabled children performed poorer relative to expected age level vocabulary performance, there was no difference between the groups in the actual number of vocabulary words that they knew. Moreover, the RD students were within 1 SD of the normative mean, indicating that they were cognitively normal with an unexpected reading impairment. Test statistics for these two measures are presented in Table 1.

Statistical Analyses

A 3-way ANOVA was used to analyze the children's errors on the experimental tasks, with reader group (RD versus non-RD) as the between subjects factor; phonological feature (voicing and place) and word position (initial position versus final position) were the two within subjects factors (repeated measures). Real word accuracy and nonword accuracy were analyzed separately using the same 3-way ANOVA model. Only trials where the words in the pairs differed (i.e., WORD-DIFFERENT trials) were considered in these ANOVAs. This is because the two within subjects factors (phonological feature and word position) do not vary when the words in the pairs are the same. Additionally, reaction time was analyzed using the same 3-way ANOVA model with reader group (RD vs. non-RD) as the between subjects factor; phonological feature (voicing vs. place) and word position (initial position vs. final position) were the two within subjects factors (repeated measures). Once again, real word reaction time data and nonword reaction time data were analyzed separately. Only trials in which the words in

the pairs differed (i.e., WORD-DIFFERENT trials) were considered in these analyses. Statistical tests were conducted at $p < .05$.

Responses to Real Words

Errors (real words). A 3-way ANOVA was conducted to assess effects in the word judgment task. The dependent measure was the number of errors made on the WORD-DIFFERENT trials (e.g., TEN (auditory) – DEN (visual)). The independent variables were reader group (non-RD vs. RD), phonological feature (voicing vs. place) and word position (initial vs. final). Statistical values for all main effects and interactions are presented in Table 2.

Table 2
Test Statistics in the Analyses of Variance of Responses on the WORD-DIFFERENT trials in the task where students judged word pairs as same or different

	Real Words		Nonwords	
	Dependent Measures		Dependent Measures	
	Errors[a] F(1,32)	RT F(1,33)	Errors F(1,33)	RT F(1,33)
Main Effects				
Reader Group	.25 n.s.	.00 n.s.	.01. n.s.	.64 n.s.
Phonological Feature	6.32 **	4.36*	17.42 ***	.27 n.s..
Word Position	.45 n.s.	.14 n.s.	6.54 **	.73 n.s.
Interaction Effects				
Reader x Phono Feature	1.52 n.s.	5.26 *	1.42 n.s.	1.05 n.s.
Phono Feature x Position	.41 n.s.	.35 n.s.	1.02 n.s.	3.05 n.s.
Reader x Position	.21,n.s.	.40 n.s.	1.24 n.s.	.31 n.s.
Reader x Position x Phono Feature	.54 n.s.	.14 n.s.	1.26 n.s.	.37 n.s.

[a] Errors were calculated only on word-different trials.

* $p < .05$, ** $p < .02$, *** $p < .0001$

The results of the ANOVA showed no statistically significant main effect for reader group on the real word error measure. These results do not support the hypothesis that reading-disabled children would be less accurate in making judgments about word pairs (presented audio-visually) that differed by a single consonant phoneme than non-RD children. As shown in Table 3, the mean number of errors made by the non-RD group was 11.1 in contrast to a mean of 12.4 errors made by the RD group. Non-RD and

RD students erred on 14% and 16% of the trials, respectively. Thus most of the responses were correct. In addition, no main effect was found for word position. Thus, whether the contrasting phoneme appeared in the initial or final position of the word, did not significantly affect the children's judgments of the pairs as the same or different.

Only one significant main effect emerged in the ANOVA. This involved the phonological feature variable, and this effect was significant at $p<.02$. Both reader groups were significantly more accurate at judging word pairs involving a place feature change, in contrast to a voice feature change. The mean for voicing feature trials was 6.6 errors whereas the mean for the place feature trials was 5.1 errors (see Table 3). The fact that the phonological feature variable influenced performance lends confidence in the potential of the audio-visual word-matching task to reveal differences.

Table 3
Mean Errors to judge the real word pairs where they differed or as a function of Reader Ability, Phonological Feature and Word Position

	Reader Group					
	Non-RD			RD		
Phonological Feature	Initial Position	Final Position	Initial Plus Final	Initial Position	Final Position	Initial Plus Final
Voicing (V) M	3.0	2.9	5.9	3.8	3.6	7.4
SD	(2.6)	(2.9)	(4.8)	(2.5)	(3.1)	(4.1)
Place (P) M	3.0	2.1	5.1	2.5	2.5	5.0
SD	(2.8)	(2.4)	(4.7)	(2.2)	(2.5)	(3.7)
M (V+P)	6.0	5.1		6.3	6.1	
SD	(5.1)	(5.1)		(3.2)	(5.3)	
Overall M	11.1			12.4		
SD	(8.8)			(6.8)		

Note. The maximum number of responses per cell was 20 errors.

No statistically significant interactions were found, confirming that the effects of phonological feature did not vary as a function of word position or reader ability.

Errors on the WORD-SAME trials were low for both groups, with the non-RD group making 2.6 (3%) errors on average compared to a mean of 5.6 (7%) errors in the RD group. A nonparametric test comparing mean ranks showed a statistically significant difference between the groups (M-W (U)= 85.500, $p<.05$). The possibility that the RD children operated with a response bias in this task was considered as an explanation why they showed a greater tendency to respond "different" to WORD-SAME pairs. To check

this, the children's verbal reports of the words they heard and saw were examined for the WORD-SAME trials. An analysis of these trials showed that the RD children's verbal reports on WORD-SAME trials contained 22 words with vowel alterations, whereas the non-RD children's reports contained only 3 words with vowel alterations. This suggests that RD students' responses were reflecting a greater commission of true errors rather than a greater tendency to say "different". Moreover, subjects were responding with a high degree of accuracy to both types of items (for WORD-SAME pairs 93% – 97%, and for WORD-DIFFERENT pairs, 84% -86%). Clearly the responses were way above chance level, and thus room for the operation of a response bias seems minimal.

The children's errors were also analyzed to determine the mean proportion of "HEARD" and "SEEN" reports on WORD-DIFFERENT trials. That is, when judging a word pair as the same, when in reality the word pairs were different, would the two groups show a differential preference in either reporting the word heard or the word seen? The hypothesis was that the errors made by the reading disabled children would reflect a bias toward reporting the written word, while the typical readers would not show this preference. This hypothesis was not confirmed. The two groups showed a strikingly similar pattern of errors, with both groups slightly favoring the auditory over the visual modality. A dependent t-test comparing the mean proportions across reader groups showed no statistically significant difference between the *heard* and *seen* word reports ($t(32) = -1.2$, $p>.05$). Likewise, the mean proportions for the *heard* and *seen* word reports analyzed separately by reader group also showed no statistically significant differences (RD: $t(15)= =.52$, $p>.05$; non-RD: $t(16)=.61$, $p>.05$). Mean proportions and standard deviations. are presented in Table 4.

Table 4.

Mean errors and proportion of word seen and word heard in cases where word pairs were judged in error, as the same.[a]

	Real Words (80 trials)				Nonwords (40 trials)			
	non-RD (n=17)		RD (n=17)		non-RD (n=17)		RD (n=17)	
	M	SD	M	SD	M	SD	M	SD
Mean errors	11.1	8.8	12.4	6.8	10.9	5.5	11.1	7.4
Heard word reported	.54	.33	.59	.31	.77	.28	.68	.27
Seen word reported	.46	.33	.41	.31	.23	.28	.32	.27

[a] Only errors from WORD-DIFFERENT trials are presented here.

Reaction Time (real words). Due to computer error, one block of trials from one student in the non-RD group was lost. In addition, one child in the RD group completed only two of the four blocks. As a result, a total of 5,640 trials were analyzed.

