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VERBAL WORKING MEMORY AND SPEECH PRODUCTION ABILITIES
IN CHILDREN WITH DIFFERENTIAL READING SKILL:
A CHRONOLOGICAL- AND READING-AGE COMPARISON

BY

BRENDA H. STONE

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
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ABSTRACT

The primary goal of this study was to investigate the association between verbal working memory and speech production and to address a number of ongoing questions about the nature of the relationship between these two phonological processes and reading ability. In an effort to clarify these relationships, the following areas were explored. First, previous research has suggested that poor readers generally do not perform as well as their normal-reading peers on phonological processing tasks, but their performance is not consistently worse than younger children reading at the same level. In order to examine this issue, this study compared the performance of less-skilled readers with that of skilled readers of the same age, as well as with the performance of younger children who were reading at the same level. Second, verbal working memory deficits have been found to account for about 10% of the variance in reading ability; however, the relationship between phonological processing skill and the various components of reading has not been clearly delineated. To clarify this relationship, three aspects of reading (i.e., nonword reading, real word reading, comprehension) were assessed in this study. Third, although evidence supports an association between verbal working memory and speech production, the exact nature of this relationship is not clear. This study used a variety of memory and speech production measures to further examine the association between these two phonological processes. And finally, although there is evidence supporting a relationship between accuracy of speech production and reading ability, the link between speed of speech production and reading ability is not as strong. In fact, there are

indications that speech rate may be related to chronological age but not to reading. In order to explore this issue, speech production accuracy and speech production speed tasks were administered to skilled and less-skilled readers of the same age, as well as to a group of younger readers.

Ninety second- and third-grade children served as subjects for this study. These children were divided equally among three groups who did not differ significantly in cognitive ability: (1) less-skilled third-grade readers; (2) skilled third-grade readers who were the same age as the less-skilled readers; and (3) second-graders who were reading at the same level as the less-skilled readers. In addition to reading and cognitive ability measures, three verbal working memory tasks, two speech production accuracy tasks, and three speech production speed tasks were individually administered to each of the 90 subjects.

As expected, the less-skilled third-grade readers had significantly lower scores than their age-mates on the verbal working memory and speech production accuracy measures. In addition, their performance was significantly lower than that of the younger readers on two memory and two speech production accuracy tasks. Performance on a pseudoword repetition measure contributed significantly to the prediction of all three components of reading for the 90 subjects in this study. The tasks measuring verbal working memory and speech production accuracy loaded on a common factor. There were no significant group differences on two of the speech production speed measures, but on the third measure, the skilled third-grade readers significantly outperformed both the other groups.

The results of this study indicate that a common factor (e.g., phonological encoding, planning for output) may underlie competence, or the

lack of competence, on both verbal working memory and speech production accuracy tasks. The finding that less-skilled readers have phonological processing deficits even when compared to younger children suggests that a deficit, rather than a developmental lag, model of reading disability should be considered.

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CHAPTER I.

INTRODUCTION

Processing at the metaphonological level has been strongly implicated in reading success; however, the relationship of underlying phonological processes to reading is not as well established (Jorm & Share, 1983; Pennington, Van Orden, Kirson, & Haith, 1991; Wagner & Torgesen, 1987). Phonology relates to the sound structure of one's language. Whereas processing at the metaphonological level necessitates a conscious awareness of, and access to, this sound structure, underlying phonological processes simply require the ability to use phonological information to process written and oral language (Mattingly, 1972; Wagner & Torgesen, 1987). Verbal working memory and speech production are two underlying phonological processes that have been associated with reading ability; there are, however, unanswered questions about the nature of the associations. This study will examine verbal working memory and speech production in second- and third-grade children in an effort to clarify the relationship between these phonological processes and their association with three major components of reading achievement: nonword reading, real word reading, and comprehension. Several questions will be addressed. The study will explore whether the deficits of less-skilled readers on verbal working memory and speech production tasks have a common origin, whether they can be explained in terms of a developmental lag, and whether speech production deficits are evident in both accuracy and speed of processing. Before describing the study in more detail, background information about verbal working memory, speech production, and their relation to reading is provided.

The Importance of Verbal Working Memory to Reading Performance

The term working memory refers to a multifaceted system that is responsible for briefly maintaining and manipulating information during the performance of complex cognitive tasks (Baddeley, 1986; Baddeley & Hitch, 1974). One component of the system is responsible for the temporary storage of speech-based information and is referred to as verbal working memory. In addition to being multifaceted, working memory is widely viewed as a limited-capacity system that encompasses both storage and processing components (Brady, 1991; Daneman & Carpenter, 1980; Perfetti & Lesgold, 1977; Wagner & Torgesen, 1987). The system is limited in its capacity because the storage and processing capabilities are served by a common pool of resources. Consequently, as processing becomes more efficient, storage resources functionally increase.

The most frequently observed problem that has emerged from research investigating the role of underlying phonological processes in reading success has been that poor readers have deficits in verbal working memory (Brady, 1986; Brady, 1991). These deficits have been found to account for about 10% of the variance in reading achievement (Brady, 1991). When given lists of items that can be verbally coded, poor readers generally recall fewer items than good readers. This association between reading ability and verbal working memory has been found for readers of syllabic and logographic scripts, as well as for readers of alphabetic writing systems (Mann, 1985). It is noteworthy that these deficits have been found to be relatively independent of general cognitive ability (Stanovich, 1986). In addition, poor readers demonstrate a verbal working memory impairment

whether material is presented visually or aurally (Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979; Torgesen, 1988). That is, the memory deficits of poor readers are not specific to the printed word or to reading tasks, but reflect a more general problem with phonological processing.

Further evidence for the relationship between reading and memory comes from a study of 12 hyperlexic children (Healy, Aram, Horwitz, & Kessler, 1982). Hyperlexic children read at a much higher level than would be expected given their age and intelligence (Snowling, 1987). The hyperlexic children in the Healy et al. study were good decoders but had very low cognitive functioning. The one cognitive strength these children had, however, was verbal working memory ability. Evidence for a link between reading skill and verbal working memory ability also emerges from a comparison of different kinds of learning disabilities. Torgesen and Houck (1980) reported that reading-disabled children had verbal memory deficits, whereas learning-disabled children without specific reading disabilities did not have memory impairments.

Verbal working memory may be particularly important for the beginning reader because of its impact on another phonological ability, metaphonological awareness. Understanding that words have a phonological structure appears to be a critical step in learning to read (see Adams, 1990, for a review). It has been proposed that the ability to efficiently code phonological information in working memory may play an important role in the emergence of metaphonological awareness (Wagner et al., 1987). In a study with 111 kindergarten nonreaders, Wagner et al. found that verbal working memory and phonological awareness were accounted for by one factor. They concluded that performance on phonological awareness tasks

depends on efficiency of coding in working memory and suggested that basic phonological processes are important for the development of both phonological awareness and reading skills.

Whereas evidence supporting an association between verbal working memory and reading ability is substantial (see Brady, 1986; Jorm, 1983; Wagner & Torgesen, 1987, for reviews), the specific relationship of verbal working memory to the components of reading skill (i.e., nonword reading, real word reading, comprehension) has not been carefully explored (Crowder, 1982; Pennington et al., 1991; Wagner & Torgesen, 1987). The association between verbal working memory and decoding may be particularly important in the initial stage of reading acquisition, but for the skilled reader, verbal working memory may be more closely associated with comprehension (Pennington et al., 1991; Perfetti, 1985). According to Perfetti, in order to decode, the beginning reader must retrieve the sounds of individual letters, place them in temporary storage until all the sounds in the word have been retrieved, and then blend the sounds together to form the word. Therefore, deficits in verbal working memory could be detrimental to the beginning decoder. By the time all the sounds have been retrieved, a child with a memory impairment may have forgotten the initial sounds. Two studies (Gathercole, Baddeley, & Emslie, submitted; Gathercole, Willis & Baddeley, 1991) indicate that the closest link between verbal working memory and reading occurs when children have been reading for about one year. At this point in the reading process, children are shifting from a primarily visual reading strategy to the use of an alphabetic strategy (Frith, 1985). Verbal working memory may become important as children begin to relate printed symbols (graphemes) to spoken sounds (phonemes). Working memory may

be taxed in order to learn the basic grapheme-phoneme correspondences necessary to apply the alphabetic principle (Gathercole et al., 1991). In addition, in the early stages of reading acquisition, verbal working memory may be more crucially implicated because the sounds of individual letters must be held in temporary storage until all the sounds in a word have been identified (Gathercole et al., 1991; Perfetti, 1985). Whether memory impacts on mastering grapheme-phoneme correspondences or on holding phonemes in temporary storage, reading acquisition may be compromised by deficits in verbal working memory ability.

Deficits in verbal working memory may also hinder higher language processes (Perfetti, 1985). That is, because verbal memory is a limited-capacity system, the more resources that are used up decoding the words of the text, the fewer resources will be left over for comprehension. An alternative proposal is that verbal memory is not strongly associated with the early stages of reading development but is related to the more complicated process of comprehension (Pennington et al., 1991). However, contradictory evidence for this proposal comes from a study with fifth-graders in which verbal memory was associated with both decoding and comprehension (Futransky, 1992). Comprehension also may be affected if verbal working memory deficits impair the ability to access the meaning of words or to store syntactic information (Fowler, 1988; Mann, Shankweiler, & Smith, 1984; Vellutino & Scanlon, 1982).

Longitudinal studies have provided further support for the importance of verbal working memory to reading. Performance on verbal working memory tasks has been used to successfully predict later reading achievement (Jorm, Share, Maclean, & Matthews, 1984; Mann, 1984; Mann & Liberman, 1984).

Evidence for a causal role of memory in reading performance has not been demonstrated, however. A consistent predictive relationship has not always been found between verbal working memory and later reading skill (see Pennington et al., 1991, for a discussion), and in one study, verbal working memory performance actually was found to be a consequence, rather than a cause, of reading ability (Bryant & Bradley, 1985).

Research suggests that the most efficient way to store verbal information is by using a phonological code (Baddeley & Hitch, 1974; Conrad, 1964). Because verbal working memory is a limited-capacity system, inefficient phonological encoding uses up more resources and results in less capacity for storage of information (Perfetti, 1985). Several lines of evidence support the view that the memory difficulties of poor readers are a result of problems either creating phonological representations or in using a phonological code to store information (Brady, 1986; Byrne & Shea, 1979; Cohen & Netley, 1981; Torgesen, 1988). Evidence from studies investigating the effects of phonological similarity on recall has been used as support for poor readers' inefficient use of a phonological code (Mann, Liberman, & Shankweiler, 1980; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). In these studies, recall differences between good and poor readers were greatest for stimuli that were phonologically distinct (e.g., nonrhyming words) (Brady, Shankweiler, & Mann, 1983; Liberman & Shankweiler, 1979; Torgesen, 1988). There have been inconsistencies in the phonological similarity research (see Brady, 1991, for a discussion), but other types of investigations have provided support for the role of phonological coding in verbal working memory performance. More consistent evidence for inefficient coding is that poor readers' memory deficits are confined to material that can be

represented linguistically. When stimuli to be remembered cannot be easily coded verbally, poor readers perform comparably to good readers (Katz, Shankweiler, & Liberman, 1981). Research has shown that good and poor readers differ significantly in their recall of digits (e.g., Cohen & Netley, 1981), letters (e.g., Shankweiler et al., 1979), syllables (e.g., Dreyer, 1989), words (e.g., Brady et al., 1983; Mann et al., 1980; Rapala & Brady, 1990; Vellutino & Scanlon, 1982), pseudowords (e.g., Brady, Mann & Schmidt, 1987; Brady, Poggie, & Rapala, 1989; Taylor, Lean, & Schwartz, 1989) and sentences (e.g., Mann et al., 1980; Mann et al., 1984). All these tasks share the requirement that in order to retain the material efficiently in working memory, phonological coding is needed. Analyses of errors on working memory tasks indicated that poor readers did attempt to use a phonological code (in contrast to a semantic or visual code), but they did so less well (Brady et al., 1987; Brady et al., 1983).

In general, good readers perform significantly better than poor readers on word-repetition tasks (Brady, 1986; Brady et al., 1989; Catts, 1986; Rapala & Brady, 1990; Snowling, Goulandris, Bowlby, & Howell, 1986). The inferior performance by poor readers on these tasks has been hypothesized to be a result of problems in initial encoding (Brady, 1986; Brady et al., 1989; Catts, 1986; Rapala & Brady, 1990). When good and poor readers have been compared on difficult encoding tasks, poor readers' performance has been affected to a greater degree than good readers' performance. For example, Brady et al. (1983) observed that poor readers made significantly more errors than good readers when listening to speech sounds in noise, although no group differences were found under clear listening conditions. In contrast, good and poor readers did not differ in their perception of nonspeech sounds.

Brady et al. (1983) concluded that poor readers are not impaired in all auditory perception skills, but have a specific difficulty encoding phonological information.

A later study also reported significantly lower scores for poor readers on a repetition task, but only for pseudowords (Snowling, Goulandris, Bowlby, & Howell, 1986). These authors proposed that poor readers have encoding deficits for nonlexical, but not for lexical, material. They also hypothesized that the two types of stimuli have different processing pathways (i.e., a direct [semantic] route for lexical items; a phonological route for nonlexical items). An alternative explanation is that the processing pathway for nonlexical information may be the same as for lexical information but may be harder to complete successfully because less information is available. That is, the sole input for a pseudoword is the phonological information arriving auditorily, whereas real words are no doubt facilitated by information stored in the lexicon. However, not all pseudowords are alike (Treiman, Goswami, & Bruck, 1990). Some pseudowords share vowel-consonant (VC) combinations with many words, whereas other pseudowords share their VC combinations with few or no real words. Lexical advantage may vary depending on the types of pseudowords used. The well-known word frequency effect, that more familiar words are perceived more easily (e.g., Brady et al., 1989), also indicates a range of lexical advantage, depending on how fully the word is understood and represented in the lexicon (Beck, Perfetti, & McKeown, 1982). A second study by Brady et al. (1989) noted inferior performance by poor readers with multisyllabic real words as well as with pseudowords, suggesting that poor readers' encoding processes are less efficient for all speech stimuli, not for nonlexical stimuli only.