Reaction-time (RT) was calculated by subtracting the duration of the auditory stimulus from the total reaction-time (i.e., time from onset of auditory stimulus to the pressing of the space bar). RTs that were less than the duration of the auditory stimulus were judged invalid. Accordingly, 579 (11%) of the 5,640 trials were excluded from the analyses. RTs to WORD-DIFFERENT and WORD-SAME pairs were analyzed separately.

To assess the differences in RT (WORD-DIFFERENT pairs) between the groups, a 3-way ANOVA was conducted. The dependent variable was RT and the independent

variables were reader group, phonological feature and word position. Statistical values for all effects are presented in Table 2.

The results of the ANOVA showed no statistically significant main effect for reader group. Thus, the hypothesis that reading-disabled children would be slower than non-RD children at judging phonemically similar real word pairs was not confirmed. As shown in Table 5, the RTs for the Non-RD and RD groups were strikingly similar. The mean RT for the non-RD group was 2,315 milliseconds and the mean for the RD group was 2325 milliseconds.

Table 5
Mean reaction times for WORD-DIFFERENT trials by word type

	Reader Group	
	non-RD (n = 17)	RD (n =18)
Word Type		
Real Words (80 trials)	2315 (M) 813 (SD)	2325 (M) 790 (SD)
Nonwords (40 trials)	2553 (M) 986 (SD)	2367 (M) 952 (SD)

Note. Means are expressed in milliseconds.

The RT data were further analyzed to determine if RT varied as a function of phonological feature or word position. In other words, did the children exhibit significantly faster (or slower) RT judgments to word pairs that differed in the initial phoneme compared to word pairs that differed in the final phoneme? Similarly, did the children exhibit significantly faster (or slower) RT judgments to word pairs that

contained one phoneme that differed in the voicing feature compared to word pairs that differed in the place feature? The ANOVA showed no significant main effects for word position. Thus, whether the phoneme change occurred in the beginning of a word compared to the end of a word, did not significantly affect RT. A significant main effect was found for phonological feature as well as a significant interaction between phonological feature and reader group. RTs in the non-RD group were virtually the same for word pairs contrasting the voicing feature (Mean RT= 2311 seconds) and word pairs contrasting the place feature (Mean RT =2318 seconds). In contrast, RD students responded faster to place than to voicing contrasts. Means and standard deviations are presented in Table 6. For RD students these RT findings are consistent with accuracy findings indicating that voicing contrasts are harder to process than place contrasts.

Table 6
Mean reaction times for WORD-DIFFERENT trials by phonological feature

	Reader Group	
	non-RD (n = 17)	RD (n =18)
Phonological Feature		
Voicing (40 trials)	2311 (M) 626 (SD)	2410 (M) 627 (SD)
Place (40 trials)	2318 (M) 706 (SD)	2239 (M) 541 (SD)

Note. Means are expressed in milliseconds.

A 1-way ANOVA was conducted to assess whether the reader groups differed in RT on the WORD-SAME trials. No significant differences were found between the group ($F(1,33)=.003$, $p>.05$) . Mean RTs for the WORD-SAME trials are presented in 7.

Table 7
Mean reaction times for WORD-SAME trials by word type

	Reader Group	
	non-RD (n = 17)	RD (n =18)
Word Type		
Real Words (80 trials)	2125 (M) 717 (SD)	2105 (M) 700 (SD)
Nonwords (40 trials)	2329 (M) 976 (SD)	2207(M) 952 (SD)

Note. Means are expressed in milliseconds.

Responses to Nonword Trials.

Errors (nonwords). A 3-way ANOVA was conducted to assess effects in the nonword judgment task. The dependent measure was the number of errors made on the NONWORD-DIFFERENT trials. The independent variables were reader group (non-RD vs. RD), phonological feature (voicing vs. place) and word position (initial vs. final). Statistical values for all main effects and interactions are presented in Table 2.

The results of the ANOVA showed no statistically significant main effect for reader group. These results do not support the hypothesis that reading-disabled children would be less accurate in making judgments about nonword pairs that differed by a single consonant phoneme than non-RD children. As shown in Table 8, the mean number of errors made by the non-RD group was 10.9 (27%), in contrast to a mean of 11.1 (28%) errors made by the RD group.

Table 8
Mean Errors to judge the nonword pairs where they differed or as a function of Reader Ability, Phonological Feature and Word Position

	Non-RD			RD		
Phonological Feature	Initial Position	Final Position	Initial Plus Final M	Initial Position	Final Position	Initial Plus Final M
Voicing (V) M	3.8	3.7	7.5	2.7	3.9	6.6
SD	(2.7)	(2.2)	(4.0)	(2.7)	(2.9)	(4.9)
Place (P) M	1.2	2.2	3.4	1.6	2.8	4.4
SD	(1.2)	(1.8)	(2.7)	(1.7)	(2.7)	(3.6)
M (V+P)	5.0	5.9		4.3	6.7	
SD	(2.9)	(3.4)		(6.7)	(4.9)	
Overall M		10.9			11.1	
SD		(5.5)			(7.4)	

Statistically significant main effects emerged for both word position and phonological feature. Both groups made more errors on word final judgments as compared to word initial judgments. As with the real words, both reader groups made fewer errors on word pair judgments contrasting the place feature as compared to errors on word pair judgments involving the voicing feature. On average, the non-RD group

made 3.4 errors on place feature judgments and 7.5 errors on voicing feature judgments. The RD group made 4.4 errors on place feature judgments and 6.6 errors on voice feature judgments. Means and standard deviations are shown in Table 8.

The ANOVA showed no significant interaction effects, confirming that neither phonological feature nor word position effects varied as function of reader group; likewise there were no interaction effects between word position and phonological feature.

As with the real words, both groups of children performed at ceiling on the NONWORD-SAME trials, with average accuracy for both groups at 92%. The mean number of errors was 3.2 for both groups. The fact that error rates were much lower than chance level (50%) on both the nonword same and nonword different trials shows that students were successful at making these discriminations.

The nonword trials proved to be more a difficult task than the real word trials for both the typical and RD children, as evidenced by the error rates on the real versus the nonword trials (WORD-DIFFERENT trials). The mean error rate for the real words was 14% for the typical readers and 16% for the RD group. In contrast, the mean error rate for the nonwords was nearly double that of the real words, i.e., 27% for the typical readers and 28% for the RD group. The fact that the error rates for the nonwords were nearly identical for the groups is somewhat surprising given that the non-RD group performed significantly better than the RD group on the pretest measure of nonword reading ability (see Table 1). Mean percent values are depicted in Figure 1.

Figure 1

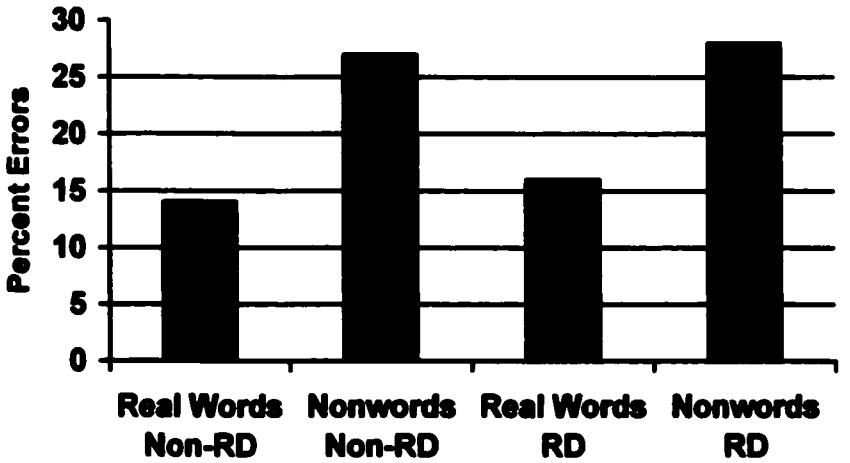

Figure1. Mean percent errors for judging real and nonword pairs as the same or different. Only data from the WORD-DIFFERENT and NONWORD-DIFFERENT trials are displayed here (80 real word trials and 40 nonword trials).

The children's errors were analyzed to determine the mean number of "HEARD" and "SEEN" reports on the NONWORD-DIFFERENT trials. That is, when judging a nonword pair as the same, when in reality the nonword pairs were different, would the two groups show a differential preference in reporting either the word heard or the word seen? According to the decoding deficiency hypothesis, the errors made by the RD children should reflect a bias toward reporting the spoken nonword, while the non-RD readers should not show this preference. This hypothesis was not confirmed. In

concordance with the real word results, the two groups showed a similar pattern of errors, with both groups favoring the auditory over the visual modality. Dependent t-tests conducted separately by reader group (i.e., mean proportion of HEARD reports versus mean proportion of SEEN reports) showed that the bias towards the auditory modality was statistically significant for both groups (non-RD: $t(17)=-4.1$, $p< .001$; RD: $t(18)=-2.9$, $p< .01$).

An examination of Table 4 shows a greater difference between the proportion of heard reports and seen reports in the nonword trials compared to the real word trials. Both the RD and non-RD children were more than twice as likely to report the nonword heard, compared to the nonword seen. The results of the real word trials showed that both groups were only slightly more likely to report the heard word compared to the seen word, but as previously stated, this difference was not statistically significant.

Reaction-time (nonwords). Reaction-time (RT) was calculated by subtracting the duration of the auditory stimulus from the total reaction-time (i.e., time from onset of auditory stimulus to the pressing of the space bar). RTs that were less than the duration of the auditory stimulus were considered invalid. Accordingly, of the 2800 trials run, 306 (11%) of the responses were excluded from the analyses. RTs to NONWORD-DIFFERENT and NONWORD-SAME pairs were analyzed separately.

To assess the differences in RT (NONWORD-DIFFERENT pairs) between the groups, a 3-way ANOVA was conducted. The dependent variable was RT and the independent variables were reader group, phonological feature and word position. F-values for all main and interaction effects are presented in Table 2.

The ANOVA showed no statistically significant main effect for reader group. Thus the hypothesis that reading-disabled children would be slower than non-RD children at judging phonemically similar nonword pairs was not confirmed. As shown in Table 5, the RTs for the non-RD and RD groups were similar. The mean RT for the non-RD group was 2,553 milliseconds and the mean for the non-RD group was 2,367 milliseconds.

Parallel to the real word RT analysis, the nonword RTs were further analyzed to determine if RT varied as a function of phonological feature or word position. In other words, did the children exhibit significantly faster (or slower) RT judgments to word pairs that differed in the initial phoneme compared to word pairs that differed in the final phoneme? Similarly, did the children exhibit significantly faster (or slower) RT judgments to word pairs that contained one phoneme that differed in the voicing feature compared to word pairs that differed in the place feature? The ANOVA showed no significant main effects for either phonological feature or word position. Thus RTs were not affected by a change in the voicing feature of a phoneme compared to a change in the place feature of a phoneme. Furthermore, whether the phoneme change occurred in the beginning of a word compared to the end of a word did not significantly affect RT. Similarly, all interaction effects were not significant.

A 1-way ANOVA was conducted to assess whether the reader groups differed on judgments involving matching nonword pairs (NONWORD-SAME pairs). No significant differences were found between the groups ($F(1,33)=.28$, $p>.05$). Mean RTs for the NONWORD-SAME nonword trials are presented in Table 7.

Accuracy of Modality Report

How accurate were the two groups of children in making modality judgments during the experiment? That is, when *correctly* reporting that the two words presented were different, how accurate were the children in: 1) reporting the word seen, when shown the picture of the eye and 2) reporting the word heard, when shown the picture of the ear? To answer this question, a sample of the real word blocks (i.e., WORD-DIFFERENT trials from one of the four blocks, or 20 of the 40 trials in the block) and nonword blocks (i.e., NONWORD-DIFFERENT trials from one of the two nonword blocks, or 20 of the 40 trials in the block) were analyzed to determine the percent accuracy of modality judgments. A total of 459 real word responses and 409 nonword responses were analyzed.

The dependent measure was the number of times that students judged correctly that word or nonword pairs were different followed by a reporting of words seen or heard without regard to the correctness of the modality requested. To illustrate, upon seeing "BIT" and hearing "PIT", a student correctly judged the words to be different, and then upon seeing the eye prompt reported either "BIT" or "PIT" as the word. Responses with vowel or consonant alterations or missing reports were excluded. Of interest was how often students reported the words they saw correctly, the words they heard correctly, and the words whose modalities were mixed up.

The first ANOVA was conducted on the total number of correct judgments followed by one of the words or nonwords. The independent variables were reader group (RD and non-RD) and word type (real word vs. nonword). Only one main effect emerged as significant. Real words were judged more accurately than nonwords, $\underline{M}$ =

13.5 real vs. 11.7 nonwords, $F(1,34)= 8.66$, $p< .006$. The main effect of reader group and the interaction were not significant, both F's < 1. This indicates that RD and non-RD students did not differ in judging words and nonwords correctly and reporting either the word seen or the word heard, M = 12.9 (RD) vs. 12.2 (non-RD).

To assess whether students were able to report the correct modalities of the words they judged correctly, an ANOVA was conducted on the number of words or nonwords reported correctly in response to the eye and ear prompts. The independent variables were reader group, word type and type of prompt (eye vs. ear). The latter two variables were repeated measures. Results revealed a main effect of word type F (1,32) = 12.22, p <.002, and an interaction between word type and prompt type $F(1,32) = 19.31$, $p <. 002$. Mean performance is reported in Table 9. None of the other main effects or interaction reached significance, all $ps > .05$. Reader groups did not differ, $F < 1$.

Table 9
For word pairs judged accurately as being different, mean number of times that words and nonwords heard were reported correctly and words and nonwords seen were reported correctly.

Word Type	Prompted by Ear		Prompted by Eye		Mean	
	M	SD	M	SD	M	SD
Real (max=20)	7.15	2.8	4.8	1.7	6.00	2.6
Nonword (max=20)	4.56	2.6	5.15	2.7	4.85	2.7

From Table 9, it is apparent that students were more accurate in reporting real words that were heard than real words that were seen. However, the same pattern favoring heard over seen words did not hold for nonwords where performance reporting seen and heard words was more similar. Also, the difference favoring real words over nonwords held mainly for heard stimuli, not for seen stimuli where the difference was

slight. Separate ANOVAs were conducted to determine where significant differences might lie. Results revealed that students reported real words that they heard more accurately than real words that they saw, $F(1,32) = 16.07$, $p < .0004$. However, seen and heard nonwords did not differ, $F < 1$. Moreover, for words they heard, students reported more real words than nonwords, $F(1,32) = 31.32$, $p < .001$, but for words they saw, words and nonwords were reported to a similar extent, $F > 1$.

Another response of interest was whether students mixed up the modalities of the words they reported. The dependent measure was the number of times students reported the heard word in response to the eye prompt and the seen word in response to the ear prompt. The independent variables were reader group and type of word. Results of the ANOVA revealed a main effect of reader group, $F(1,32) = 4.65$, $p < .04$. Disabled readers switched modalities significantly more often than non-RD students, M=2.29 (RD) vs. 1.29 (non-RD). None of the other effects reached significance, all p's>.05.

To summarize findings regarding students' ability to detect when word pairs differed and to report the words seen or heard, RD and non-RD students were more successful judging and reporting real words (68% correct) than nonwords (59% correct). Regarding the modality of the words, students were more accurate in reporting real words that they heard than reporting real words that they saw or nonwords that they heard or saw. The latter word types were reported accurately to a similar extent. The only difference that distinguished RD from non-RD students was in mixing up modalities when they reported words seen or heard. They did not differ in reporting modalities correctly.