Research investigating individual differences in reading ability indicates that poor readers generally do not perform as well as their normal-reading peers on verbal working memory tasks; however, poor readers' scores are not consistently lower than younger individuals who are reading at the same level (Brady, 1986; Jorm, 1983; Pennington et al., 1991; Stanovich, Nathan, & Zolman, 1988). The fact that poor readers' performance on verbal working memory tasks is similar to that of younger children suggests a developmental lag model of reading (Olson, Davidson, Kliegl, & Davies, 1984; Stanovich et al., 1988). That is, poor readers may not have a deficit per se in verbal working memory ability but may simply be progressing at a slower rate than their normal-reading peers. Two implications of this model are: (a) poor readers' abilities will eventually catch up to those of their normal-reading peers, and (b) the pattern of poor readers' skill acquisition is the same as that of normal readers. Because the developmental lag model suggests that the problems poor readers have represent pervasive cognitive difficulties rather than a specific deficit (Stanovich, 1986), an additional implication is that poor readers' word recognition skills cannot exceed their level of phonological skill (Rack, Snowling, & Olson, 1992). That is, the aspects of reading that require greater use of phonological processing (e.g., decoding novel words) will be particularly problematic for poor readers. Unless these poor readers are able to use compensatory strategies (e.g., acquisition of a large sight-word vocabulary), their reading skill may be restricted to the level of their phonological processing ability. Stanovich, Nathan, and Vala-Rossi (1986) suggest that the developmental lag model may be more appropriately used to describe children with mild reading problems rather than children who are dyslexic. That is, children with mild, but pervasive, cognitive difficulties may

not fit the specific cognitive deficit pattern characteristic of children who have been labeled as reading-disabled. Studies investigating the relationship between various cognitive abilities and reading achievement typically have used older subjects (Conners & Olson, 1990; Pennington, Van Orden, Smith, Green, & Haith, 1990) or have formed reading groups based on comprehension scores (Stanovich et al., 1988). The question arises whether young less-skilled readers who have been grouped according to decoding ability would show similar patterns of slow development. Reading clearly involves more than decoding, but a child who can speak and understand language has mastered all but the decoding component of reading (Gough & Hillinger, 1980). According to Pennington et al. (1991), there is widespread agreement that decoding rather than comprehension is the source of difficulty in reading disability. Paradoxically, even when reading by analogy, beginning readers benefit from the ability to phonologically recode words (Ehri & Robbins, 1992). Although the analogical relationship between known and unknown words is one route to word identification, understanding letter-sound correspondences and possessing segmenting and blending skills provides support for this route.

To summarize, although there is substantial evidence that verbal working memory performance is related to reading ability, the nature of this relationship is not clear. Poor readers generally do not perform as well as their normal-reading peers on verbal memory tasks; however, their scores are not consistently lower than younger children who are reading at the same level. Controversy remains as to whether verbal working memory contributes primarily to initial reading acquisition or whether it continues to be associated with comprehension. In addition, evidence suggests that inefficient

phonological encoding may be responsible for poor readers' impaired verbal working memory. To help clarify the association between phonological encoding and verbal memory, as well as the role verbal working memory plays in reading achievement, this study will examine the relationship of nonword reading, real word reading, and comprehension to performance on a variety of verbal working memory measures. In order to better understand the developmental nature of verbal memory factors in reading disability, differences between groups matched for age but differing in reading ability, and groups matched for reading ability but differing in age will be compared.

The Importance of Speech Production to Reading Ability

The verbal working memory deficits of poor readers may be indicative of phonological problems which are common to other phonological processes as well. For example, the ability to encode phonological information may be a necessary component of both speech production and verbal working memory, and inefficient phonological encoding may play a role in poor readers' inferior performance on speech production tasks, as well as on verbal working memory tasks. While there is growing evidence that poor readers' speech production is not as accurate as that of good readers, there is not as much support for a relationship between speed of speech production and reading ability. Before reviewing research examining the association between speech production and reading ability, evidence for a relationship between verbal working memory and speech production will be discussed.

The relationship between verbal working memory and speech production. Research suggests that verbal working memory and speech production are related abilities, although the exact nature of this relationship is

not clear (Wagner & Torgesen, 1987). Significant correlations have been found between how fast an individual speaks and how much information is retained in working memory. This relationship has been found for adults (Baddeley, Thomson, & Buchanan, 1975; Hoosain, 1982) as well as developmentally (Case, Kurland, & Goldberg, 1982; Hulme, Thomson, Muir, & Lawrence, 1984; Rapala & Brady, 1990). Significant correlations also have been found between memory performance and accuracy of speech production for good and poor readers (Rapala & Brady, 1990). As noted, the nature of the relationship between verbal working memory and speech production remains to be determined. A parsimonious explanation is that a unitary deficit is responsible for impairments in both verbal working memory and speech production (Wagner et al., 1987). However, research investigating whether various phonological processes load on a single factor has not provided a definitive answer (Brady, 1991; Pennington et al., 1991). A lack of consistency in the measures used and the age groups studied has made drawing conclusions difficult. If verbal working memory and speech production are not the result of a unitary deficit, then the two abilities may be mediated by the same process (Ellis, 1980; Jorm & Share, 1983; Pennington et al., 1991). According to Ellis, this process is a response buffer which is primarily involved in the efficient programming of speech production but which also may be involved when immediate recall is required. An alternative perspective that may provide a more tenable explanation suggests that deficiencies in encoding phonological information may underlie problems in both verbal working memory and speech production (Catts, 1989b; Jorm & Share, 1983; Torgesen, 1985). According to Jorm and Share, the more efficiently information is encoded, the more quickly it can be retrieved. In

addition, phonological representations may guide overt productions (Katz, 1986). For poor readers, the ability to encode information phonologically may be defective. Speech production tasks, because they are less complex (i.e., minimum storage requirement), may be purer measures of the shared processing component.

Support for an association between speech production and memory was found in a study with 5- to 9-year-old speech-disordered children (Locke & Scott, 1979). These children had significantly lower scores than their normal-speaking peers on short-term memory tasks and provided less evidence for use of phonological encoding. Locke and Scott used phonetic mediation, which is subjects' relative recall of rhyming and nonrhyming words, as their measure of phonological encoding. The speech-disordered children provided less evidence of phonetic mediation than their normal-speaking peers. Concordant error patterns by adults on working memory tasks and in speech production also have been found (Ellis, 1979). Ellis has proposed that these recall and speech errors are the same type of error occurring in two different contexts.

As noted, correlations between speech rate and memory have been found in studies with adults, as well as in developmental studies (Baddeley et al., 1975; Case et al., 1982; Hulme et al., 1984; Hoosain, 1982; Rapala & Brady, 1990). In a serial recall task, adults were able to recall more short than long words (Baddeley et al., 1975). The spoken duration of the words was a more salient characteristic of the words than the number of phonemes or syllables they contained. That is, the adults recalled as much as they could say in a given amount of time, which in this study was approximately 2 seconds. Hoosain (1982) also found support for a relationship between

verbal working memory and speech production. He reported a negative correlation between adults' naming speed for digits and their recall on a digit span task.

Results from developmental studies have supported the view that speech production processes are related to memory. A strong correlation was found between how rapidly 3- to 6-year-old children could repeat words and the size of their memory spans (Case et al., 1982). Older children repeated words more quickly and remembered more words on a recall task. The investigators concluded that as the efficiency of encoding and retrieval operations in verbal working memory increased with development, more memory resources were available for storage. Case et al. provided support for this conclusion by controlling the speed with which adults could repeat words. Repetition speed was reduced to that of a six-year-old by having the adults repeat pseudowords. It was noteworthy that the adults' memory spans also dropped to that of six-year-olds. That is, memory span could be predicted from the speed of repeating pseudowords.

A related study found a linear relationship between speaking rate and recall performance for subjects ranging in age from 4 to adult (Hulme et al., 1984). Hulme et al. concluded that increases in speech rate with age reflected increases in the speed of articulation of individual words rather than a decrease in pause time between words. Younger children did not pause longer between words in continuous speech. Further support for the relationship between speech rate and verbal working memory comes from an investigation with 4-, 6-, and 8-year-olds (Rapala & Brady, 1990). In this study, older children were able to repeat verbal stimuli more rapidly and more

accurately than younger children and had longer memory spans. This relationship remained even after age was removed as a factor.

Speed of speech production. The fact that speech rate is related to memory and that memory is related to reading ability leads to the supposition that speech rate may also be related to reading. The evidence supporting this view is equivocal, however. Dyslexic college students were slower at repeating phrases than their normal-reading peers (Catts, 1989a). Group differences were most evident with phonologically complex phrases (e.g., blue plaid pants). In contrast, studies with younger subjects have not found a relationship between speed of speech production and reading. Rapala and Brady (1990) compared the performance of third-grade good and poor readers on speech production and memory measures. They found that the groups differed significantly on verbal memory performance and on accuracy of difficult-to-say disyllabic pseudoword production (e.g., seeshee). However, differences were not found for speed of speech production. Similarly, in Brady et al.'s (1989) study with third-graders, poor readers were as fast as good readers at repeating multisyllabic real words and single-syllable pseudowords, but were less accurate.

Results from a study using third-, fifth-, and seventh-grade children matched for comprehension ability supported a developmental lag model of reading disability (Stanovich et al., 1988). The cognitive profiles for the three groups on a variety of reading, memory, and speech production measures were similar enough for Stanovich et al. to conclude that the less-skilled readers were simply progressing at a slower rate than their normal-reading peers. Although significant differences between groups were found, the investigators concluded that speed of articulation was strongly age-dependent

but not related to reading ability. Stanovich et al. reached this conclusion because articulation performance was highly correlated with chronological age but was not correlated with reading comprehension. That is, there was a stronger association between speed of articulation and chronological age than between speed of articulation and reading ability.

The relationship between speed and accuracy of speech production to reading ability needs to be investigated further. Speed of speech production may be related to reading ability if decoding, rather than comprehension, is used as the measure of reading level; and speed of production measures may need to be more sensitive in order to detect group differences. Alternatively, accuracy of speech production, rather than speed of production, may have a more robust relationship with reading ability.

Accuracy of speech production. Research indicates that poor readers are more likely to misarticulate than good readers (Brady et al., 1989; Catts, 1986, 1989a; Ellis, 1980; Kamhi, Catts, Mauer, Apel, & Gentry, 1988; Rapala & Brady, 1990). Clinical reports indicate that reading-disabled individuals often have speech production problems (Blalock, 1982; Chasty, 1985; Klein, 1985). According to Chasty, these problems may arise in three areas: (a) difficulty with production of particular sounds, (b) difficulty with the consistent sequencing of sounds, especially in multisyllabic words, and (c) difficulty expressing ideas coherently in a sentence. Other evidence from clinical observations indicates that poor readers may not have difficulty with spontaneous speech, but articulation errors may be evident when individuals are asked to repeat multisyllabic words or reproduce low-probability sentences (Klein, 1985).

Research investigating the relationship between speech production and reading ability also has been conducted. From a methodological standpoint, speech production tasks may provide the best measure of phonological encoding (Kamhi & Catts, 1986; Taylor et al., 1989). According to Taylor et al., these tasks are not as demanding as memory tasks and require a minimal response, making them appropriate for young children. Yet, as Kamhi and Catts propose, the successful repetition of pseudowords necessitates that the phonetic information inherent in the word be correctly perceived and accurately represented in memory. Because the words are not real words, it is not possible to rely on previously stored lexical information. As noted previously, however, some pseudowords are more similar to real words than others (Treiman et al., 1990). It should be noted that word-repetition tasks have been variously described as measures of speech perception, of verbal working memory, and of speech production, depending on which task requirements (e.g., encoding, storage, output) were the focus of the investigation (e.g., Brady et al., 1983; Gathercole & Baddeley, 1990; Taylor et al., 1989).

Speech production tasks also differentiate good and poor readers over a wide age range (Catts, 1986; Snowling et al., 1986; Taylor et al., 1989). Research using reading-group comparisons has found that poor or disabled readers were less accurate than good readers when repeating words, pseudowords, and phrases (Apthorp, 1988; Brady et al., 1989; Kamhi & Catts, 1986; Kamhi, Catts, & Mauer, 1990; Kamhi et al., 1988; Snowling, 1981; Taylor et al., 1989). A study with third-graders found that poor readers were not as accurate as good readers at repeating multisyllabic real words (e.g., badminton and gladiators) and pseudowords (e.g., chife and blakes) (Brady et

al., 1989). Similar results were found in an investigation with older subjects. Twelve- to 17-year-old disabled readers made more speech production errors than their normal-reading peers when asked to repeat both multisyllabic words and short phrases (Catts, 1986). A moderate to high correlation between speech production error rate and reading ability was also found. Catts concluded that disabled readers' error patterns suggested difficulties in encoding phonological information in memory. In contrast to Snowling's proposal that poor readers' deficits on word repetition tasks are restricted to nonlexical information, the results of the Brady et al. and Catts studies indicate that significant reading group differences are evident for the repetition of lexical information as well.

Summary. Correlations between speech rate and memory have been found for both adults and children, and there are indications that speech rate may be related to chronological age. Evidence for a link between speed of speech production and reading skill is weak, however. On the other hand, both clinical and research evidence suggests that poor readers are more likely to misarticulate than good readers. Poor readers have been found to be less accurate when repeating words, pseudowords, and phrases. Reading-group differences were most dramatic under complex conditions. Yet further work is needed to confirm that poor readers are not slower at the phonological processing entailed in speech production but are less accurate. In addition, further research is needed to investigate whether these phonological deficits are evident even when poor readers are compared with younger reading-age control subjects.

General Summary and Hypotheses

Prior research indicates that verbal working memory and speech production are importantly associated with reading achievement. Poor readers generally do not perform as well as good readers on tasks measuring these processing abilities; however, their scores are not consistently lower than younger children reading at the same level. One question that arises is whether less-skilled readers are simply progressing at a slower rate than their normal-reading peers or whether they have noteworthy phonological processing deficits. Are their cognitive profiles similar to those of younger children reading at the same level, or do less-skilled readers have deficits even when compared to these younger children?

A second question concerns the nature of the relationship of verbal working memory and speech production to reading ability. Verbal working memory deficits have been found to account for about 10% of the variance in reading ability; however, reading is a multifaceted process. Is the relationship between verbal memory and reading the same no matter how reading is defined, or is it differentially related to nonword reading, real word reading, and comprehension ability? In a similar vein, is the relationship between speech production and reading affected by how reading is defined?

Although verbal working memory and speech production seem to involve some of the same phonological processes (i.e., forming and outputting phonological representations), the nature of the relationship between these constructs has not been firmly established. Evidence suggests that inefficient phonological encoding may contribute to inferior performance on tasks measuring both processing abilities. The question arises whether measures designed to assess the two processes load on a single factor, and whether

speech production speed tasks and speech production accuracy tasks are similarly related to verbal working memory.

An additional area of interest involves the relationship of speech production speed and accuracy tasks to reading achievement and development. Is accuracy of production more closely associated with reading achievement than with chronological age? Is speed of production more strongly related to chronological age than to reading level?

In the present study, the relationship between reading ability, verbal working memory, accuracy of speech production, and speed of speech production were examined. Three groups of children were tested: third-grade skilled readers, third-grade less-skilled readers, and second-grade children who were reading at the same level as the third-grade less-skilled readers. In addition to reading and cognitive ability measures, three verbal working memory tasks, two accuracy of speech production tasks, and three speed of speech production tasks were administered to these subjects.

Because two of the three memory measures and the two accuracy of speech production tasks used in this study rely heavily on phonological encoding, it was hypothesized that the less-skilled readers' scores on these tasks would not only be significantly lower than those of the skilled third-grade readers but also would be significantly lower than those of the second-grade readers. It was also hypothesized that the verbal memory and accuracy of speech production measures would load on a single factor. In contrast, a weaker association was predicted between measures assessing speed of speech production and verbal working memory.

Based on the fact that the children in this study are in the early stages of reading acquisition, it was hypothesized that performance on nonword

reading, real word reading, and comprehension measures would be significantly correlated. It was hypothesized further that performance on the verbal working memory and accuracy of speech production tasks would be significantly correlated with all three components of reading.

In line with the evidence from previous research which suggests that speech rate is age-related but not reading-related, it was hypothesized that in the current study significant differences between skilled and less-skilled readers would not be found on the speed of speech production measures. It was also hypothesized that both third-grade reading groups would perform significantly faster than the younger readers on these measures.

To summarize, predictions were as follows:

1) The less-skilled readers' scores on the verbal working memory and accuracy of speech production measures will be significantly lower than both the skilled third-grade and second-grade readers.

2) Performance on nonword reading, real word reading, and comprehension will be significantly correlated with each other, as well as with performance on the verbal working memory and accuracy of speech production measures.

3) The accuracy of speech production measures will be more strongly associated than the speed of speech production measures with the verbal working memory tasks. In addition, the verbal memory and speech production accuracy measures will load on one factor.

4) There will be no significant differences between the two third-grade groups on the speed of speech production measures; however, the second-grade readers will be significantly slower than either of the third-grade groups on these measures.

CHAPTER II.

METHOD

Subjects

Ninety children (47 girls and 43 boys) from two school districts in Rhode Island were selected to participate in the study. The districts were urban/suburban in nature and the population of the districts represented a mix of socioeconomic and educational backgrounds. The 90 children were assigned to one of three groups based on grade level and reading ability. Reading level for the three groups was determined on the basis of scores on the Word Attack subtest of the Woodcock Reading Mastery Tests Revised (WRMT-R), Form G (Woodcock, 1987). The first group of children were third-graders who had below-average reading skills for their grade (mean grade equivalent = 2.1). It should be noted that the reading level for these children is based on a reading ability/grade comparison rather than on a reading ability/IQ basis (Stanovich et al., 1986). That is, although these children are reading at a level below what is expected for their grade, they do not all fit the psychometric criteria currently used to be labeled as reading-disabled. The second group of children were third-graders with above-average reading skills for their grade (mean grade equivalent = 11.1). The third group of children were second-graders who were matched for reading ability with the below-average third-grade readers (mean grade equivalent = 2.1).

In addition to grade level and decoding ability, the following criteria were used for selection:

1. Age. In order to limit age differences between the below-average and above-average readers, third-grade children were selected only if their ages

were between 8 years 2 months and 9 years 4 months on December 31, 1991. A t-test revealed that there was no significant age difference between the two third-grade groups, $t(58) = 1.46$, $p = .15$. Second-graders were selected only if their ages were between 7 years 0 months and 8 years 1 month on December 31, 1991. This selection process resulted in a group of readers who were one year younger than the less-skilled third-grade readers.

2. Cognitive functioning. In order to limit cognitive differences between groups, subjects' standard scores on both the Peabody Picture Vocabulary Test-Revised (PPVT-R) (Dunn & Dunn, 1981) and the Block Design subtest of the Wechsler Intelligence Scale for Children-Revised (WISC-R) (Wechsler, 1974) had to be between 80 and 125.

3. Hearing. Most of the experimental tasks were aural-dependent. For this reason, children with hearing impairments were excluded from the study. Hearing acuity was determined from the results of school-administered hearing screenings, which were conducted just prior to testing.

4. Articulation. Several speech production measures were used in this study; therefore, children who had obvious articulation disorders or who were receiving services for speech disorders were not included.

5. English as the primary language. Because this study examined the relationship between reading and language ability, an attempt was made to control for the effects of background language experience. Students participating in "Intense Language Development" classes were not included in the study. The purpose of these classes is to provide concentrated language training to bilingual children. Children in regular classes were asked what languages were spoken at home and were included only if the primary language of the home was English.

6. Additional criteria. Attentional factors may impact on memory performance; therefore, children who had been diagnosed as having Attention Deficit Hyperactivity Disorder (ADHD) were not included. Children also were excluded if they had been identified by school officials as having emotional or behavioral problems or physical handicaps.

Descriptive statistics for age, cognitive ability, and reading level are summarized in Table 1.

Measures

The instruments used were the PPVT-R (Dunn & Dunn, 1981), the Block Design subtest of the WISC-R (Wechsler, 1974), the WRMT-R (Woodcock, 1987), three verbal working memory tasks, and three speech production tasks.

Cognitive Functioning Measures

Both verbal and nonverbal cognitive ability were assessed.

1. Verbal cognitive ability

The PPVT-R (Dunn & Dunn, 1981) was used as the measure of verbal cognitive ability. This measure assessed each subject's receptive knowledge of English vocabulary. Subjects were asked to point to the one picture out of four that best represented the word spoken by the examiner. The PPVT-R has a median internal consistency reliability of .75 and a median delayed test-retest reliability coefficient of .78 (N = 962). The median correlation between the PPVT-R and the WISC-R is .68. The PPVT-R was discontinued after six out of eight consecutive items were failed. The raw score equaled the number of correctly identified words. Raw scores were converted to standard scores

(mean = 100; standard deviation = 15).

2. Nonverbal cognitive ability

The Block Design subtest of the Wechsler Intelligence Scale for Children-Revised (WISC-R) was used as the measure of nonverbal cognitive functioning

Table 1.

Means, Standard Deviations, and Ranges for Age, Cognitive Ability, and Reading for the Third-grade Less-skilled, Third-grade Skilled, and Grade 2 Readers

	Third-grade Less-skilled Readers	Third-grade Skilled Readers	Grade 2 Readers
Age			
Mean (SD)	8.8 (3.9)	8.7 (3.1)	7.7 (4.1)
Range	8.2 - 9.3	8.3 - 9.0	7.0 - 8.1
PPVT-R			
Mean (SD)	100.5 (10.8)	103.1 (10.5)	102.8 (9.8)
Range	80 - 123	83 - 123	86 - 122
Block Design			
Mean (SD)	102.2 (10.7)	105.7 (9.0)	102.7 (11.7)
Range	80 - 125	80 - 120	80 - 125
Word Attack			
Mean (SD)	2.1 (.48)	11.1 (5.1)	2.1 (.45)
Range	1.2 - 2.9	4.2 - 16.9	1.2 - 2.9
Word Identification			
Mean (SD)	3.0 (.50)	5.0 (.89)	2.8 (.46)
Range	2.1 - 4.0	3.6 - 7.1	2.0 - 4.1
Comprehension			
Mean (SD)	3.3 (.80)	4.5 (1.5)	3.0 (.41)
Range	2.0 - 6.4	3.0 - 7.3	1.9 - 3.5

(Wechsler, 1974). Subjects were asked to assemble red and white blocks in a pattern that matched a displayed design. This subtest has a median internal consistency reliability of .85. The median correlation between Block Design and the Performance Scale of the WISC-R is .68. The Block Design subtest was discontinued after the subject failed to reproduce two consecutive designs. The raw score equaled the number of correctly produced designs. Raw scores were converted to standard scores (mean = 100; standard deviation = 15).

Analyses of variance (ANOVAs) were run to ensure that the three groups did not differ significantly on either the PPVT-R or on the Block Design subtest of the WISC-R. The results of these analyses are summarized in Table 2.

Table 2.

ANOVA Summary Table for Cognitive Ability Scores by Group

Source of variation	Sum of squares	df	Mean square	F	Sig. of F
PPVT-R:					
Group	124.689	2	62.344	.582	.56
Residual	9324.967	87	107.184		
Block Design:					
Group	215.000	2	107.500	.973	.38
Residual	9607.500	87	110.431		

Reading Measures

The Word Attack, Word Identification, and Passage Comprehension subtests of the WRMT-R, Form G (Woodcock, 1987) were used to assess reading ability. The WRMT-R is a comprehensive, individually administered battery of tests designed to evaluate various aspects of reading ability. The Word Attack subtest, which was used to select subjects for participation in the study, measures a child's decoding ability by requiring the child to read phonetically regular nonsense words (e.g., raff, pog). This subtest was used for selection because it measures a child's ability to apply phonic and structural analysis skills to reading rather than simply relying on the recognition of familiar words.¹ The split-half reliability coefficient for the Word Attack subtest for Grade 3 is .91 ($N = 581$), and the subtest correlates .85 with the WRMT-R total reading score. The Word Attack subtest is discontinued after six consecutive items are failed. The child's raw score equaled the number of items read correctly. Raw scores were then converted to grade equivalent scores using the tables provided with the test. A grade equivalent score reflects the child's performance in terms of the grade level in the norming sample for which the median score is the same as the child's score.

The Word Identification and Passage Comprehension subtests were also administered. Word Identification requires the child to read familiar words, and Passage Comprehension requires a child to read a passage and to orally fill in a blank with the most appropriate word. The split-half reliability coefficients for the two subtests for Grade 3 are: .97 (Word Identification) and

¹ Currently, a number of people are speculating that difficulty reading nonwords is the most salient characteristic of poor readers (e.g., Felton & Wood, 1992; Rack et al., 1992). It should be noted, however, that because reading is a complex process, the selection criteria used in this study may have excluded some individuals with inconsistent reading profiles. For example, a third-grader with average nonword reading skills but poor comprehension ability would not have been selected as a less-skilled reader.

.92 (Passage Comprehension). Word Identification and Passage Comprehension correlate .93 and .84, respectively, with the WRMT-R total reading score.

A series of analyses were conducted to examine group differences in reading level, with the following results:

1. The results of Hotelling's T^2 indicated that there was a significant difference between the two third-grade groups on the three reading measures, $F(2, 58) = 49.38, p < .001$. Follow-up t-tests indicated that the difference was significant for each of the three measures: (a) Word Attack, $t(58) = -9.70, p < .001$; (b) Word Identification, $t(58) = -11.01, p < .001$; and Passage Comprehension, $t(58) = -3.77, p < .001$.

2. The results of Hotelling's T^2 indicated that there was a significant difference between the less-skilled third-grade readers and the second graders on the three reading measures, $F(2, 58) = 88.44, p < .001$. Follow-up t-tests indicated that the difference was not significant for Word Attack, $t(58) = .20, p = .85$, or for Word Identification, $t(58) = 1.32, p = .19$, but was significant for Passage Comprehension, $t(58) = 2.30, p = .025$. The second-graders' scores were not as high as the less-skilled third-graders' scores on the Passage Comprehension measure. This unexpected difference was attributed to the fact that the third-graders had had more contextual reading experience (e.g., science and social studies textbooks); and, in addition, had had more experience than the second-graders in developing strategies to overcome nonword and real word reading weaknesses. As mentioned earlier, scores on the Word Attack subtest were used for group placement.

Verbal Working Memory Measures

In order to assess each child's ability to remember verbally encoded information, three memory tasks were administered. It should be noted that these tasks were not standardized tests but were research measures designed to tap specific components of memory (i.e., storage, processing). The measures used in this study were either used in earlier studies (i.e., pseudoword repetition) or were adaptations of tasks used in earlier studies (i.e., word span, concurrent processing). Reliability for these measures was assessed with an alpha coefficient. At the completion of the testing sessions, tape recordings of subjects' responses were used to rescore the protocols for the three memory measures. Interrater reliability scores were obtained in this way.

1. Word span

Each subject's ability to recall and sequence sets of unrelated but meaningful words was assessed with a memory task adapted from Rapala and Brady (1990). This task was included to provide a measure of storage capacity. The task consisted of 13 lists of monosyllabic concrete nouns (e.g., rose, plate) which subjects were asked to recall in the order presented. There were three three-word lists, five four-word lists, and five five-word lists. The word lists were recorded on audiotape and were presented to the children through headphones. The words in each list were presented at one-second intervals, and the tape was stopped after each list to enable the subject as much time as necessary to respond. The children were instructed to recall the words in the order they were heard as soon as presentation of the list was completed. They were also instructed to say "blank" for any word that could

not be recalled. Each subject's score on this task was the number of words recalled in correct serial position. The subject's responses were written on the protocol by the examiner and were also tape recorded to ensure scoring accuracy and to enable review by a second scorer. See Appendix A for a copy of the Word Span protocol.

The internal reliability estimate on this measure for this sample was $r = .73$ (Cronbach's alpha) ($N = 90$). It should be noted that this reliability may be attenuated because the word-span memory measure gradually increased in difficulty and was therefore not consistent throughout. That is, earlier task items were easier to remember than later items. Interrater reliability for this measure was $r = .99$.

2. Memory span with concurrent processing

In order to assess each subject's ability to remember a series of words while engaged in another processing task, an adaptation of Daneman and Carpenter's (1980) Reading Span Test was administered. Subjects used headphones to listen to a series of unrelated sentences which had been recorded on audiotape. As soon as each sentence was read, they decided whether the sentence was true or false. After the complete series of sentences had been read, subjects recalled the last word of each sentence in the series. Each sentence ended in a different word.

The content of the sentences was determined based on review of second- and third-grade curricular material. Material was chosen that would be conceptually easy for second- and third-graders to understand. The sentences ranged in length from 4 to 8 words, with a mean length of 5.78 words. Each sentence contained 6 to 9 syllables, with a mean length of 7.17

syllables. The last word of each sentence was either a one- or two-syllable word. There were 12 sets of sentences, arranged as follows: a) four sets of two sentences, b) four sets of three sentences, and c) four sets of four sentences. The sentences were recorded with a three-second interval between each of the sentences within the set. A tone sounded three seconds after the last sentence in each set. The children knew at the outset how many sentences would be in each set and that the tone was their signal to recall the last word of each sentence in the set. The words did not need to be recalled in the order presented. The child's score was the total number of words correctly recalled. Responses were written on the protocol by the examiner and were also recorded on audiotape. Because the purpose of the true/false aspect of the task was to create a processing component, the accuracy of the answers was not considered important, and this information was not included in the children's scores. See Appendix B for a copy of the Memory Span with Concurrent Processing protocol.

This task was piloted with a group of second- and third-graders who had been screened but not selected for one of the three groups. These children were average readers with average cognitive ability. The purpose of piloting the task was to determine whether the directions were easily understood and whether the material in the sentences was appropriate for this age group. The thirty children in the pilot group had no difficulty with the task, and it was included as originally constructed in the study.

The internal reliability estimate on this measure for this sample was $r = .74$ (Cronbach's alpha) ($N = 90$). As noted with the word-span memory measure, the reliability for this measure also may be attenuated because the task gradually increased in difficulty, with earlier items being easier to recall than

later items. Interrater reliability for the Memory Span with Concurrent Processing measure was $r = .99$.

3. Pseudoword repetition

This measure was given to assess the ability to store phonological representations. The Pseudoword Repetition task consisted of 28 pseudowords, each of which was derived from a polysyllabic word (Taylor et al., 1989). The words ranged from three to six syllables in length, with a mean length of 4.18 syllables. Taylor et al. derived the pseudowords from real words by means of phoneme substitutions. In the Taylor et al. study, the inter-item reliability was .87, and the test-retest reliability was .89.