The most likely explanation for the poorer performance of RD students is that they were reporting the word heard while avoiding a report of the word seen. This explanation is supported by the pattern of reports to word pairs judged in error as the same, as shown in Table 4. The RD children were twice as likely (proportionally) to report the nonword that they heard compared to the nonword that they saw when judging nonword pairs incorrectly as the same.

Vowel Production Errors

During the data collection process, it became apparent that the RD children were making errors when they reported the experimental words and nonwords that they heard or saw, and that these errors tended to involve alterations. of the vowels. This error pattern, however, was not observed in the non-RD group. Vowel production errors were not anticipated, especially since the children were taught the experimental real words that they did not know, and the vowels represented in the spoken and written real word pairs and nonword pairs were always the same. This observation prompted an analysis of the children's inaccuracy in producing vowels in the reported words and nonwords. A vowel production error was scored if the following criteria were met: the child produced the correct initial consonant of either the heard word or the seen word and the vowel spoken differed from the vowel presented in the pair (e.g., when hearing BEEP and seeing DEEP, the child produced either the /b/ in beep or the /d/ in deep, along with a vowel different from /i/). These criteria insured that responses appearing to be pure guesses would not be included in the analyses.

Real Word Vowel Errors Unlike the consonant analyses, data from both the WORD-DIFFERENT and WORD-SAME trials were analyzed together. This was done because the vowels were the same in all trials, so that the child's task with respect to vowel identification did not differ between the types of word pairs.

Close to 50% (8/17) of the non-RD children made no vowel errors, whereas only one RD child made one or more vowel errors. Accordingly, a nonparametric analysis of the vowel data was conducted. A Mann Whitney test comparing the mean rank errors on vowel production showed that the RD group made significantly more errors (M-W $U=60$, $p< .003$) than the non-RD group on this task. On average, the RD group made more than three times as many vowel errors as the non-RD group; the non-RD group performed close to zero on this measure. Mean and mean ranks are shown in Table 10. This result was surprising, given that the two groups were matched on word reading ability, and did not differ in the number of words that they needed to learn prior to beginning the experiment.

Table 10
Vowel errors in children's reporting experimental real and nonwords heard and seen.

	Mean M (SD)	Mean Rank	Range Min	Max
Reader Group				
Non-RD				
Real Words (n=17)	1.12 (3.71)	12.53	0 -	4
Nonwords (n=17)	1.29 (1.69)	12.35	0 -	5
RD				
Real Words (n=17)	3.71(3.16)	22.47	0 -	11
Nonwords (n=18)	4.61(4.22)	23.33	0 -	18

Note. Maximum errors possible is 160 for real words and 80 for nonwords.

A second analysis of the vowel errors examined the distribution of vowel production errors in word seen and word heard trials. The question of interest was whether children were more likely to make vowel production errors when they were requested to report a word seen or a word heard. To begin, a reliability check was

conducted on the WORD-DIFFERENT trials (real word and nonword) to determine whether the children accurately followed the experimental procedures, and hence reported a word similar to the word seen when shown a picture of the eye, and similar to the word heard when shown a picture of the ear. A verbal production was scored as similar to the requested modality when the children reported both consonants in the word correctly, but supplied an altered vowel (e.g., when presented with "MAD" visually and "MAT" auditorily, children produced the word "MUD" when shown picture of the eye). The reliability analysis showed that in response to a request for a word seen, 80% (44/55) of the errors produced by RD children consisted of reporting a similar word and 93% (14/15) of the errors of the non-RD children consisted of reporting a similar word. In response to the request for a word heard, 69% (24/35) of the RD children's errors were a word similar to the word heard, and 73% (8/11) of the non-RD children's errors were a word similar to the word heard. To summarize, when they made vowel errors, the children were fairly accurate at modality judgments, i.e., reporting a word similar to the word in the requested modality.

In the non-RD group, 25% of the vowel errors were committed on ear trials (i.e., word heard) whereas 75% of the vowel errors were committed on eye (i.e., word seen) trials. The RD group also committed more vowel errors on the eye trials, with 59% of errors made on eye trials and 41% of the errors made on the ear trials. Means and percentages are shown in Table 11. This indicates that vowel errors arose from reading more than listening sources. Seeing spellings and having to report the written word caused students to shift away from the vowel that was heard and common to both words.

Table 11
Total number and percentage of vowel errors as a function of word and report type

	Reader Group			
	non-RD		RD	
Word Type	Raw	%	Raw	%
Real Words				
ear report	5/20	25%	26/63	41%
eye report	15/20	75%	37/63	59%
(160 trials)				
Nonwords				
ear report	11/20	55%	31/88	35%
eye report	9/20	45%	57/88	65%
(80 trials)				

Nonword Vowel Production Errors. As with the real words, data from both the NONWORD-DIFFERENT and NONWORD-SAME trials were analyzed together. With one exception, all children in the RD group made at least one vowel error. On the other hand, only half (8/17) of the non-RD children made one or more vowel errors. Accordingly, a nonparametric analysis (Mann-Whitney U) of the vowel errors was

conducted. Once again, a statistically significant difference (M-W U=57, p< .001) was found between the mean rank errors scores of the two groups. Once again, the RD group made more than three times as many vowel production errors as the non-RD group; and again, the non-RD children performed close to zero on this measure. Mean and mean ranks are presented in Table 10. This result parallels the children's performance on the pretest nonword reading test, where the non-RD children's scores were significantly superior to the RD children's scores, as shown in Table 1.

An analysis of the distribution of vowel production errors in word seen and word heard trials showed a different performance pattern between the groups. For the non-RD group, vowel errors were only slightly more likely in reports of the word heard (55%) as the word seen (45%). However, vowel errors in the RD group were almost twice as likely to occur in an eye report (65%) as in an ear report (35%). This error pattern perhaps reflects decoding weaknesses and lack of full knowledge of vowel grapheme-phoneme correspondences in the RD group. Means, percentages and test statistics are presented in Table 11.

Origin of Vowel Errors.

To explore possible origins of the vowel errors produced by RD students, the responses containing the errors were categorized as real words, nonwords, or intra-list errors. One possibility is that students reported other words or nonwords they had encountered in the experiment. Because the real word task preceded the nonword task, all intra-list errors were other real words appearing on the list. In contrast, both words and nonwords qualified as intra-list errors on the nonword task. There were 65 vowel

errors in reports of real words and 86 vowel errors in reports of nonwords. Table 12 reports the percentages of occurrence of the various categories.

Table 12
Categorization of Vowel Errors by RD Children

	Percent Vowel Errors		
	Real Word s	Nonwords	Intra-list
Reporting Real Words (n=65)	60%	15%	25%
Reporting Nonwords (n=86)	41%	52%	7%

From Table 12 it is apparent that the majority of vowel errors did not arise because students were substituting other words they had heard or seen during the judgment task. Most of the responses were words or nonwords that came from outside the task. Interestingly, even though students had encountered only real words in the first task, they did produce some nonwords. In the nonword task, they produced many more nonwords. This indicates that students were not simply substituting words/nonwords that had been primed during the experiment. They were truly having difficulties with vowel identification.

Pattern of Vowel Errors.

The final question asked with respect to vowel errors in the RD group was as follows: were vowel substitutions random, or did the children consistently misrepresent one vowel sound with, for example, a phonetically similar vowel sound?

A matrix (see Table 13) was constructed to display the spoken/written vowel presented and the vowel produced by children. The first column shows the percent of trials that a particular vowel was presented. The second column shows an example of a sample word or nonword used in the study that contains the vowel. Vowels are presented in IPA format.