The words were tape recorded and presented to the children through headphones in the order they appear on the protocol (see Appendix C for a copy of the Pseudoword Repetition Task protocol). The children were told they would hear a list of nonsense words presented one at a time. They were asked to repeat each word as soon as it was heard. The tape was stopped after each word to allow as much time as needed to repeat the word. Responses were written on the protocol by the examiner and were also tape recorded.

The child's score on this task was the total number of pseudowords presented (i.e., 28) minus the number of errors. A response was scored as correct if all the phonetic components of the word were in the correct sequence. Errors included phonetic omissions, additions, substitutions, and

transpositions.² Each response was scored for multiple error types, but a given error type was scored only once per attempt. Scoring was based on that of the Taylor et al. study.

For this sample, the internal reliability estimate was $r = .82$ (Cronbach's alpha) ($N = 90$). Interrater reliability was $r = .99$.

Speech Production Measures

In order to assess each subject's ability to produce words quickly and accurately, three speech production tasks were administered. It should be noted that the tasks described below were not standardized tests but were research measures designed to tap specific components of speech production (i.e., accuracy, speed). The tasks used in this study were either used in earlier studies (i.e., tongue twister) or were adaptations of tasks used in earlier studies (i.e., word-pair repetition, rapid naming). Reliability for these measures was assessed with either an alpha coefficient or a split-half procedure. Tape recordings of subjects' responses were used to rescore the protocols for the three speech production measures. Interrater reliability scores were obtained in this way.

1. Word-pair repetition

A task adapted from Hulme et al. (1984) was used to assess each child's ability to rapidly produce familiar words. The stimuli were word pairs which were combinations of either monosyllabic or multisyllabic concrete nouns

² Errors were scored as follows. An omission was a phoneme deleted from a word, and an addition was a phoneme added to a word. A substitution occurred if one phoneme was replaced by a different phoneme, whereas a transposition was scored if two phonemes in a word were interchanged. For example, if "panamity" became "pamamity," a substitution was scored; however, if "panamity" became "pamanity," the error was considered a transposition.

(e.g., car/hat; banana/elephant). The task consisted of six monosyllabic word-pairs and four multisyllabic word pairs. Half the word pairs were constructed to encourage phonological errors. For example key/cloud when said rapidly often results in kley/coud. The word pairs were presented orally by the examiner to the children one at a time. The children were asked to repeat each word pair once to ensure that it had been perceived correctly. If a child mispronounced a word pair, corrective feedback was given, and the child was asked to say the word pair again. This procedure was followed until the child correctly repeated the word pair. The children were then told to repeat the word pair as rapidly as possible without making mistakes until told to stop. The examiner started the stopwatch at the beginning of the first repetition and stopped the watch after the 10th repetition. To ensure a continuous production of speech and to minimize the potential effect of subjects anticipating the number of repetitions being counted, the children were told to stop at some point between the 11th and 13th repetitions. This point varied randomly with each word pair; that is, either the 11th, 12th, or 13th repetition was chosen as the stopping point. See Appendix D for a copy of the Word-pair Repetition protocol.

This task was scored for both accuracy and speed. The accuracy score was the total number of errors for the 10 word pairs. Errors included phonetic omissions, additions, substitutions, and transpositions. The speed score was the average length of time it took to repeat the word pairs. Only word pairs that were repeated without errors were included in the speed score calculation. For the 90 subjects, an average of seven word pairs were repeated without error; however, on average, the skilled third-grade readers

repeated more word pairs without error than the other two groups (see Table 3).

Table 3.

Means, Standard Deviations, and Ranges for Number of Word-pairs and Tongue Twisters Repeated Accurately for the Third-grade Less-skilled, Third-grade Skilled, and Grade 2 Readers

	Third-grade Less-skilled Readers	Third-grade Skilled Readers	Grade 2 Readers
Word-pairs			
Mean (SD)	7.1 (1.4)	7.9 (1.4)	6.1 (1.6)
Range	4 - 9	5 - 10	2 - 9
Tongue Twisters			
Mean (SD)	6.1 (1.8)	7.5 (1.5)	7.5 (1.6)
Range	2 - 9	5 - 10	4 - 10

Responses were written on the protocol by the examiner and were also tape recorded. The tape recorded responses were analyzed on a Macintosh computer to determine the speed score. This process involved the use of a MacRecorder and Sound-Edit software. The subjects' recorded responses were played into the MacRecorder and were then displayed on the computer screen. The beginning and end of each response could then be precisely determined and timed.

The internal reliability estimate on this measure for this sample was $r = .47$ (Cronbach's alpha) ($N = 90$). Interrater reliability for the Word-pair Repetition measure was $r = .99$.

2. Tongue twisters

The tongue twister task was used to assess each child's ability to rapidly produce nonsense words (Rapala and Brady, 1990). The task consisted of 10 disyllabic pseudowords which had a tongue-twister-like quality (e.g., seeshee). The two-syllable length was used because the age groups included in this study typically are able to recall word strings of this length (Dempster, 1981; Rapala & Brady, 1990). In the Rapala and Brady study, the split-half reliability for speed was .95 and for accuracy, .71. The pseudowords were pronounced in a manner that minimized their wordlikeness. For example, the stress for "seeshee" was on the first syllable.

The pseudowords were presented orally by the examiner to the children one at a time. The children were asked to repeat each pseudoword once to ensure that it had been encoded correctly. If a child mispronounced a word, corrective feedback was given, and the child was asked to say the word again. This procedure was followed until the child correctly repeated the word. The children were then told to repeat the pseudoword as rapidly as possible without making mistakes until told to stop. The examiner started the stopwatch at the beginning of the first repetition and stopped the watch after the 10th repetition. For the same reasons noted with the word-pair repetition task, the children were told to stop at some point between the 11th and 13th repetitions. This point varied from trial to trial. See Appendix E for a copy of the Tongue Twister Task protocol.

This task was scored for both accuracy and speed. The accuracy score was the total number of errors produced during repetition of the 10 tongue twisters. Errors included phonetic omissions, additions, substitutions, and transpositions. The speed score was the average length of time it took to

repeat the tongue twisters. Only tongue twisters that were repeated without errors were included in the speed score calculation. For all 90 subjects, an average of seven tongue twisters were repeated correctly. The less-skilled third-graders produced on average fewer correct responses than either of the other two groups (see Table 3). Responses were written on the protocol by the examiner and were also tape recorded. A Macintosh computer was used to determine the speed score, using the same procedure described for the Word-pair Repetition task.

The equal length Spearman-Brown reliability coefficient for accuracy for this sample was $r = .65$ ($N = 90$). Interrater reliability for accuracy on the Tongue Twister Task was $r = .99$. A reliability coefficient for time on this task could not be calculated because only tongue twisters that were repeated without errors were used. This technique resulted in a varying number of scores from subject to subject.

3. Rapid Naming

This measure was given to assess each child's ability to rapidly name pictured objects. A rapid naming task is sometimes used to measure lexical access. However, in this study minimal retrieval demands were made because the names of the objects were well primed. Therefore, rather than as a measure of lexical access, the task was used to assess the speed with which a child can formulate and articulate familiar words. A visual display was used in order to minimize the demands on memory. The pictures were 45 black and white line drawings of familiar objects arranged in five rows of nine pictures each. Five different drawings were used with each drawing being used nine times. The five drawings are displayed in Appendix F. The

drawings were randomly arranged but the same object did not appear twice in succession. To ensure the use of a specific label for each item, the drawings were named by the examiner and the children were asked to repeat the names. See Appendix G for a copy of the Rapid Naming protocol. To check that appropriate labels were being used, the children named each drawing in the first row prior to beginning the actual task. The children were then told to name all the drawings on the page as rapidly as possible without making mistakes. They were instructed to begin with the drawing in the upper left corner and to name all the drawings in the row without skipping any. When they finished naming the drawings in the first row, they were instructed to go to the next row and then the next row until they finished the page. The child's score was the time to name all 45 objects. The examiner started the stopwatch as soon as the child began naming the objects and stopped the watch as soon as the child named the last object. Responses were also tape recorded. A Macintosh computer was used to determine the speed score. Accuracy scores for this measure were not used because very few children made errors when naming the drawings.

Procedure

Over 450 children were given informed consent forms. Two hundred sixty-six children returned signed forms giving permission for testing. Each child received a pencil when a signed consent form was returned (either approving or denying participation). The PPVT-R, the Block Design subtest of the WISC-R, and the Word Attack and Word Identification subtests of the WRMT-R were individually administered to each of these children. Each test

was administered in the standardized manner recommended in the manuals. The testing session lasted approximately 30 minutes.

The 90 children who were selected for the study participated in two additional testing sessions. Stickers were given at the end of each of the three testing sessions. The memory and speech production tasks, as well as the Passage Comprehension measure, were individually administered during these two sessions. The tasks were divided into two sets. Set A included the following tasks: (a) word span, (b) pseudoword repetition, and (c) word-pair repetition. Set B included the following tasks: (a) memory span with concurrent processing, (b) tongue twisters, (c) Passage Comprehension, and (d) rapid naming. The order of tasks within each set was chosen to avoid presenting difficult tasks last and to provide variation in task demands. To control for order effects, presentation of the sets was counterbalanced. Approximately half the subjects in each reading group were tested on Set A in the second session and on Set B in the third session. For the other half of the subjects, the sets were reversed. All the measures were administered in a standardized manner. Each session lasted 30-40 minutes. The experimenter tested approximately two-thirds of each group; a trained research assistant tested the remaining one-third of each group.

CHAPTER III.

RESULTS

After descriptive statistics were generated and analyzed to determine whether assumptions were met, the following analyses were performed on the data from the 90 children selected to participate in the study:

1. Pearson correlations
2. Principal Components Analysis (PCA)
3. Multivariate Analysis of Variance (MANOVA)
4. follow-up analyses
5. Multiple Regression (MR) analyses.

Descriptive Statistics

Descriptive statistics for the verbal working memory and speech production variables were examined for violations of assumptions. For several of the variables (i.e., accuracy and time for Word-pair Repetition and accuracy and time for Tongue Twisters), the data were slightly non-normal. In addition, the Tongue Twister (Accuracy) task violated the assumption of homogeneity of variance. Normality was achieved for the Tongue Twister accuracy data with a square root transformation. This transformation also alleviated the homogeneity of variance problem for this variable. Square root transformations also significantly reduced the non-normality of both the Word-pair Repetition accuracy and time data. Normality was achieved for the Tongue Twister time data with a Log10 transformation. Transformed scores for these four variables were used in all further analyses. Descriptive statistics for the three groups are summarized in Table 4.

Table 4.

Means, Standard Deviations, and Ranges for Verbal Working Memory and Speech Production Scores for the Third-grade Less-skilled, Third-grade Skilled, and Grade 2 Readers

	Third-grade Less-skilled Readers	Third-grade Skilled Readers	Grade 2 Readers
Word Span			
Mean (SD)	29.8 (9.7)	36.5 (8.0)	33.8 (8.9)
Range	17 - 53	23 - 51	21 - 50
Concurrent Processing			
Mean (SD)	18.2 (4.2)	21.9 (3.6)	17.53 (4.4)
Range	8 - 26	11 - 28	7 - 26
Pseudoword Repetition			
Mean (SD)	17.5 (4.4)	23.3 (3.0)	21.9 (3.3)
Range	7 - 26	15 - 27	12 - 26
Word-pair Repetition (Accuracy)			
Mean (SD)	9.5 (5.7)	3.5 (3.3)	5.0 (4.4)
Range	2 - 26	0 - 15	0 - 17
Tongue Twister (Accuracy)			
Mean (SD)	11.6 (6.9)	4.3 (3.4)	6.3 (4.3)
Range	1 - 25	0 - 14	1 - 15
Word-pair Repetition (Time)			
Mean (SD)	12.3 (2.0)	11.5 (1.5)	12.1 (1.8)
Range	9.03 - 16.56	9.60 - 14.61	9.46 - 18.57
Tongue Twister (Time)			
Mean (SD)	7.7 (1.8)	7.6 (1.3)	7.8 (1.4)
Range	5.13 - 11.46	5.61 - 12.18	5.68 - 11.26
Rapid Naming (Time)			
Mean (SD)	53.9 (11.76)	48.1 (9.2)	58.4 (10.3)
Range	34.23 - 81.53	33.41 - 73.71	40.68 - 85.21

Correlational Analyses

In order to examine how the various measures used in this study were related to one another, correlational analyses were done. This information was used not only to obtain an overview of the relationships between variables, it also was used to examine the occurrence of multicollinearity prior to conducting the MR analyses.

First, the results of a correlational analysis using the data from all 90 subjects were examined to get a broad overview of how the various measures were related (see Appendix H). Of particular interest was whether the measures making up the hypothetical constructs used in this study (i.e., reading, verbal working memory, speech production accuracy, speech production time) were closely related to one another. Significant correlations were obtained between measures comprising reading, memory, and speech production accuracy. That is, all three reading measures were significantly correlated, as were the three memory and two speech production accuracy measures. Two of the three speech production time pairs were significantly correlated: Word-pair Repetition time was significantly correlated both with time for Tongue Twisters and time for Rapid Naming; however, time to produce Tongue Twisters did not correlate significantly with Rapid Naming time. In sum, the measures comprising three of the four hypothetical constructs were significantly correlated, but two of the measures tapping the fourth construct were not related strongly enough to reach significance.

Examination of this correlational matrix also revealed that performance on the PPVT-R, which measures verbal ability, was significantly correlated with scores on the Word Identification and Passage Comprehension subtests

but not with performance on the Word Attack subtest. That is, for the 90 subjects in this study, knowledge of receptive vocabulary was not strongly associated with the ability to read nonwords, but vocabulary knowledge was significantly correlated with both the ability to read real words and the ability to comprehend what has been read.

Further examination of this matrix indicated that performance on the three verbal working memory tasks was significantly correlated with all three measures of reading. In addition, both accuracy tasks were significantly correlated with nonword reading skill and skill at reading real words, and one of the accuracy tasks was significantly correlated with comprehension ability. The rapid naming task was also significantly correlated with all three components of reading.

In order to examine the relationships between variables more precisely, additional correlational analyses were performed. The first of these analyses minimized age as a possible confounding factor by using the data from the 60 subjects in the two third-grade reading groups (see Appendix I). The results of this analysis paralleled the results of the analysis using the data from all 90 subjects. That is, the measures comprising three of the four hypothetical constructs were significantly correlated, but two of the measures tapping the fourth construct were not related strongly enough to reach significance; and, in addition, knowledge of receptive vocabulary was not strongly associated with the ability to read nonwords, but vocabulary knowledge was significantly correlated with both the ability to read real words and the ability to comprehend what has been read.