Table 13
Distribution of Vowel Errors for the RD Group

			Vowel Substitution											
	%	example		i	I	eI	ɛ	æ	a	ʌ	oU	u	aU	oU	aI
	9%	seat	i		6	5									
	16%	dig	I				4	3		1			1		4
Vowel	12%	shake	eI	25			2	2							2
Heard/	11%	bed	ɛ	2	27	1		3	1						
Seen	18%	rag	æ		3	5	11			3					
	11%	shop	a		1					6		2	1	3	
	8%	duck	ʌ						3		3	1	2		
	1%	coat	oU			1									
	5%	bull	U												
	3%	tupe	u						1	2	3				
	1%	down	aU												
	5%	ride	aI		6	1	1	3							

Three vowel misrepresentations were made more than 10 times: the pedagogical short a (/æ/) was pronounced as the pedagogical short e sound (/ɛ/) in 11 instances; the

pedagogical short e sound (/ɛ/) was pronounced as the pedagogical short I sound (/I/) in 27 instances; and the pedagogical long a sound (/eI/) was pronounced as the pedagogical long "e" sound (/i/) in 25 instances. These errors suggest articulatory/acoustic phonetic confusions. For example, an examination of the first and second formant frequencies for /æ/ and /ɛ/ (Peterson & Barney, 1952), shows that there is significant overlap in the acoustic structure of these vowels. The first formant in vowel perception relates to mouth opening and the second formant is a cue for place of maximum approximation of the tongue with the walls of the vocal tract (Borden & Harris, 1984). Thus there are relatively small differences in the production of these two vowels relative to mouth opening and tongue placement, and as such, they are perceptually similar as well. Similarly, the second formant frequencies for short i /I/ and short e (/ɛ/) are close together (Peterson and Barney, 1955), as are the production of the dipthong, long a (/eI/) and the long "e" sound (/i/) (Holbrook & Fairbanks 1962, Peterson & Barney, 1955). Also of interest to note is that even though the vowels /I/ and /ɛ/ tend to be neutralized when preceding a nasal consonant, none of the children's vowel errors occurred in this articulatory context.

Another relationship emerged from these errors concerning vowel duration. In one of the three patterns discussed above, a phonetically long vowel was confused with a second phonetically long vowel, (i.e., /eI/-/i/). Because the children both heard and saw the vowels, it is possible that they were using vowel duration as a cue for the production of either the written or the spoken word.

It should be noted that most of the vowel errors do not reflect difficulties in the application of orthographic rules. A close examination of Table 13 shows that 17% (25/151) of the errors reflected orthographic confusions (i.e., confusing a pedagogical

short vowel with its matching pedagogical long vowel, and for example, reporting the word "rid" when presented with the word "ride") whereas 41% (63/151) of the errors reflected phonetic confusions, as discussed above. If this task was simply a word reading task, we might expect the errors to reflect more difficulties in the application of orthographic rules.

Discussion

The present study focused on the following research question: Do the phonological deficiencies of children with a reading disability result from imprecise phonological representations, or do they result from difficulties in phonological recoding? To address this question, a reading level match designed was used. Two groups of children (reading-disabled and typically developing readers) were given an audio-visual task in which they 1) reported whether an auditory word matched a phonologically similar written word and 2) reported either the word they heard or the word they saw. Separate trials of real words and nonwords were administered.

Do reading disabled children have more difficulty than typically developing readers in judging whether a real word presented auditorily matches a phonologically similar written word, presented visually? In this study, the answer was no. RD children had no difficulty relative to reading-level matched non-RD children in judging word pairs as the same or different based upon a change in either the initial or final consonant of a CVC word. These results suggest that RD children do not have poorer phonological representations of familiar real words than non-RD children.

Using a similar design, Fox (1994) found significant differences between the RD and non-RD children matched on reading level. However, differences in study design and participants may explain the disparate results. To begin, the children in the present study were given practice reading the experimental words, so that differences in ability to read the experimental words could not likely explain differences between the groups.

In the Fox study, the children were not pretested on the words. Thus inability to read the experimental words could have explained some of the results. Furthermore, in the Fox study, the experimenter read the words aloud to the children. As such articulation of the spoken words was not controlled. Finally, the positive results could have been attributable to the selection of a small group (nine children) of more severely impaired readers. Whereas both studies examined RD students reading, on average, two years below grade level, the present study included a wider range of reading deficits (only one year below expected grade level at minimum).

In the present study, the RD and non-RD children did not significantly differ in their reaction time to word pairs (containing real words) either in the case where words in the pairs were different, or when words in the pairs were the same . In addition the children's RTs in both reader groups were not significantly affected by whether the contrasting word pairs differed in the initial or the final phoneme of the word. A significant interaction was found between phonological feature and reader group, showing that RD children performed faster on word pairs contrasting the place feature compared to the voicing feature. However, the non-RD group did not show this difference. This result suggests that the place feature is an easier distinction for the RD children, parallel to the result obtained in the analysis of errors (see Table 2). However this result was not obtained in the nonword reaction time data. Thus, the result may simply be a statistical artifact.

The reaction time results were consistent with those found by Fox (1994) using a similar paradigm. The Fox study found significant differences in reaction time between reading disabled children and chronologically age-matched peers in a task where they

judged phonologically similar real words as the same or different. However, no significant differences in reaction time were found between the RD children and younger, reading level matched children.

One limitation in the analysis of the reaction time data concerns the inclusion of both correct and incorrect responses in all analyses. The present study used a single keystroke to record reaction-time, instead of two different keystrokes, which would have allowed for the computerized collection of correct/incorrect responses (i.e., choosing the correct button for a "same" judgment of the word pair and a different button for a "different" judgment of the word pair). A single keystroke response was used to limit the cognitive demands of the response, and avoid incorrect scoring attributable to the child pushing the wrong button for "same" or "different". It is possible that differences between the groups in RT would be discovered once the incorrect responses were excluded from the analysis.

The next question addressed in the study was as follows: when making errors in same/different judgments (i.e., reporting that two words are the same, when in reality, they are different), are reading disabled children more likely to report the written word or the spoken word, relative to typically developing readers? The results showed that both reading disabled and non-RD children tended to report the word that they heard more often than the word that they saw. These results suggest that for young readers, the auditory signal is more accurately identified than the orthographic/visual symbol for a word. For the non-RD children, this result may be explained by the fact that the children had, at most , one and one half years of formal reading education, whereas they have

been exposed to oral language since birth. On the other hand, many of the reading disabled children had three to four years of reading instruction; however, they still were more likely to override the visual word with the auditory word. These results suggest that the RD children do not have impaired phonological representation of words which cause them to rely more on orthographic representations.

The same theoretical questions were asked in the second part of the experiment, using the same paradigm. However, this time nonwords were used as stimuli. In this task, the children were presented with both a novel auditory stimulus as well as a novel written stimulus. Do reading-disabled children have more difficulty than typically developing readers in judging whether an auditory nonword matches a phonologically similar written nonword? Once again, the answer in this study was no. The two groups showed no accuracy differences in judging the phonologically similar word pairs. RD children had no difficulty relative to reading-level matched non-RD children in judging word pairs as the same or different based upon a change in either the initial or final consonant of a CVC word. Therefore , it appears that phonological recoding deficiencies did not account for the results of the RD children in this task.

Next, when making errors in same/different judgments (i.e., reporting that two nonwords are the same, when in reality, they are different), are RD children more likely to report the written nonword or the spoken word, relative to non-RD children? Once again, both groups of children were more likely to report the nonword they heard, rather the nonword seen. This task required children to create a phonological representation of an auditory stimulus that was not stored in memory. At the same time, it required them

to create a phonological representation from a novel string of letters. The results showed that even when a novel auditory stimulus was involved, both groups of children were still more accurate at identifying the auditory than the visual stimulus. Thus, for beginning readers, the phonological representation generated from both spoken nonwords and familiar real words overrides the phonological representation generated from the written word.

Consistent with the real word RT data, no differences in RT were found between the groups in judging nonword pairs when the auditory word was different from the visual word or when the auditory word was the same as the visual word. Also consistent with the real word RT data, neither phonological feature nor feature position in the nonword significantly influenced RT in the reader groups.

The next issue addressed in this study concerned the children's accuracy for nonword pair judgments involving specific phonological contrasts and properties. The two questions were as follows: 1) do RD and non-RD children have more difficulty in judging nonword pairs when the contrasted phoneme is in the initial versus the final position of the word? and 2) do RD and non-RD children have more difficulty in judging nonwords pairs that contrast the place feature in the word pair versus the voicing feature?

The results showed that both reader groups were significantly more accurate in judging nonword pairs when the contrasting phoneme was in the beginning of the word, compared to the end of the word. However this effect was not found with the real words. In addition, accuracy for both reader groups was significantly higher when the nonword pair judgment involved a place feature change in contrast to a voice feature change. This

result supports the work of Treiman and colleagues (Treiman et al., 1998) showing that kindergarteners had more difficulty judging CV (nonword) pairs when the contrasted words differed in voicing as compared to CV pairs that differed in place of articulation.

As previously stated, significant effects for phonological feature were also found with the real words. Thus, it appears that when a lexical task is purely phonological, (i.e., devoid of semantic content), linguistic features (word position, phonological features) exert a greater impact on word discrimination. As such, in evaluating word discrimination studies, it is necessary to consider the type of stimuli used because results may vary according to the lexical status of the stimuli, as well as the complexity of the stimuli. In the present study, however, another explanation for the differential impact of linguistic features on word discrimination (i.e., real word stimuli versus nonword stimuli) is that the real words were practiced whereas the nonwords were not. It is possible that the effect of nonword feature position would have disappeared if the nonwords were studied prior to the experiment.

Vowel Errors

The most striking findings in this study were unanticipated. The question under study was whether children's reading deficiencies arise from imprecise phonological representations, or alternatively, poor phonological decoding skills. The hypothesis was put to the test by comparing children's accuracy for minimal pair contrasts, where only the consonants in CVC words were varied; vowels were held constant. Nonetheless, an analysis of the children's verbal productions of the heard and seen words showed that

the RD children had significantly more errors in producing the vowel segments in both the real and the nonwords. Rarely did the children in either group report a consonant that matched neither the spoken nor the written word. Several studies (Tal and Siegel, 1996; Seidenberg, Bruck, Fornalo, & Backman, 1985; Fowler, Liberman & Shankweiler,1977) have shown that beginning readers make significantly more errors reading the vowels in words relative to the consonants. Thus, why are these results surprising ? The answer is that this experiment posed a match to sample task, one that is presumably easier than a pure word reading task. Moreover, the children were trained to read the real words prior to beginning the experiment, so that the accuracy results could not be explained by the fact that the children had no experience reading the words in the study. As such, the finding that the RD group still had significantly more difficulty than the non-RD group in identifying/producing the vowels in words, points to the burden that vowel identification places on RD children.

The vowel errors were also analyzed to determine their distribution in word seen and word heard trials. Were vowel errors more likely to be produced when children were asked to report the word that they heard or the word that they saw? In the case of the real words, both the non-RD and RD children were more likely to produce a vowel error when reporting the word they saw, in contrast to the word heard. The differences however were more striking in the non-RD group. In the non-RD group, 75% of the total vowel errors were made on word seen reports. In contrast, 59% of the errors made by the RD group were made on word seen reports. It should be noted, however, that errors in vowel production were close to zero in the non-RD group, as shown in Table 9 and Table 10, and so these patterns should be interpreted with caution.

A different pattern of performance emerged in the nonword trials. In these trials, the RD children were just as likely to make a vowel error on a word heard report, as a word seen report. In contrast, the RD group made almost two thirds of their errors on word seen trials as compared to one third of their errors on word heard trials.

The vowel analyses for both the real word and nonword trials suggest that children's reading deficiencies arise from poor phonological recoding skills, rather than imprecise phonological representations stored in memory. RD children were more likely to make vowel errors than non-RD children, and were more likely to misidentify a vowel generated from a visual/orthographic symbol as compared to a spoken word. Even though the effects were small (see Table 9), they are important because they were found in a match to sample task, presumably a much easier task than word reading. This finding was more striking in the trials with nonwords, which were not practiced and which placed a heavier demand on phonological recoding skill as compared to real word trials. Further evidence for phonological recoding deficits comes from the pretest data. Whereas, as shown in Table 1, the children performed similarly on a test of word identification (Word Identification), significant differences in the groups were found between the groups on the nonword reading test (Word Attack).

It is possible that both imprecise phonological representation as well as phonological recoding difficulties play a causal role in reading difficulties. It may also be that this study did not sensitively measure phonological representation. A limitation of this study is that children were required only to contrast consonants sounds. It may be that children's phonological representation difficulties are restricted to vowels. Given that the children did make vowel errors in reporting words and nonwords

presented auditorily, it is still valid to question whether difficulties in vowel perception/representation plays a causal role in reading difficulties, and at what level these difficulties manifest themselves (i.e., vowel discrimination, vowel identification).

Post, Swank, Hiscock & Fowler (1997) examined vowel discrimination and identification in reading impaired and normally developing readers. Second through fourth grade readers were asked to: 1) discriminate (same/different judgment) between two spoken words that differed in the medial vowel sound and 2) identify vowels in spoken words using one of two forced choice formats (e.g., for the short "a" sound, the children pointed to a doll named "Pam" , and for the short "e" sound, the children pointed to a doll named "Ken"). Both groups of readers performed at ceiling on the discrimination task. However, identification of vowels was significantly poorer in the reading impaired groups.

In another study (Post, Foorman & Hiscock, 1997), second and third grade children, classified as either skilled or unskilled readers, were given a speech perception and speech production task with two syllable nonsense words (tippy, teepy, deepy, dippy). In the speech production task, the children listened to the nonsense words on audiotape and repeated what they heard. In the perception task, the children listened to the nonsense words on audiotape and identified the vowel that they heard by pointing to either a block with the cursive letter "i", or a block with the cursive letters "ee". No significant differences in speech production were found between the groups. However in a forced choice identification task of the short vowel "i" and the long vowel "e" (in the

two syllable words), the unskilled readers demonstrated significantly poorer vowel identification skills.

The results of the present study, along with the evidence cited above, suggest that RD children have a specific perceptual deficit in categorizing vowels produced from spoken as well as written language. It is not that they cannot tell the difference between two vowel sounds given a contrasting vowel segment, it is that they are poor at assigning a visual symbol to the sound.

Theoretical Considerations: Phonological Representations

Definitions and theories of phonological representations are in the beginning stages, and still somewhat vague. The terminology used to describe poor phonological representation has been varied, with researchers pointing to problems in establishing "complete", "full", "clear", "precise", "distinct" phonological representations in long-term memory (Fowler, 1991, Katz, 1986, Snowling et. al, 1988, Swam & Goswami, 1997, Elbro, 1998b). Moreover, the research paradigms have been few and disparate. For example, Snowling et al. (1988) used an object naming tasking to infer poor phonological representation in disabled readers, whereas Elbro (1998a, 1998b) used the quality of vowel production in single words to infer indistinct phonological representation in disabled readers. Furthermore, there remains a lack of understanding as to whether the problem is related to storage of lexical items, access to lexical items, or the ability to encode lexical items. Study design should vary, depending on how the difficulties in phonological representation are operationalized.

In the present study, difficulties in phonological representation were conceived of as both a storage problem and an encoding problem. Using familiar real words, it was conceivable to test whether disabled readers have poor phonological representation of familiar real words relative to typical readers. The audio-visual paradigm required the children to compare phonetically similar real words; the task was to compare a phonological representation from the spoken word, with a phonological representation created from the visual word. Because these were familiar and practiced words, it was reasoned that the children would be reading these words by sight, bypassing the phonological recoding process, and thus directly accessing the stored representation of the word. If these words were not precisely represented in the memory of RD children, it was reasoned that they would have more difficulty with this comparative task than non-RD children. In the case of nonwords, there is no stored representation. Thus, the children were required to *encode* phonological representations from the spoken and written forms. In contrast to the real words, phonological recoding most likely occurs in the process of encoding the phonological representation.