A correlational analysis using the data from the less-skilled third-grade

readers and the second-grade readers provided information about the relationship of variables for subjects with similar nonword reading skill (see Appendix J). Three findings from this analysis were similar to the results of the previous two analyses. First, receptive vocabulary was not significantly related to the ability to read nonwords but was significantly correlated with both the ability to read real words and reading comprehension. Second, two of the three speech production time pairs were significantly correlated, but the third pair (i.e., Tongue Twisters and Rapid Naming) was not. Third, the two speech production accuracy measures were significantly correlated. The other two findings differed somewhat from the results of the previous two analyses. The three verbal working memory measures were not as strongly associated in this analysis. Although subjects' scores on Word Span correlated significantly with their scores on Concurrent Processing and Pseudoword Repetition, the scores on these latter two measures were not significantly correlated. The other way this analysis differed from the previous analyses was in the relationship between the reading measures. Word Identification scores were significantly correlated with both Word Attack and Passage Comprehension scores; however, there was no significant relationship between performance on Word Attack and Comprehension. As noted, more experience with contextual reading and use of strategies may have enhanced the third-graders' comprehension performance.

Correlational matrices for the less-skilled third-grade readers, the skilled third-grade readers, and the second-grade readers are provided in Appendices K, L, and M, respectively. Examination of these analyses reveals that verbal ability (i.e., PPVT-R score) was not significantly correlated with nonword reading ability (i.e., Word Attack score) for any of the reading groups;

however, the ability to read real words (i.e., Word Identification score) was significantly correlated with verbal ability for both the third-grade reading groups but not for the second-grade readers. In contrast, reading comprehension was significantly correlated with verbal ability for the skilled third-grade readers and for the second-grade readers but not for the less-skilled third-grade readers.

Further examination of these matrices indicates that verbal working memory was not as strongly associated with reading ability for the individual reading groups as it was for the entire group of 90 subjects. For the skilled third-grade readers, Pseudoword Repetition was significantly correlated with both nonword reading ability and the ability to read real words, and Word Span was significantly correlated with skill at reading real words; however, the other correlations between memory and reading measures were not significant. For the other two groups, the only memory/reading correlations that were significant were Pseudoword Repetition and Word Identification for the less-skilled readers, and Concurrent Processing and Passage Comprehension for the second-graders.

Principal Components Analysis

In order to obtain a parsimonious summary of the verbal working memory and speech production variables for all 90 subjects, a Principal Components Analysis (PCA) was performed (see Table 5 for results). Three factors, the variance among the variables, were extracted. The first two factors alone accounted for 56% of the variance. Factor one included the three verbal working memory variables and the two speech production accuracy variables. Factor two consisted of two speech production time variables (i.e., Tongue

Twisters and Word-pair Repetition). The Rapid Naming variable loaded most strongly on Factor three; however, this variable also loaded on Factor one.

Table 5.

Factor Loadings for Each Factor's Predictor Variables

	Factor 1	Factor 2	Factor 3
Word Span	-.765		
Concurrent Processing	-.730		
Pseudoword Repetition	-.650		
Tongue Twister (Accuracy)	.614		
Word-pair (Accuracy)	.559		
Rapid Naming (Time)	.527		.661
Tongue Twister (Time)		.848	
Word-pair (Time)		.699	

Note: Only loadings >.50 are given

Multivariate Analysis of Variance (MANOVA)

A MANOVA procedure was used to determine whether the reading groups differed significantly on the verbal working memory and speech production measures. Based on the results of the PCA, three variables were examined. The first variable was a composite of Word Span, Concurrent Processing, Pseudoword Repetition, Word-pair Repetition (Accuracy), and Tongue Twister (Accuracy) scores. The second variable consisted of the Word-pair Repetition (Time) and Tongue Twister (Time) scores. The third variable was the Rapid Naming (Time) score.

The results of the MANOVA indicated that there was a significant group effect on the three variables, $F(6, 168) = 5.90$, $p < .001$. Univariate comparisons revealed that two of the three variables were affected by group. These two variables were the composite variable that included the memory

and speech production accuracy scores, $F(2, 87) = 12.69$, $p < .001$, and the Rapid Naming variable, $F(2,87) = 7.34$, $p = .001$. There was no group effect for the variable composed of the time scores for Word-pair Repetition and Tongue Twisters. The results of the univariate F-tests are in Table 6.

Table 6.

Univariate F-tests Summary Table

Variable	Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
Var. 1	3220.46	11042.60	1610.23	126.93	12.69	.001
Var. 2	.22	7.98	.11	.09	1.20	.305
Var. 3	1608.89	9538.59	804.44	109.64	7.34	.001

Follow-up Analyses

In order to determine which variables were significantly affected by group, follow-up Analyses of Variance (ANOVAs) were conducted on the variables showing a significant group effect in the MANOVA procedure. ANOVAs on the three memory and two speech production accuracy variables revealed that there was a significant group effect for each of the five variables. The results of of these analyses are summarized in Table 7.

The Student-Newman-Keuls procedure was used to determine which groups differed significantly on the Word Span, Concurrent Processing, Pseudoword Repetition, Word-pair (Accuracy), Tongue Twister (Accuracy), and Rapid Naming (Time) variables. The results of these analyses indicated that the skilled third-grade readers performed significantly better than both the less-skilled third-grade readers and the second-grade readers on the Concurrent Processing and Rapid Naming measures ($p < .05$). The

Table 7.

ANOVA Summary Table for the Memory and Speech Production (Accuracy) Variables

Variable	Source of variation	Sum of squares	df	Mean square	F	Sig. of F
Word Span	Group	521.67	2	260.83	5.79	.004
	Residual	3916.43	87	45.02		
Concurrent Processing	Group	332.02	2	166.01	10.09	.001
	Residual	1430.97	87	16.45		
Pseudoword Repetition	Group	989.96	2	494.98	24.88	.001
	Residual	1731.20	87	19.90		
Word-pair (Accuracy)	Group	28.34	2	14.17	15.26	.001
	Residual	80.80	87	.93		
Tongue Twister (Accuracy)	Group	28.82	2	14.41	13.75	.001
	Residual	91.19	87	1.05		

less-skilled third-grade readers and the second-grade readers did not differ significantly on these two measures. The results of the Student-Newman-Keuls procedure also indicated that the less-skilled third-grade readers performed significantly worse than either of the other two groups on the Word Span, Pseudoword Repetition, Word-pair (Accuracy), and Tongue Twister (Accuracy) measures ($p < .05$). The skilled third-grade readers and the second-grade readers did not differ significantly on these four measures.

In order to determine which dependent variables were best at distinguishing between the three reading groups, a Discriminant Function

Analysis (DFA) was performed. Predictor variables were the three verbal memory tasks (i.e., Word Span, Concurrent Processing, Pseudoword Repetition), the two speech production accuracy tasks (Word-pair Repetition and Tongue Twisters), and the three speech production time tasks (Word-pair Repetition, Tongue Twisters, Rapid Naming).

Two discriminant functions were calculated, with a combined $X^2 (16) = 83.09$, $p < .001$. After removal of the first function, there was still highly significant discriminating power, $X^2 (7) = 20.08$, $p < .01$. Together the two discriminant functions accounted for 63% of the variance in group membership. Of this 63%, 81% was accounted for by the first discriminant function and 19% by the second discriminant function. As shown in Figure 1, the first discriminant function separated the less-skilled third-grade readers from the other two groups. The second discriminant function maximally discriminated skilled third-grade readers from second-grade readers, with the less-skilled third-grade readers falling between these two groups.

A loading matrix of correlations between predictor variables and discriminant functions suggests that the primary variable distinguishing between the less-skilled and skilled third-grade readers (first function) was the ability to repeat pseudowords (see Table 8). Also contributing to discrimination between these two groups were skill at accurately repeating word-pairs and tongue twisters and the ability to remember lists of words. In the second discriminant function, both the rapid naming and concurrent processing measures made strong contributions in distinguishing between the skilled third-grade readers and the second-grade readers. Loadings below .30 were not considered meaningful and were not interpreted.

Figure 1. Plot of the group centroids for the less-skilled third-grade readers (LS), the skilled third-grade readers (SK), and the Grade 2 readers (G2) on two discriminant functions derived from the verbal working memory and speech production variables. The first discriminant function is plotted on the X axis, and the second discriminant function is plotted on the Y axis.

Table 8.

Results of Discriminant Function Analysis of Verbal Working Memory and Speech Production Variables

Predictor variable	Correlations of predictor variables with discriminant functions	
	1	2
Pseudoword Repetition	-.71	
Word-pair (Accuracy)	.56	
Tongue Twister (Accuracy)	.53	
Word Span	.34	
Rapid Naming (Time)		-.75
Concurrent Processing		.75

Multiple Regression Analyses (MR)

Hierarchical regression was used to determine if the verbal working memory and speech production variables improved the prediction of reading ability beyond that predicted by age and verbal cognitive ability. The criterion variable for the first MR analysis was ability to read nonwords (see Table 9).

Table 9.

Hierarchical Multiple Regression with Nonword Reading Ability as the Criterion Variable (N = 90)

Variables entered in three steps	Beta	T	Sig. of T	Adj. R ²	Change in R ²
a. Age	.36	3.79	.01	.056	
b. PPVT-R	-.07	-0.71	.48	.064	.008
c. Pseudoword Repetition	.47	4.18	.01	.371	.307
Word-pair (Accuracy)	-.15	-1.46	.15		
Tongue Twister (Accuracy)	-.15	-1.39	.17		
Rapid Naming (Time)	-.11	-1.05	.30		
Word Span	-.08	-0.69	.49		
Word-pair (Time)	-.07	-0.63	.53		
Concurrent Processing	.06	0.50	.62		
Tongue Twister (Time)	.03	0.27	.79		

The results of this analysis indicated that the eight phonological processing variables contributed an additional 31% to the proportion of variance accounted for in nonword reading skill beyond that predicted by age and verbal cognitive ability. One variable, Pseudoword Repetition, contributed

significantly to the prediction of nonword reading skill, accounting for 12% of the variability among the 90 subjects.

To determine whether the verbal working memory and speech production variables contributed to the prediction of reading ability regardless of how reading was defined, two additional MR analyses were performed. The first analysis used the ability to read real words (i.e., Word Identification subtest score) as the criterion variable (see Table 10), and the second analysis used comprehension skill (i.e., Passage Comprehension score) as the criterion variable (see Table 11). The phonological processing variables contributed an additional 34% to the proportion of variance accounted for in real word reading skill beyond that predicted by age and verbal cognitive ability. Again, Pseudoword Repetition made a significant contribution to the prediction, accounting for 14% of the variance in real word reading ability among the 90 subjects. Although not significant, the phonological processing variables contributed an additional 12% to the proportion of variance accounted for in comprehension ability. Pseudoword Repetition made a significant contribution to the prediction of comprehension skill, accounting for 3% of the variance. In addition, accuracy of repeating word-pairs and accuracy of repeating tongue twisters were significant predictors of comprehension ability, with each variable accounting for an additional 3% of the variance.

Table 10.

Hierarchical Multiple Regression with Real-word Reading Ability as the Criterion Variable (N = 90)

Variables entered in three steps	Beta	T	Sig. of T	Adj. R ²	Change in R ²
a. Age	.42	4.83	.01	.074	
b. PPVT-R	.09	1.07	.29	.148	.074
c. Pseudoword Repetition	.48	4.76	.01	.492	.344
Word-pair (Accuracy)	-.12	-1.34	.18		
Rapid Naming (Time)	-.10	-1.12	.26		
Tongue Twister (Accuracy)	-.11	-1.16	.25		
Concurrent Processing	.11	1.08	.28		
Tongue Twister (Time)	.04	0.34	.73		
Word-pair (Time)	-.01	-0.14	.89		
Word Span	-.01	-0.11	.92		

Table 11.

Hierarchical Multiple Regression with Comprehension Ability as the Criterion Variable (N = 90)

Variables entered in three steps	Beta	T	Sig. of T	Adj. R ²	Change in R ²
a. Age	.33	3.23	.01	.056	
b. PPVT-R	.25	2.59	.01	.179	.123
c. Pseudoword Repetition	.26	2.22	.03	.298	.119
Word-pair (Accuracy)	-.24	-2.17	.03		
Tongue Twister (Accuracy)	.23	2.05	.04		
Concurrent Processing	.20	1.66	.10		
Tongue Twister (Time)	.20	1.64	.10		
Word-pair (Time)	-.15	-1.22	.23		
Word Span	-.09	-0.72	.47		
Rapid Naming (Time)	-.07	-0.67	.50		

CHAPTER IV. DISCUSSION

The primary goal of the present study was to investigate the association between reading ability and two basic phonological processes, verbal working memory and speech production. Although poor readers generally do not perform as well as good readers on tasks measuring these processing abilities, their scores on verbal working memory and speech production tasks are not consistently lower than that of younger children reading at the same level. The question arises whether less-skilled readers have phonological processing deficits or whether they are simply progressing at a slower rate than their normal-reading peers. That is, do less-skilled readers have a similar, but slower, pattern of reading development, or do they have deficits in some aspect of their development, most notably in the area of phonological processing? In order to explore this issue, performance differences on phonological processing tasks between reading groups matched for age but differing in ability and differences between reading groups matched for ability but differing in age were examined.

The results of the current study provided interesting evidence that poor readers are not simply progressing at a slower rate than their normal-reading peers but rather have significant deficits in their ability to process phonological information. As expected, the less-skilled third-grade readers had significantly lower scores than the skilled third-grade readers on all three memory measures and on both speech production accuracy measures. These results were consistent with previous research which has found that poor readers generally do not perform as well as their normal-reading peers on verbal working memory

measures (Brady, 1986; Jorm, 1983; Wagner & Torgesen, 1987) and on tasks requiring the accurate repetition of words and phrases (Brady et al., 1989; Catts, 1986; Kamhi et al., 1988; Rapala & Brady, 1990). The finding from this investigation that is of particular interest, however, is that the less-skilled third-grade readers had significantly lower scores on memory and speech production accuracy tasks not only when compared with their age-mates but also when compared with the younger readers. The less-skilled third-graders had significantly lower scores than the second-grade readers on two of the verbal working memory measures (i.e., Word Span and Pseudoword Repetition) and on the two speech production accuracy measures (i.e., Word-pair Repetition and Tongue Twisters). In other words, even though the two groups of subjects had the same nonword reading ability, the less-skilled third-graders' performance on these phonological processing tasks was significantly below that of the younger readers. These results do not support a developmental lag model of reading (Olson et al., 1984; Stanovich et al., 1986). Instead, it appears that rather than simply progressing at a slower rate than their normal-reading peers, less-skilled readers may have phonological processing deficits that are impeding their reading progress.³ One implication of this finding is that the pattern of less-skilled readers' skill acquisition is not the same as that of normal readers, and, consequently, they cannot be expected to catch up without interventions specifically designed to address their phonological deficits. These results are even more interesting given the fact that the majority of the less-skilled readers in this study had not been identified as reading-disabled and therefore were not receiving special education services. The less-skilled

³ It should be noted that phonological processing deficits may or may not characterize less-skilled readers whose selection is based on different criteria. For example, whether phonological processing deficits are characteristic of individuals who have adequate nonword reading skill but poor comprehension ability remains to be determined.

readers used here represented children who were at the lower end of the range of reading ability that can be expected in a typical classroom. According to Stanovich et al. (1986), the developmental lag model is more helpful in understanding normal achievement variations, whereas the deficit model may be more correctly applied to dyslexic children. However, the results of this study suggest otherwise. Children across a range of reading difficulty also had an atypical pattern of phonological development.

Multiple regression analyses were used to assess the predictive value of the phonological processing variables. These analyses revealed that as a group the eight measures included in the present study made a significant contribution to the prediction of both nonword and real word reading skill beyond that predicted by age and verbal cognitive ability. In fact, the eight variables contributed an additional 31% and 34% to the proportion of variance accounted for in nonword reading skill and in real word reading skill, respectively.

In addition to examining the predictive value of the phonological processing variables as a whole, multiple regression analyses also were used to determine which variable was the most salient predictor of reading ability. Skill at repeating pseudowords emerged as the variable with the best predictive value. For the 90 subjects in this study, performance on the Pseudoword Repetition task contributed significantly to the prediction of skill at nonword reading, at real word reading, and at comprehending what has been read. Even when the contributions of age and verbal cognitive ability had been accounted for, the Pseudoword Repetition task remained a significant contributor to the prediction of all three components of reading.

The results from this study suggest that the Pseudoword Repetition task may be a useful measure for the identification of less-skilled readers. The task is a reliable measure ($\alpha = .82$ in this study; $\alpha = .87$ in the Taylor et al., 1989, study) that takes approximately 5 to 10 minutes to administer. The subjects in the present study found the task enjoyable and did not appear frustrated or discouraged even when they were producing inaccurate responses. Although a variety of verbal working memory tasks have been found to discriminate between good and poor readers, one advantage of the Pseudoword Repetition task is that it places relatively minimal demands on memory, attention, and higher cognitive functions (e.g., use of mnemonic strategies) (Taylor et al., 1989). Results from investigations using tasks that rely on higher cognitive functions may be hard to interpret because a variety of factors could contribute to verbal working memory performance. In contrast, results using the Pseudoword Repetition task may be easier to interpret because these confounding factors have been minimized. The fact that in this study the Pseudoword Repetition task was a good predictor of overall reading ability, had good reliability, and was easy to administer supports Taylor et al.'s view that the task may be an important tool in the identification of reading disability. In fact, the results suggest that this task may be useful in identifying not only severely reading-disabled students but also those children who are somewhat impaired at reading though not sufficiently to be identified as needing special education services.

In exploring cognitive differences associated with reading disability, the concern arises as to how reading ability is being defined. An individual's reading level can be determined by evaluating various aspects of the reading process. Nonword reading, real word reading, and comprehension tasks are all

used to measure reading achievement. Performance scores on two or more measures can be combined to form a composite score, or performance on one component of reading can be used as the measure of reading achievement. In this study group placement was based on the ability to read nonwords. It was of interest to determine whether skill at reading nonwords was representative of overall reading ability. The first step in addressing this issue was to look at the strength of the relationships between the three reading measures. Examination of the correlation matrix indicated that the three measures were significantly related, with nonword and real word reading being more strongly related to each other than either ability was to comprehension skill. Further analyses were conducted to determine whether subjects' performance on the nonword reading measure differed significantly from performance on the other two reading measures. As expected, the third-grade skilled readers performed significantly better than the less-skilled readers on all three reading measures. The results of the comparison between the less-skilled third-grade readers and the second-grade readers were not as consistent, however. The younger readers were selected to match the less-skilled readers on nonword reading ability, but the question remained whether they also performed comparably on measures of the other two components of reading. Although there were no significant differences between the less-skilled readers and their younger counterparts on the real word reading measure, the second-graders' comprehension scores were significantly lower than those of the less-skilled third-grade readers. In fact, four of the third-graders had comprehension scores that were at or above the fourth-grade level, whereas none of the second-graders scored above the third-grade level. This unexpected difference was attributed to the fact that the third-graders had had more experience in general

because they were a year older; more contextual reading experience (e.g., science and social studies textbooks), and more experience than the second-graders in developing strategies to overcome nonword and real word reading weaknesses. Although other factors may contribute to enhanced performance on comprehension measures, the results of this study indicated that, in general, for second- and third-graders, nonword reading ability was representative of overall reading skill. That is, for young children in the early stages of reading acquisition, poor nonword readers were poor real word readers and were usually poor comprehenders.

In addition to the primary goal of investigating the association between reading ability and phonological processing, a related area of interest was the relationship of verbal working memory and speech production to the various components of reading. Was the relationship between the two phonological processes and reading the same regardless of how reading was defined? In general, each of the eight phonological processing measures related to the three components of reading in a similar way. All three verbal working memory measures were significantly correlated with the three components of reading. A comparable association was found for the two accuracy of speech production measures. The ability to accurately produce word pairs was significantly correlated with all three components of reading, and the ability to accurately produce tongue twisters was significantly correlated with nonword and real word reading. The three speed of speech production measures did not have an equally strong relationship to reading. That is, the Rapid Naming task was more strongly associated with the three components of reading than either of the other speed measures. These two shorter speed tasks were not only less strongly related to reading than the Rapid Naming task, but they were also not

as strongly related to reading as the three verbal working memory and the two accuracy of speech production tasks. In sum, this study not only provided support for the idea that nonword reading is representative of overall reading skill but also that verbal working memory and speech production have a similar pattern of correspondence to the three different components of reading.

Because multiple measures were used to assess the constructs of verbal working memory, of accuracy of speech production, and of speed of speech production, it was important to determine the strength of the association between tasks measuring each construct. Analyses revealed that the three verbal working memory measures were not only significantly related to each other but also were significantly related to the two speech production accuracy measures. This result provided support for the idea that a common factor (e.g., phonological encoding, planning for output) may underlie competence, or the lack of competence, in both areas (Catts, 1989b; Jorm & Share, 1983; Torgesen, 1985). The tasks designed to measure the speed of speech production did not relate in as straightforward a manner. Although two of the three measures were significantly related to each other, the Rapid Naming task proved to be a complex task that not only contributed unique variance but also was more closely associated with the memory/accuracy measures than with the other two speed tasks. That is, the two measures requiring rapid repetitions of words and pseudowords appeared to be purer measures of the speech production speed construct than the measure requiring the formulation and articulation of familiar words, which seemed to have more in common with the memory/accuracy measures. A possible explanation for the Rapid Naming task's association with the memory/accuracy measures is that performance on this measure also may have relied on the same common factor (e.g., ability to

encode phonological information). Having to retrieve phonological information may have taxed encoding more than the other speed of speech production measures, thus making the Rapid Naming task a more sensitive measure of phonological processing.

In sum, while the variables included in the present study did not fit neatly into the hypothetical constructs of verbal working memory, accuracy of speech production, and speed of speech production, there appeared to be a common thread linking the three verbal working memory and the two speech production accuracy measures. This thread also may have extended to the Rapid Naming task, although this measure was complex in nature. Time to produce word pairs and time to produce tongue twisters appeared to be measuring a construct related to the speed of speech production.

Results from prior research suggest that the association between speech production and reading ability may depend on which aspect of speech production is considered. Evidence indicates that the ability to accurately produce speech has a closer association with reading ability than speed of speech production does (see Brady, 1991, for a review). Speed of speech production may actually be age related, with older children being able to produce speech more rapidly than younger children (Stanovich et al., 1988). In general, the results of the present study found support for accuracy of production being related to reading ability but did not find support for speed of production being age-related.

As noted previously, the less-skilled readers had significantly lower scores than both their age-mates and their younger reading-mates on the speech production accuracy tasks. The fact that the less-skilled readers were significantly less accurate than even their second-grade counterparts provides

strong evidence for accuracy of speech production being related to reading ability. Mixed results were found for the speed of speech production measures. The less-skilled readers had significantly lower scores than their age-mates, but not their younger reading-mates, on the speech production speed measure which required the formulation and articulation of familiar words (i.e., Rapid Naming). The skilled third-grade readers were able to name the drawings at a significantly faster rate than either of the other two groups. This result is particularly interesting because it suggests that speed of speech production may be associated with reading ability but not with age. This view is in contrast with Stanovich et al.'s (1988) conclusion that speed of articulation is strongly age dependent but is not correlated with reading ability. Further lack of support for speed of articulation being age dependent was found by examining the performance of the three groups on the other two speed measures (i.e., Word-pair Repetition and Tongue Twisters). Significant group differences were not found on either of these measures. That is, the younger second-grade readers were as fast as the third-graders at repeating words and pseudowords. In sum, the results of the present investigation do not support the view that speed of speech production is age dependent. In contrast, some support was found for speed of production being associated with reading ability. It should be noted, however, that this association may be tenuous due to the complex nature of the Rapid Naming task. Rapid naming tasks also have been used as measures of lexical access, and the results of this study are consistent with those of other investigations which have found that poor readers have significantly more difficulty retrieving words than good readers (Felton & Wood, 1989; Wolf, submitted). Although the Rapid Naming task was designed as a measure of speech production, it may have more in common with lexical access measures.

In addition, since this task is closely related to the memory/accuracy measures, its association with reading ability may be due to a factor it holds in common with those two abilities.

To summarize, one of the most important findings of this study was that less-skilled third-grade readers had deficits in phonological processing even when compared with younger children who were matched for reading level. The implication of this finding is that these children are not simply progressing at a slower rate than their normal-reading age-mates; rather, their pattern of phonological development is different. These less-skilled readers may not be able to catch up without interventions specifically designed to address their phonological processing weaknesses. It is particularly noteworthy that the majority of subjects in the present study had not been identified as reading-disabled, but instead represented a far larger population of children with below-average reading skills who are being educated in regular, as opposed to special, education classrooms. The fact that these children have an atypical pattern of development strengthens the evidence for an association between phonological processing and reading ability. Additional investigations using a reading-age-match design need to be conducted to confirm which abilities are developmentally lagging in poor readers and which represent bona fide deficits. One question to be addressed is whether certain tasks (e.g., pseudoword repetition) are purer measures of an underlying ability (e.g., phonological encoding) that may be truly deficient in the reading-disabled population. Perhaps because tasks such as these do not provide alternative processing routes, developing compensatory strategies is less likely than with complex tasks (e.g., Rapid Naming, Concurrent Processing) which rely on a broader range of skills. Another issue that needs further investigation is whether

weaknesses in phonological processing portend other cognitive weaknesses (e.g., vocabulary acquisition). Research with preschool children points to an association between phonological processing and vocabulary acquisition (Gathercole & Baddeley, 1989). Recent studies with older poor readers find that they experience more difficulty than good readers at learning aurally taught words (Aguiar & Brady, 1991). Likewise, phonological processing difficulties could be expected to impede second language acquisition (Service, 1992). The fact that poor readers have phonological processing deficits is well documented. As evidence accrues suggesting that these deficits may affect larger numbers of school children and may have more far-reaching consequences than was once suspected, the need to identify children at risk and to devise appropriate interventions becomes more pressing.

A second finding from the present study may help address the first of these needs. Because the Pseudoword Repetition task was a good predictor of reading ability, had good reliability, and was easy to administer, it may prove to be a useful tool in the identification of young children who are destined to become poor readers. Systematic research using the Pseudoword Repetition task may help hone its predictive value and add to the body of knowledge regarding the association between phonological processing and reading ability. Research possibilities include investigating whether phonological problems persist into adulthood, or whether poor readers improve in their ability to process phonological information. In addition, investigating younger children's (e.g., prereaders) performance on a pseudoword repetition task would provide beneficial information. Will floor effects be found, or will repeating pseudowords have discriminatory power even among very young children? Also, can prereaders' ability at pseudoword repetition predict future reading ability? If

potential poor readers can be identified at an early age, preventive steps could be taken to help children from becoming reading-disabled.

Interventions aimed at remediating phonological processing weaknesses also need to be developed. The fact that verbal working memory and accuracy of speech production are significantly related to each other, as well as to reading ability, offers hope that effective training programs can be designed. That is, a training program aimed at improving performance in one area of phonological processing (e.g., accuracy of speech production) may also ameliorate performance in related processes (e.g., verbal working memory). The ultimate goal, of course, would be to improve skill at reading. Some evidence for this type of indirect benefit was found in a kindergarten training study (Brady, Stone, Fowler, & Winbury, in progress). In that study, training phonological awareness improved the accuracy of speech production. One component of the phonological awareness training was attention to how certain phonemes were articulated; however, neither accurate nor rapid production of words was included in the training (Lindamood & Lindamood, 1975). The results of the study indicate that, although practice in accuracy of speech production was not part of the training, this ability, as well as phonological awareness, improved. Investigations into whether articulation training, or more in-depth speech production training, might also benefit verbal working memory and reading ability would be beneficial.

Appendix A

Word Span Task

Name: _____ Date: _____ Counter No.: _____

School: _____ Examiner: _____

3-word lists: _____ # correct

1. watch fruit sock _____
_____ (Record response and position #)2. key light fence _____
_____3. chair lunch song _____

4-word lists: _____

4. heart crown wheel braid _____
_____5. clock brain fish school _____
_____6. bread train wall plate _____
_____7. charm grass quilt rice _____
_____8. rose crutch thread flute _____

5-word lists: _____

9. toast plane drum church glove _____
_____10. nest thief chalk snake flood _____
_____11. teeth blimp smoke trap child _____
_____12. friend chain bird cloth game _____
_____13. tail stamp chief skunk grouch _____

Total correct _____

Appendix B

Concurrent Processing Task

Name: _____ Date: _____ Counter No.: _____

School: _____ Examiner: _____

Demonstration:

1. Apples are red.
2. Dogs meow.

Response

Practice:

1. Rabbits have short ears.	F _____	ears	_____
2. A fire gives off heat.	T _____	heat	_____

Sets of two:

1. At night we sleep in school.	F _____	school	_____
2. Some people like to play baseball.	T _____	baseball	_____
-----			
1. Most beaches are covered with sand.	T _____	sand	_____
2. Baby cats are called puppies.	F _____	puppies	_____
-----			
1. People drink out of forks.	F _____	forks	_____
2. We see colors in a rainbow.	T _____	rainbow	_____
-----			
1. Many people shop in stores.	T _____	stores	_____
2. Animals do not drink water.	F _____	water	_____

Sets of three:

1. Too much sun can burn your skin.	T _____	skin	_____
2. The weather is always the same.	F _____	same	_____
3. Most people have three eyes.	F _____	eyes	_____
-----			
1. Birthday cakes grow on trees.	F _____	trees	_____
2. We're taught to read in school.	T _____	school	_____
3. You can see yourself in a mirror.	T _____	mirror	_____
-----			
1. Fish are covered with feathers.	F _____	feathers	_____
2. Clocks are used to tell time.	T _____	time	_____
3. We have snowstorms in the summer.	F _____	summer	_____
-----			
1. Soap helps to get us clean.	T _____	clean	_____
2. Bananas are always blue.	F _____	blue	_____
3. Matches are used to start fires.	T _____	fires	_____

Appendix B: Concurrent Processing Task (cont.)