The results showed that this task was either not sensitive to deficits in phonological representation, or that these deficits are not an underlying cause of reading disability. However, the results of the vowel analysis suggest that phonological representations may be differentially impaired, and that vowels are more vulnerable to imprecision than consonants. As such this finding is in accord with Elbro (1998a, 1998b), who examined vowel alterations in children's speech . In his study, spoken vowels were judged with respect to what would be produced from the written, i.e, most distinct form of the word. Nonetheless, further study is needed to validate these findings.

Implications for Teaching Strategies.

The findings in this study concerning consonant perception have implications for the teaching of consonant sound identity to beginning readers. Children have less difficulty discriminating words that differ in the place of articulation feature relative to the voicing feature. This suggests that consonants that differ solely in the voicing feature (e.g, "B" and "P") should not be taught at the same time. A delay would give children an opportunity to develop a clear representation of one phoneme/grapheme relation before the second phoneme/grapheme relation is taught.

The most unequivocal finding in this study is that vowel identification poses an obstacle to young reading disabled children, and without secure vowel identification ability, acquisition of reading skills is severely compromised. Even when children were trained to read simple CVC words, and exposed to the words in a match to sample task, vowel errors in word reading were apparent in the reading disabled group. This suggests that intensive focus on vowel identification should be instituted in early reading instruction. The question remains as to how best to implement this training. Should vowel training begin with perception/identification of vowel sounds paired with the alphabetic symbol for the sound? Or, should children initially be trained to discriminate the sounds first, without reference to a graphic symbol? Post et. al. (1999) advocate highly systematic instruction linking vowel sound identity to spelling. One strategy that they suggest is to contrast the vowel sounds in man and men, e.g., a child might be shown the word man and asked whether the word before him/her is man or men.

Another issue regarding the training process is whether children would benefit from a training approach which only involved auditory perception or one that required production of the sound as well. For example, do articulation cues aid children in the identification of vowel sounds?

Future Research.

Two lines of research are suggested by the present study. One concerns the understanding of basic perceptual processing and the other relates directly to instructional practices.

With regard to basic perceptual processing, one question raised by this study is whether phonological representations of vowels differ from consonants. Would a study requiring RD and non-RD children to contrast word pairs differing only in one vowel sound show different results? Another question emanating from this study is as follows. It was found that both reading disabled and typically developing *early* readers are both more reliable at reporting words heard rather than words seen. Would the same pattern of results hold for more experienced readers? A study of this kind might involve degrading the auditory signal in some way (such as manipulating the voice onset time or transition length of the words), because the experimental tasks in the present study would be too easy for mature readers.

With regard to instructional issues, the results of the present study suggest that the acoustic properties of vowels be considered in the planning of vowel instruction to beginning and remedial readers. Would disabled readers make better progress in vowel

identification if the vowels were taught in a specific sequence designed to avoid phonetic confusability ? Would training be more effective with auditory perceptual training combined with production training? Should letters be introduced immediately, or should auditory perception precede letter training? Investigation of all these research issues may all lead to improved instructional practices.

APPENDIX A
WORD LIST

Initial Voicing	
ten	den
coat	goat
time	dime
pull	bull
came	game
gave	cave
bit	pit
push	bush
down	town
tip	dip

Final Voicing	
feed	feet
mat	mad
seat	seed
had	hat
ride	right
led	let
sat	sad
duck	dug
rag	rack
bag	back

Initial Place	
pan	can
cake	take
get	bet
cook	took
date	gate
dot	got
deep	beep
pop	top
dad	bad
gun	done

Final Place

pat	pack
shake	shape
did	dig
shop	shot
hop	hot
cup	cut
hit	hip
cat	cap
bed	beg
sit	sick

Nonword Pairs

Initial Voicing

geed	keed
dade	tade
dep	tep
gell	kell
kiff	giff
tabe	dabe
toff	doff
tupe	dupe
gack	kack
bim	pim

Final Voicing

feek	feeg
dag	dack
leb	lep
mub	mup
sate	sade
fup	fub
gad	gat
roop	roob
shig	shick
vig	vick

Initial Place

ket	tet
giss	diss
pafe	tafe
poog	toog
pide	kide
pate	tate

bime	gime
gop	dop
beb	geb
kib	tib

Final Place

fop	fot
seeb	seeg
deeb	deeg
deet	deek
hib	hig
pib	pid
shid	shib
dod	dob
vok	vot
gub	gud

APPENDIX B

TRAINING SCRIPT FOR REAL WORDS

You are going to play a word game on the computer. I'm going to teach you how to play. In this game, you are going to hear a word through these headphones, and at the same time you are going to see a written word on the computer screen. This game has two parts. The first part is to press the spacebar on the keyboard ***as soon*** as you know whether the word you heard is the same as the word you saw. You are also to call out the answer out loud – SAME or DIFFERENT while you are pressing the spacebar.

In the next part, you will see a picture of and EYE or and EAR. If you see the picture of the EYE, I want you to tell me the word that you SAW. But, if you see a picture of the EAR, I want you to tell me the word that you HEARD through the headphones. Sometimes, I may ask you to repeat the word that you say. I want to make absolutely sure that I write down the word you say correctly. It doesn't mean that you gave the wrong answer.

I'm going to demonstrate how to play the game. Then you'll get to try. Any questions before we start?

TRAINING SCRIPT FOR NONWORD EXPERIMENT

We are going to continue playing the same game. Except this time you are going to see and hear made-up words, like ZOT and WOT. This is a little harder. Sometimes, I may ask you to repeat the made-up word that you tell me. I want to make absolutely sure that I write down the word you say correctly. It doesn't mean that you gave the wrong answer.

Any questions before we start ?

EXPERIMENT SCRIPT

REAL WORDS

Now you are going to play the game. You need to listen and look carefully, because this time the words are going to be pretty similar – like *tock* and *dock*.

(Administer items in blocks of 40 trials – randomize order of block presentation).

NONWORDS

Now you are going to play the game. Listen and look carefully.

(Administer items in blocks of 40 trials – alternate order of presentation and present either SET A or SET B. Note Set A and Set B are counterbalanced for audio-visual presentation of the words, i.e., see "FOP" and hear "FOT in Set A and hear FOP and see FOT in Set B)

References

Borden, G., & Harris, K. (1984). Speech Science Primer (2nd edition). Maryland:Williams & Wilkens.

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

Bradley, L. & Bryant (1985). Rhyme and reason in reading and spelling. Ann Arbor, MI: University of Michigan Press.

Brady, S. (1997). Ability to encode phonological representations: an underlying difficulty of poor readers. In Blachman, B. (ed.), Foundations of reading acquisition and dyslexia. New Jersey:Erlbaum, 21-47.

Brandt, J., & Rosen, J.J. (1980). Auditory phonemic perception in dyslexia: Categorical identification and discrimination of stop consonants. Brain & Language, 9, 324 –337.

Bruck, M., & Treiman, R. (1990). Phonological awareness and spelling in normal children and dyslexics: The case of initial consonant clusters. Journal of Experimental Child Psychology, 50, 156 – 178.

Byrne, B., & Fielding-Barnsley, R. (1990). Acquiring the alphabetic principle: A case for teaching recognition of phoneme identity. Journal of Educational Psychology, 82, 805 – 812.

Bus, A. & van Ijzendoorm, M. (1999). Phonological awareness and early reading: A meta-analysis of experimental training studies. Journal of Educational Psychology, 91(3), 403-414.

Cool-Edit Pro [Computer Software] (1998). Syntrillium Software Corporation, Phoenix, Arizona.