Sets of four:

1. Pencils are used for writing.	T	_____	writing	_____
2. We milk cows to get eggs.	F	_____	eggs	_____
3. Elephants are bigger than flies.	T	_____	flies	_____
4. Good friends never talk to each other.	F	_____	other	_____

1. Most fish fly in the air.	F	_____	air	_____
2. As children grow, they get shorter.	F	_____	shorter	_____
3. Plants and animals are living things.	T	_____	things	_____
4. Some bears like to eat honey.	T	_____	honey	_____

1. A turtle has a hard shell.	T	_____	shell	_____
2. Ice cubes are made in the oven.	F	_____	oven	_____
3. Bicycles are faster than planes.	F	_____	planes	_____
4. Crayons come in different colors.	T	_____	colors	_____

1. People use their ears to see.	F	_____	see	_____
2. A bank is a place to keep money.	T	_____	money	_____
3. Giraffes have very long necks.	T	_____	necks	_____
4. Scissors are never used for cutting.	F	_____	cutting	_____

Number of words recalled correctly: _____

Appendix C

Pseudoword Repetition Task

Name: _____ Date: _____ Counter No.: _____

School: _____ Examiner: _____

Pseudoword	Adapted from	Response	Error Types
1. Tropaply	(Probably)	_____	_____
2. Ereshant	(Elephant)	_____	_____
3. Foltano	(Volcano)	_____	_____
4. Skapeddi	(Spaghetti)	_____	_____
5. Spapistics	(Statistics)	_____	_____
6. Teroscote	(Telescope)	_____	_____
7. Imbichent	(Indigent)	_____	_____
8. Kebestrian	(Pedestrian)	_____	_____
9. Karpigular	(Particular)	_____	_____
10. Etosprosee	(Apostrophe)	_____	_____
11. Panamity	(Calamity)	_____	_____
12. Carimature	(Caricature)	_____	_____
13. Ponverlation	(Conversation)	_____	_____
14. Grishanthenum	(Chrysanthemum)	_____	_____
15. Torichipal	(Dirigible)	_____	_____
16. Zacradery	(Secretary)	_____	_____
17. Araminam	(Aluminum)	_____	_____
18. Phirotofigal	(Philosophical)	_____	_____
19. Didliokrafy	(Bibliography)	_____	_____
20. Sarnatutical	(Pharmaceutical)	_____	_____

Appendix C: Pseudoword Repetition Task (cont.)

Pseudoword	Adapted from	Response	Error Types_
21. Onamifidy	(Anonymity)	_____	_____
22. Gysiolochipal	(Physiological)	_____	_____
23. Deconfiliation	(Reconciliation)	_____	_____
24. Iliodintratic	(Idiosyncratic)	_____	_____
25. Terspecacity	(Perspicacity)	_____	_____
26. Gonflidration	(Conflagration)	_____	_____
27. Nagmivishent	(Magnificent)	_____	_____
28. Gretiminary	(Preliminary)	_____	_____

Number of omissions: _____

Number of additions: _____

Number of substitutions: _____

Number of transpositions: _____

Total number of errors: _____

Appendix D

Word-pair Repetition Task

Name: _____ Date: _____ Counter No.: _____

School: _____ Examiner: _____

Practice	S Rptd Once	Trials	Time	No. Errors
A. girl/bus	_____	0 0 0 0 0 0 0 0 0 0	Aa. _____	Ab. _____

Now let's do some more.

Word Pair	S Rptd Once	Trials	Time	No. Errors
1. car/hat	_____	0 0 0 0 0 0 0 0 0 0	1a. _____	1b. _____
2. train/plate	_____	0 0 0 0 0 0 0 0 0 0	2a. _____	2b. _____
3. bird/church	_____	0 0 0 0 0 0 0 0 0 0	3a. _____	3b. _____
4. friend/fence	_____	0 0 0 0 0 0 0 0 0 0	4a. _____	4b. _____
5. key/cloud	_____	0 0 0 0 0 0 0 0 0 0	5a. _____	5b. _____
6. rock/sun	_____	0 0 0 0 0 0 0 0 0 0	6a. _____	6b. _____

Now let's try this one.

Practice	S Rptd Once	Trials	Time	No. Errors
B. sandpaper/ volcano	_____	0 0 0 0 0 0 0 0 0 0	Ba. _____	Bb. _____

Now let's do some more.

Word Pair	S Rptd Once	Trials	Time	No. Errors
7. porcupine/ ballerina	_____	0 0 0 0 0 0 0 0 0 0	7a. _____	7b. _____
8. banana/ elephant	_____	0 0 0 0 0 0 0 0 0 0	8a. _____	8b. _____
9. telescope/ dinosaur	_____	0 0 0 0 0 0 0 0 0 0	9a. _____	9b. _____
10. alligator/ aquarium	_____	0 0 0 0 0 0 0 0 0 0	10a. _____	10b. _____

Appendix E

Tongue Twister Task

Name: _____ Date: _____ Counter No.: _____

School: _____ Examiner: _____

Practice	S Rptd Once	Trials	Time	No. Errors
1. NU TU	_____ (new two)	0 0 0 0 0 0 0 0 0 0	1a. _____	1b. _____
2. DI ZI	_____ (dee zee)	0 0 0 0 0 0 0 0 0 0	2a. _____	2b. _____

Now let's do some more.

Twisters	S Rptd Once	Trials	Time	No. Errors
1. SI TI	_____ (see tee)	0 0 0 0 0 0 0 0 0 0	1a. _____	1b. _____
2. BLU BU	_____ (bloo boo)	0 0 0 0 0 0 0 0 0 0	2a. _____	2b. _____
3. RU TU	_____ (roo too)	0 0 0 0 0 0 0 0 0 0	3a. _____	3b. _____
4. FI THI	_____ (fee thee)	0 0 0 0 0 0 0 0 0 0	4a. _____	4b. _____
5. BU LU	_____ (boo loo)	0 0 0 0 0 0 0 0 0 0	5a. _____	5b. _____
6. SI SHI	_____ (see shee)	0 0 0 0 0 0 0 0 0 0	6a. _____	6b. _____
7. RU LU	_____ (roo loo)	0 0 0 0 0 0 0 0 0 0	7a. _____	7b. _____
8. NI FI	_____ (nee fee)	0 0 0 0 0 0 0 0 0 0	8a. _____	8b. _____
9. KRU KU	_____ (kroo koo)	0 0 0 0 0 0 0 0 0 0	9a. _____	9b. _____
10. BI TI	_____ (bee tee)	0 0 0 0 0 0 0 0 0 0	10a. _____	10b. _____

Appendix F
Rapid Naming Task Drawings

phone

popsicle

umbrella

strawberry

astronaut

Appendix G
Rapid Naming Task

Name: _____ Date: _____ Counter No.: _____

School: _____ Examiner: _____

Sequence of pictures:

Row 1. phone popsicle umbrella strawberry astronaut umbrella
popsicle phone strawberry

Row 2. umbrella phone astronaut popsicle strawberry astronaut
strawberry umbrella popsicle

Row 3. strawberry umbrella phone astronaut popsicle phone
astronaut strawberry umbrella

Row 4. phone strawberry umbrella popsicle astronaut strawberry
popsicle astronaut phone

Row 5. astronaut phone strawberry umbrella popsicle umbrella
phone popsicle astronaut

Scoring:

Total responses 45

Minus errors

Number correct _____

Total time to respond _____

Appendix H

Pearson Correlation Coefficients for Age, Cognitive Ability, Verbal Working Memory, and Speech Production for the Three Groups Combined (N = 90)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	1.00													
2. PPVT-R	-.13	1.00												
3. Block Design	-.08	.11	1.00											
4. Word Attack	.26*	.10	.12	1.00										
5. Word Identification	.29**	.25*	.08	.87**	1.00									
6. Passage Comprehension	.26*	.32**	.22*	.57**	.63**	1.00								
7. Word Span	-.03	.18	.08	.31**	.40**	.24*	1.00							
8. Concurrent Processing	.14	.08	.17	.33**	.40**	.33**	.49**	1.00						
9. Pseudoword Repetition	-.27**	.33**	.08	.44**	.51**	.28**	.52**	.23*	1.00					
10. Word-pair (Accuracy)	.18	-.17	-.02	-.29**	-.31**	-.28**	-.35**	-.38**	-.32**	1.00				
11. Tongue Twister (Accuracy)	.06	-.18	.04	-.37**	-.38**	-.10	-.32**	-.32**	-.32**	.40**	1.00			
12. Word-pair (Time)	-.12	-.18	-.10	-.22*	-.23*	-.19	-.30**	-.23*	-.22*	-.07	.11	1.00		
13. Tongue Twister (Time)	-.03	.03	-.11	-.03	-.02	.02	-.03	-.11	-.12	-.16	-.29**	.53**	1.00	
14. Rapid Naming (Time)	-.30**	-.02	.09	-.36**	-.38**	-.24*	-.20	-.41**	-.14	.06	.28**	.33**	.15	1.00

* p < .05

** p < .01

Appendix I

Pearson Correlation Coefficients for Age, Cognitive Ability, Verbal Working Memory, and Speech Production for the Less-skilled and Skilled Third-grade Readers (N = 60)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	1.00													
2. PPVT-R	-.18	1.00												
3. Block Design	-.21	.10	1.00											
4. Word Attack	-.25	.15	.15	1.00										
5. Word Identification	-.28*	.31*	.15	.86**	1.00									
6. Passage Comprehension	-.16	.37**	.31*	.49**	.54**	1.00								
7. Word Span	.06	.14	-.05	.43**	.55**	.33**	1.00							
8. Concurrent Processing	-.18	-.04	.10	.31*	.36**	.27*	.53**	1.00						
9. Pseudoword Repetition	-.22	.37**	.09	.64**	.73**	.42**	.52**	.35**	1.00					
10. Word-pair (Accuracy)	.14	-.11	-.15	-.46**	-.53**	-.43**	-.43**	-.40**	-.43**	1.00				
11. Tongue Twister (Accuracy)	.05	-.10	-.04	-.48**	-.49**	-.10	-.37**	-.31*	-.43**	.40**	1.00			
12. Word-pair (Time)	-.07	-.24	.09	-.28*	-.32*	-.24	-.28*	-.31*	-.30*	.05	.17	1.00		
13. Tongue Twister (Time)	.12	-.01	.11	-.01	-.04	.01	.06	-.26*	-.13	-.08	-.23	.54**	1.00	
14. Rapid Naming (Time)	-.07	-.03	.10	-.31*	-.30*	-.13	-.27*	-.40**	-.18	.11	.36**	.41**	.24	1.00

* p < .05

** p < .01

Appendix J

Pearson Correlation Coefficients for Age, Cognitive Ability, Verbal Working Memory, and Speech Production for the Less-skilled Third-grade Readers and the Second-grade Readers (N = 60)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	1.00													
2. PPVT-R	-.19	1.00												
3. Block Design	-.16	.09	1.00											
4. Word Attack	.01	.16	-.02	1.00										
5. Word Identification	.10	.34**	-.17	.50**	1.00									
6. Passage Comprehension	.15	.34**	.09	.20	.58**	1.00								
7. Word Span	-.15	.10	.14	.04	.12	.02	1.00							
8. Concurrent Processing	-.01	.05	.16	.19	.15	.27*	.48**	1.00						
9. Pseudoword Repetition	-.54**	.36**	-.03	.13	.23	.02	.48**	.05	1.00					
10. Word-pair (Accuracy)	.43**	-.08	.10	-.20	.04	.01	-.33**	-.28*	-.26*	1.00				
11. Tongue Twister (Accuracy)	.26*	-.17	.17	-.09	-.17	.09	-.34**	-.26*	.23	.35*	1.00			
12. Word-pair (Time)	-.10	-.08	-.10	.13	-.04	-.08	-.28*	-.16	-.20	-.15	.12	1.00		
13. Tongue Twister (Time)	-.08	.06	-.13	.12	.14	.07	-.08	-.10	-.14	-.24	-.35**	.54**	1.00	
14. Rapid Naming (Time)	-.24	.05	.17	-.16	-.20	-.04	-.15	-.37**	.01	-.17	.16	.34**	.19	1.00

* p < .05

** p < .01

Appendix K

Pearson Correlation Coefficients for Age, Cognitive Ability, Verbal Working Memory, and Speech Production for the Less-skilled Third-grade Readers (N = 30)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	1.00													
2. PPVT-R	-.19	1.00												
3. Block Design	-.29	.02	1.00											
4. Word Attack	-.11	.05	.09	1.00										
5. Word Identification	-.04	.38*	-.05	.43*	1.00									
6. Passage Comprehension	-.28	.33	.24	.10	.56**	1.00								
7. Word Span	.32	-.08	-.06	.28	.19	.14	1.00							
8. Concurrent Processing	-.14	-.25	.06	.29	.02	.21	.53**	1.00						
9. Pseudoword Repetition	-.08	.45*	-.20	.29	.44*	.27	.35	.11	1.00					
10. Word-pair (Accuracy)	.18	.21	.04	-.21	-.02	-.16	-.36*	-.15	-.11	1.00				
11. Tongue Twister (Accuracy)	-.21	.06	.18	-.11	-.20	.16	-.34	-.17	-.15	.10	1.00			
12. Word-pair (Time)	-.28	-.09	.22	.04	-.22	-.20	-.23	-.28	-.32	-.08	.22	1.00		
13. Tongue Twister (Time)	-.02	.01	.19	.06	-.03	-.03	.01	-.40*	-.24	-.17	-.25	.57**	1.00	
14. Rapid Naming (Time)	-.20	.09	.20	-.07	-.11	.15	-.30	-.45*	-.01	-.28	.29	.52**	.37*	1.00

* p < .05

** p < .01

Appendix L

Pearson Correlation Coefficients for Age, Cognitive Ability, Verbal Working Memory, and Speech Production for the Skilled Third-grade Readers (N = 30)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	1.00													
2. PPVT-R	-.13	1.00												
3. Block Design	-.04	.16	1.00											
4. Word Attack	-.27	.11	.01	1.00										
5. Word Identification	-.39*	.40*	.04	.67**	1.00									
6. Passage Comprehension	.03	.39*	.31	.29	.28	1.00								
7. Word Span	-.13	.33	-.25	.32	.67**	.25	1.00							
8. Concurrent Processing	-.07	.07	-.01	-.14	.01	.03	.29	1.00						
9. Pseudoword Repetition	-.23	.29	.25	.45*	.58**	.17	.41*	.08	1.00					
10. Word-pair (Accuracy)	-.17	-.34	-.19	.05	-.16	-.30	-.13	-.25	-.04	1.00				
11. Tongue Twister (Accuracy)	.16	-.17	-.10	-.16	-.06	.21	.01	.01	-.07	.15	1.00			
12. Word-pair (Time)	.14	-.38*	-.01	-.30	-.31	-.16	-.19	-.19	-.03	-.11	-.15	1.00		
13. Tongue Twister (Time)	.36	-.03	-.01	.01	-.08	.07	.18	-.11	-.01	-.03	-.32	.51**	1.00	
14. Rapid Naming (Time)	-.01	-.12	.09	-.25	-.18	-.13	.01	-.13	.01	.24	.21	.15	.01	1.00