Dunn & Dunn (1997). Peabody Picture Vocabulary Test-III. Circle Pines, Minnesota. American Guidance Services, 1997.

E-PRIME [Computer Software] (1999). Psychology Software Tools, Pittsburgh, Pennsylvania.

Elbro, C.(1996).Early linguistic abilities and reading development: a review and hypothesis. Reading and Writing: An Interdisciplinary Journal, 9, 452-485.

Elbro, C., Nilesen, I., Petersen, D. (1994). Dyslexia in Adults: Evidence for Deficits in Non-word Reading and in the Phonological Representation of Lexical Items. Annals of Dyslexia, 44, 205-226.

Elbro, C., Borstrom, I., & Petersen, D. (1998a). Predicting dylslexia from kindergarten: the importance of distinctness of phonological representations of lexical items. Reading Research Quarterly, 33, 36-57.

Elbro, C.(1998b).When reading is "readn" or somthn. Distinctness of phonological representations of lexical items in normal and disabled readers. Scandinavian Journal of Psychology, 39, 149 – 153.

Frith, U. (1981). Experimental approaches to developmental dyslexia: an introduction. Psychological Research, 43(2), 97 – 109.

Fowler, A. (1991). How early phonological development might set the stage for phoneme awareness. In Brady, S. & Shankweiler, D. (ed.), Phonological Processes in Literacy. New Jersey: Lawrence Erlbaum, 97-118.

Fowler, A., Brady, S., & Eisen, A. (1995). The perception and awareness of phonemes in young five-year olds. Paper presented at the Society for Research in Child Development, Indianapolis, IN.

Fox, E. (1994). Grapheme-phoneme correspondence in dyslexic and matched control readers. British Journal of Psychology, 85 41-53.

Frost, R., Repp, B. & Katz, L. (1988). Can speech perception be influenced by simultaneous presentation of print? Journal of Memory and Language, 27, 741-755.

Fowler, C., Liberman, I., & Shankweiler, D. (1977). On interpreting the error pattern in beginning reading. Language and Speech, 20, 162-173.

Frost, R. (1991). Phonetic recoding of print and its effect on the detection of concurrent speech in amplitude modulated noise. Cognition, 39, 195-214.

Gough, P. & Tumner, W. (1986). Decoding, reading, and reading disability. RASE 7(1), 6-10.

Greenberg, D., Ehri, L.C. & Perin, D. (1997). Are word-reading processes the same or different in adult literacy students and third-fifth graders matched for reading level? Journal of Educational Psychology, 89(2), 262-275.

Harris, A. & Jacobson, M. (1972). Basic elementary reading vocabularies. Macmillan Co: New York.

Holbrook, A, & Fairbanks, G. (1962). Dipthong formants and their movements. Journal of Speech and Hearing Research, 5, 38-58.

Hurford, D.& Sanders, R. (1990). Assessment and remediation of a phonemic discrimination deficit in reading disabled second and fourth graders. Journal of Experimental Child Psychology, 50, 396-415.

Katz, R.B. (1986). Phonological deficiencies in children with reading disability: Evidence from and object-naming task. Cognition, 22, 225-257.

Lundberg, L, Frost, J., & Peterson, O. (1988). Effects of an extensive program for stimulating phonological awareness in preschool children. Reading Research Quarterly, 23, 263 – 284.

Lundberg, I., Olofsson, A., & Wall, S. (1980). Reading and spelling skill in the first school years predicted from phonemic awareness skill in kindergarten. Scandinavian Journal of Psychology, 21, 159 –173.

Manis, F., Custodio, R. Szeszulki, P. (1993). Development of phonological and orthographic skill: a 2-year longitudinal study of dyslexic children. Journal of Experimental Child Psychology, 56(1), 64-86.

Manis, F., McBride-Chang, C., Seidenberg, M., Keating, P. Doi, L.M., Munson, B., Petersen, A. (1997). Are speech perception deficits associated with developmental dyslexia? Journal of Experimental Child Psychology, 66 (2), 211-235.

Metsala, J. & Walley, A.(1998). Spoken vocabulary growth and the segmental restructuring of lexical representations. In Ehri, L. & Metsala, J. (eds.), Word recognition in beginning literacy. New Jersey:Lawrence Erlbaum , 89- 121.

McBride-Chang, C.(1995). Phonological processing, speech perception, and reading disability: an integrative review. Educational Psychologist, 30(3), 109-121.

McBride-Chang, C. (1996). Models of speech perception and phonological processing in reading. Child Development, 67 (4), 1836-1856.

Moe, A., Hopkins, C. & Rush, R. (1982). The Vocabulary of First-Grade Children. Springfield, Ill:Charles C. Thomas.

Peterson, G.E. & Barney, H.L.(1952). Control methods used in a study of the identification of Vowels. Journal of the Acoustical Society of America, 24, 175-184.

Post, Y., Swant, P., & Hiscock, M. (1999). Identification of vowel speech sounds by skilled and less skilled readers and the relation with vowel spelling. Annals of Dyslexia, 49, 161-195.

Post, Y., Foorman, B., & Hiscock, M. (1997). Speech perception and speech production as indicators of reading difficulty. Annals of Dyslexia, 47, 3-27.

Rack, J.P. (1985). Orthographic and phonetic coding in developmental dyslexia. British Journal of Psychology, 76(3), 325-340.

Rack, J., Snowling, M., & Olson, R. (1992). The nonword reading deficit in developmental dyslexia. Reading Research Quarterly, 27(1), 29-53.

Reed, M. (1989). Speech perception and the discrimination of brief auditory cues in reading disabled children. Journal of Experimental Child Psychology, 48(2), 270-292.

Seidenberg, M., Bruck, M., Fornarolog, G., & Backman, J. (1985). Word recognition processes of poor and disabled readers: Do they necessarily differ? Applied Psycholinguistics, 6, 161-180.

Shankweiler, D. (1999). Words to meanings. Scientific Studies of Reading, 3(2), 113-127.

Share, D., Jorm, A., Maclean, R., & Matthews, R. (1984). Sources of individual differences in reading acquisition. Journal of Educational Psycholgoy, 76, 1309-1324.

Snowling, M. (1980). The development of grapheme-phoneme correspondence in normal and dyslexic readers. Journal of Experimental Child Psychology, 29(2), 294-305.

Snowling, M., Goulandris, N., Bowlby, M. & Howell, P. (1986). Segmentation and speech perception in relation to reading skill: a developmental analysis. Journal of Experimental Child Psychology, 41(3), 489-507.

Snowling, S., Van Wagtendonk, B., & Stafford, C. (1988).Object-naming deficits in developmental dyslexia. Journal of Research in Reading, 11(2), 67-85.

Swan D, & Goswami, U. (1997). Phonological awareness deficits in developmental dyslexia and the phonological representation hypothesis. Journal of Experimental Child Psychology, 66(1), 18-41.

Snowling, M. Hulme, S. & Thomas, J. (1994). The effects of phonetic similarity and list length on children's sound categorization performance. Journal of Experimental Child Psychology, 58(1), 160-180.

Tal, N. & Siegel, L. (1996). Pseudoword reading errors of poor, dyslexic, and normally achieving readers on multisyllable pseudowords. Applied Linguistics, 17, 215-232.

Treiman, R., Broderic, V., Tincoff, R., Rodriguez, K. (1998). Children's phonological awareness: confusions between phonemes that differ only in voicing. Journal of Experimental Child Psychology, 68(1), 3-21.

Wagner, R.K. & Torgesen, J. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. Psychological Bulletin, 101, 192 –212.

Werker, F. & Tees, R. (1987). Speech perception in severely disabled and average reading children. Canadian Journal of Psychology, 41(1), 48-61.

Woodcock (1987). Woodcock Reading Mastery Test-Revised. Circle Pines, MN: American Guidance Service.