* p < .05

** p < .01

Appendix M

Pearson Correlation Coefficients for Age, Cognitive Ability, Verbal Working Memory, and Speech Production for the Second-grade Readers (N = 30)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	1.00													
2. PPVT-R	-.17	1.00												
3. Block Design	-.27	.15	1.00											
4. Word Attack	.06	.30	-.12	1.00										
5. Word Identification	-.15	.35	-.28	.58**	1.00									
6. Passage Comprehension	-.12	.56**	-.14	.44*	.62**	1.00								
7. Word Span	-.06	.28	.36*	-.25	.15	.03	1.00							
8. Concurrent Processing	-.17	.38*	.26	.09	.26	.39*	.52**	1.00						
9. Pseudoword Repetition	-.35	.21	.13	.01	.30	.07	.53**	.11	1.00					
10. Word-pair (Accuracy)	.02	-.28	.20	-.26	-.12	-.17	-.14	-.54**	.08	1.00				
11. Tongue Twister (Accuracy)	-.12	-.43*	.23	-.11	-.35	-.51**	-.16	-.51**	.16	.37*	1.00			
12. Word-pair (Time)	-.27	-.05	-.41*	.23	.18	.11	-.35	-.05	-.05	-.30	-.05	1.00		
13. Tongue Twister (Time)	-.05	.11	-.51**	.20	.41*	.41*	-.26	.27	-.16	-.31	-.52**	.50**	1.00	
14. Rapid Naming (Time)	-.06	-.05	.15	-.26	-.25	-.27	-.11	-.28	-.30	.10	.22	.14	-.11	1.00

* p < .05

** p < .01

BIBLIOGRAPHY

- Adams, M. J. (1990). Beginning to read: Thinking and learning about print. Cambridge, MA: The MIT Press.
- Aguiar, L., & Brady, S. (1991). Vocabulary acquisition and reading ability. Reading and Writing: An Interdisciplinary Journal, 3, 413-425.
- Apthorp, H. (1988). Phonetic coding in reading disabled community college students. Unpublished doctoral dissertation. University of Connecticut, Storrs.
- Baddeley, A. (1986). Working Memory. Oxford: Clarendon Press.
- Baddeley, A., & Hitch, G. (1974). Working memory. In G. Bower (Ed.), Advances in learning and motivation (Vol. 8, pp. 47-90). New York: Academic Press.
- Baddeley, A., Thomson, N., & Buchanan, M. (1975). Word length and the structure of short-term memory. Journal of Verbal Learning and Verbal Behavior, 14, 575-589.
- Beck, I., Perfetti, C., & McKeown, M. (1982). Effects of long-term vocabulary instruction on lexical access and reading comprehension. Journal of Educational Psychology, 74, 506-521.
- Blalock, J. (1982). Persistent auditory language deficits in adults with learning disabilities. Journal of Learning Disabilities, 15, 604-609.
- Brady, S. (1986). Short-term memory, phonological processing and reading ability. Annals of Dyslexia, 36, 138-153.
- Brady, S. (1991). The role of working memory in reading disability. In S. Brady & D. Shankweiler (Eds.), Phonological processes in literacy: A tribute to Isabelle Y. Liberman (pp. 129-152). Hillsdale, NJ: Erlbaum.
- Brady, S., Mann, V. A., & Schmidt, R. (1987). Errors in short-term memory for good and poor readers. Memory and Cognition, 15, 444-453.
- Brady, S., Poggie, E., & Rapala, M. (1989). An investigation of speech perception abilities in children who differ in reading skill. Language and Speech, 32, 109-122.
- Brady, S., Shankweiler, D., & Mann, V. A. (1983). Speech perception and memory coding in relation to reading ability. Journal of Experimental Child Psychology, 35, 345-367.

- Brady, S., Stone, B., Fowler, A., & Winbury, N. (in progress). Training phonological awareness: An intervention study with inner-city children.
- Bryant, P., & Bradley, L. (1985). Children's reading problems. Oxford: Basil Blackwell.
- Byrne, B. & Shea, P. (1979). Semantic and phonetic memory codes in beginning readers. Memory and Cognition, 7, 333-338.
- Case, R., Kurland, D. M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. Journal of Experimental Child Psychology, 33, 386-404.
- Catts, H. (1986). Speech production/phonological deficits in reading-disordered children. Journal of Learning Disabilities, 19, 504-508.
- Catts, H. (1989a). Speech production deficits in developmental dyslexia. Journal of Speech and Hearing Disorders, 54, 422-428.
- Catts, H. (1989b). Phonological processing deficits and reading disabilities. In A. G. Kamhi & H. W. Catts (Eds.), Reading disabilities: A developmental language perspective (pp. 101-132). Boston: College-Hill Press.
- Chasty, H. (1985). What is dyslexia? A developmental language perspective. In M. Snowling (Ed.), Children's written language difficulties: Assessment and management (pp. 11-27). Windsor, Berkshire: Nfer-Nelson.
- Cohen, R. & Netley, C. (1981). Short-term memory deficits in reading disabled children in the absence of opportunity for rehearsal strategies. Intelligence, 5, 69-76.
- Conners, F., & Olson, R. K. (1990). Reading comprehension in dyslexic and normal readers: A component-skills analysis. In D. A. Balota, G. B. Flores D'Arcais, & K. Rayner (Eds.), Comprehension processes in reading (pp. 587-589). Hillsdale, NJ: Erlbaum.
- Conrad, R. (1964). Acoustic confusion in immediate memory. British Journal of Psychology, 55, 75-84.
- Crowder, R. G. (1982). The psychology of reading. New York: Cambridge University Press.
- Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior, 19, 450-466.

- Dempster, F. N. (1981). Memory span: Sources of individual and developmental differences. Psychological Bulletin, 89, 63-100.
- Dreyer, L. (1989). The relationship of children's phonological memory to decoding and reading ability. Unpublished doctoral dissertation, Columbia University.
- Dunn, L., & Dunn, L. (1981). Peabody Picture Vocabulary Test-Revised. Circle Pines, MN: American Guidance Service.
- Ehri, L. C., & Robbins, C. (1992). Beginners need some decoding skill to read words by analogy. Reading Research Quarterly, 27, 12-26.
- Ellis, A. W. (1979). Speech production and short-term memory. In J. Morton & J. C. Marshall (Eds.), Psycholinguistics 2: Structures and processes. Cambridge, MA: MIT Press.
- Ellis, A. W. (1980). Errors in speech and short-term memory: The effects of phonetic similarity and syllable position. Journal of Verbal Learning and Verbal Behavior, 19, 624-634.
- Felton, R. H., & Wood, F. B. (1989). Cognitive deficits in reading disability and attention deficit disorder. Journal of Learning Disabilities, 22, 3-13.
- Felton, R. H., & Wood, F. B. (1992). A reading level match study of nonword reading skills in poor readers with varying IQ. Journal of Learning Disabilities, 25, 318-326.
- Fowler, A. (1988). Grammaticality judgments and reading skill in grade 2. Annals of Dyslexia, 38, 73-94.
- Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), Surface dyslexia. London: Routledge & Kegan Paul.
- Futransky, J. S. (1992). Relations among verbal working memory, listening comprehension, and reading skills. Unpublished doctoral dissertation. University of Rhode Island, Kingston.
- Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. Journal of Memory and Language, 28, 200-213.
- Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? Journal of Memory and Language, 29, 336-360.

- Gathercole, S. E., Baddeley, A. D., & Emslie, H. (submitted). Phonological memory and reading development: Evidence for a critical period.
- Gathercole, S. E., Willis, C., & Baddeley, A. D. (1991). Differentiating phonological memory and awareness of rhyme: Reading and vocabulary development in children. British Journal of Psychology, 82, 387-406.
- Gough, P. B., & Hillinger, M. L. (1980). Learning to read: An unnatural act. Bulletin of the Orton Society, 30, 179-196.
- Healy, J., Aram, D., Horwitz, S., & Kessler, J. (1982). A study of hyperlexia. Brain and Language, 17, 1-23.
- Hoosain, R. (1982). Correlation between pronunciation speed and digit span size. Perceptual and Motor Skills, 55, 1128.
- Hulme, C., Thomson, N., Muir, C., & Lawrence, A. (1984). Speech rate and the development of short-term memory span. Journal of Experimental Child Psychology, 38, 241-253.
- Jorm, A. F. (1983). Specific reading retardation and working memory: A review. British Journal of Psychology, 74, 311-342.
- Jorm, A. F., & Share, D. L. (1983). An invited article: Phonological recoding and reading acquisition. Applied Psycholinguistics, 4, 103-147.
- Jorm, A. F., Share, D. L., Maclean, R., & Matthews, R. (1984). Phonological confusability in short-term memory for sentences as a predictor of reading ability. British Journal of Psychology, 75, 393-400.
- Kamhi, A., & Catts, H. (1986). Toward an understanding of developmental language and reading disorders. Journal of Speech and Hearing Disorders, 51, 337-347.
- Kamhi, A. G., Catts, H. W., & Mauer, D. (1990). Explaining speech production deficits in poor readers. Journal of Learning Disabilities, 23, 632-636.
- Kamhi, A., Catts, H., Mauer, D., Apel, K., & Gentry, B. (1988). Phonological and spatial processing abilities in language- and reading-impaired children. Journal of Speech and Hearing Disorders, 53, 316-327.
- Katz, R. (1986). Phonological deficiencies in children with reading disability: Evidence from an object-naming task. Cognition, 22, 225-257.

- Katz, R. B., Shankweiler, D., & Liberman, I. Y. (1981). Memory for item order and phonetic recoding in the beginning reader. Journal of Experimental Child Psychology, 32, 474-484.
- Klein, H. (1985). The assessment and management of some persisting difficulties in the learning disabled. In M. Snowling (Ed.), Children's written language difficulties: Assessment and management (pp. 59-79). Windsor, Berkshire: Nfer-Nelson.
- Lindamood, C. H., & Lindamood, P. C. (1975). The A.D.D. Program: Auditory Discrimination in Depth. Boston: Teaching Resources Corporation.
- Locke, J. L., & Scott, K. K. (1979). Phonetically mediated recall in the phonetically disordered child. Journal of Communication Disorders, 12, 125-131.
- Mann, V. A. (1984). Longitudinal prediction and prevention of reading difficulty. Annals of Dyslexia, 34, 117-137.
- Mann, V. A. (1985). A cross-language perspective on the relation between temporary memory skills and early reading ability. Remedial and Special Education, 6, 37-42.
- Mann, V. A., & Liberman, I. Y. (1984). Phonological awareness and verbal short-term memory: Can they presage early reading problems? Journal of Learning Disabilities, 17, 592-599.
- Mann, V. A., Liberman, I. Y., & Shankweiler, D. (1980). Children's memory for sentences and word strings in relation to reading ability. Memory and Cognition, 8, 329-335.
- Mann, V. A., Shankweiler, D., & Smith, S. T. (1984). The association between comprehension of spoken sentences and early reading ability: The role of phonetic representation. Journal of Child Language, 11, 627-643.
- Mattingly, I. G. (1972). Reading, the linguistic process and linguistic awareness. In J. Kavanagh & I. Mattingly (Eds.), Language by ear and by eye (pp. 133-147). Cambridge, MA: MIT Press.
- Olson, R. K., Davidson, B. J., Kliegl, R., & Davies, S. E. (1984). Development of phonetic memory in disabled and normal readers. Journal of Experimental Psychology, 37, 187-206.

- Pennington, B. F., Van Orden, G., Kirson, D., & Haith, M. (1991). What is the causal relation between verbal STM problems and dyslexia: In S. Brady & D. Shankweiler (Eds.), Phonological processes in literacy: A tribute to Isabelle Y. Liberman (pp. 173-186). Hillsdale, NJ: Erlbaum.
- Pennington, B. F., Van Orden, G., Smith, S. S., Green, P. A., & Haith, M. (1990). Phonological processing skills and deficits in adult dyslexics. Child Development, 61, 1753-1778.
- Perfetti, C. A. (1985). Reading ability. New York: Oxford University Press.
- Perfetti, C. A., & Lesgold, A. M. (1977). Discourse comprehension and individual differences. In P. Carpenter & M. Just (Eds.), Cognitive processes in comprehension. Hillsdale, NJ: Erlbaum.
- Rack, J. P., Snowling, M. J., & Olson, R. K. (1992). The nonword reading deficit in developmental dyslexia: A review. Reading Research Quarterly, 27, 28-53.
- Rapala, M., & Brady, S. (1990). Reading ability and short-term memory: The role of phonological processing. Reading and Writing, 2, 1-25.
- Service, Elisabet. (1992). Phonology, working memory, and foreign-language learning. The Quarterly Journal of Experimental Psychology, 45, 21-50.
- Shankweiler, D., Liberman, I. Y., Mark, L. S., Fowler, C. A., & Fischer, F. W. (1979). The speech code and learning to read. Journal of Experimental Psychology: Human Learning and Memory, 5, 531-545.
- Snowling, M. (1981). Phonemic deficits in developmental dyslexia. Psychological Research, 43, 219-234.
- Snowling, M. (1987). Dyslexia. Oxford: Basil Blackwell.
- 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, 489-507.
- Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. Reading Research Quarterly, 21, 360-407.
- Stanovich, K. E., Nathan, R. G., & Vala-Rossi, M. (1986). Developmental changes in the cognitive correlates of reading ability and the developmental lag hypothesis. Reading Research Quarterly, 21, 267-283.

- Stanovich, K. E., Nathan, R. G., & Zolman, J. E. (1988). The developmental lag hypothesis in reading: Longitudinal and matched reading-level comparisons. Child Development, 59, 71-86.
- Taylor, H. G., Lean, D., & Schwartz, S. (1989). Pseudoword repetition ability in learning-disabled children. Applied Psycholinguistics, 10, 203-219.
- Torgesen, J. (1985). Memory processes in reading disordered children. Journal of Learning Disabilities, 18, 350-357.
- Torgesen, J. (1988). Studies of children with learning disabilities who perform poorly on memory span tasks. Journal of Learning Disabilities, 21, 605-612.
- Torgesen, J., & Houck, D. G. (1980). Processing deficiencies of learning-disabled children who perform poorly on the digit span test. Journal of Educational Psychology, 72, 141-160.
- Treiman, R., Goswami, U., & Bruck, M. (1990). Not all nonwords are alike: Implications for reading development and theory. Memory and Cognition, 18, 559-567.
- Vellutino, F. R., & Scanlon, D. M. (1982). Verbal processing in poor and normal readers. In C. Brainerd and M. Pressley (Eds.), Verbal processes in children (pp. 189-264). New York: Springer-Verlag.
- Wagner, R. K., Balthazor, M., Hurley, S., Morgan, S., Rashotte, C., Shamer, R., Simmons, K., & Stage, S. (1987). The nature of prereaders' phonological processing abilities. Cognitive Development, 2, 355-373.
- Wagner, R. K., & Torgesen, J. (1987). The nature of phonological processing in the acquisition of reading skills. Psychological Bulletin, 101, 192-212.
- Wechsler, D. (1974). Wechsler Intelligence Scale for Children-Revised. New York: Psychological Corporation.
- Wolf, M. (submitted). The word-retrieval deficit hypothesis and developmental dyslexia. Learning and Individual Differences.
- Woodcock, R. W. (1987). The Woodcock Reading Mastery Tests-Revised. Circle Pines, MN: American Guidance Service.