

PHONOLOGICAL PROCESSING AND EARLY READING ABILITY

by

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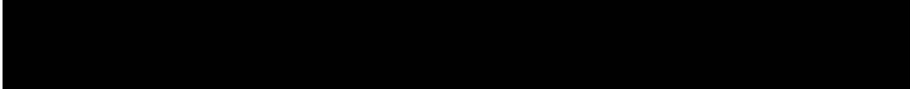
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ABSTRACT

The purpose of this investigation was to determine if representative tasks from each of three areas of phonological processing research: phonological coding in working memory, phonological coding in lexical access, and phonological awareness are representative of three separate cognitive abilities, which each contribute uniquely to primary reading skill. Two measures from each area of phonological processing, and both word decoding and reading comprehension tests were administered to second-grade children ($n = 90$). Results from correlational, hierarchical regression, and path analyses did not support the separate abilities position. However, findings were commensurate with a working memory model which classifies phonological processing tasks as involving either articulatory or acoustic coding.

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INTRODUCTION

Statement Of The Problem

Research has increasingly centred upon phonological processing as a potentially important factor in early reading skill acquisition. Three areas of phonological processing research have developed in relative isolation: phonological coding in working memory, phonological coding in lexical access, and phonological awareness. Despite this diversity, representative tasks from each research area have been shown to have significant correlations with reading ability during the primary school years, and appear to be strong predictors of the rate children acquire beginning reading skills.

It is not theoretically clear, however, whether these three areas of phonological processing represent three separate cognitive abilities, nor has this possibility been adequately investigated. Hence, it is not known how these research areas are related, or if an association exists, and there is little knowledge of their concurrent relationship to multiple measures of reading ability. These concerns are the focus of the present study.

General Overview

A plethora of research has been undertaken with the purpose of defining, measuring, and predicting problems in learning how to read. Although this research has resulted in moderately useful means of identifying children who experience reading difficulties, collectively these

studies have provided little information about the component skills and processes which form the developmental basis of reading proficiency. Hence, investigations that have focused upon determining the cognitive etiology of primary reading skill acquisition have achieved great importance.

However, a number of cognitive hypotheses of reading achievement appear to lack empirical support. Although it is obvious that beginning readers need to possess the visual skills which allow them to differentiate orthographic forms, and despite the traditional accent placed upon visual theories of reading skill acquisition, there is little evidence that reading disabled children suffer from perceptual deficits which preclude the recognition of letter shapes (c.f., Liberman & Shankweiler, 1979; Mann, 1985; Stanovich, 1982a; Swanson, 1978; Vellutino, 1979). It appears that either good and poor readers do not differ in basic visual information processing ability, or at best it accounts for only a small percentage of reading variance. Similarly, research has failed to support the position that children who experience reading difficulties fail to utilize semantic or contextual information to the same degree as normal achievers (Stanovich, 1986).

In contrast, recent research has converged on the effectiveness of phonological processing, the use of sound-based information in processing oral and written language, as a reliable discriminant of reading ability (Mann & Liberman, 1984; Swanson, Cochran, & Ewers,

1990; Vellutino & Scanlon, 1987). It has also been proposed that phonological processing is related causally to reading, in particular regarding the acquisition of word decoding skills (Baddeley, 1986; Bradley & Bryant, 1985; Stanovich, 1990).

Many divergent theories have been posited concerning the specific nature of this causal relationship. This is primarily the result of the existence of three areas of phonological processing research: phonological coding in working memory, phonological coding in lexical access, and phonological awareness, each of which has been characterized by its own criterion measures, terminology, and group of researchers (Wagner & Torgesen, 1987).

Recently however, there has developed a general consensus among these research areas (Baddeley, 1986; Perfetti, Beck, & Hughes, 1981; Swanson, Cochran, & Ewers, 1989; Torgesen, Rashotte, Greenstein, & Portes, 1987) that word decoding for beginning readers involves the following sequential process shown in Figure 1:

1. Upon presentation of a word, component sounds are isolated. The appropriate phonological codes are then activated in long-term memory, and placed in working memory. A phonological code is defined as a permanent sound-based representation of the components of oral or written language (Torgesen & Houck, 1980).

2. These codes are then blended together in working memory to form a phonological word string. This word string is an approximate

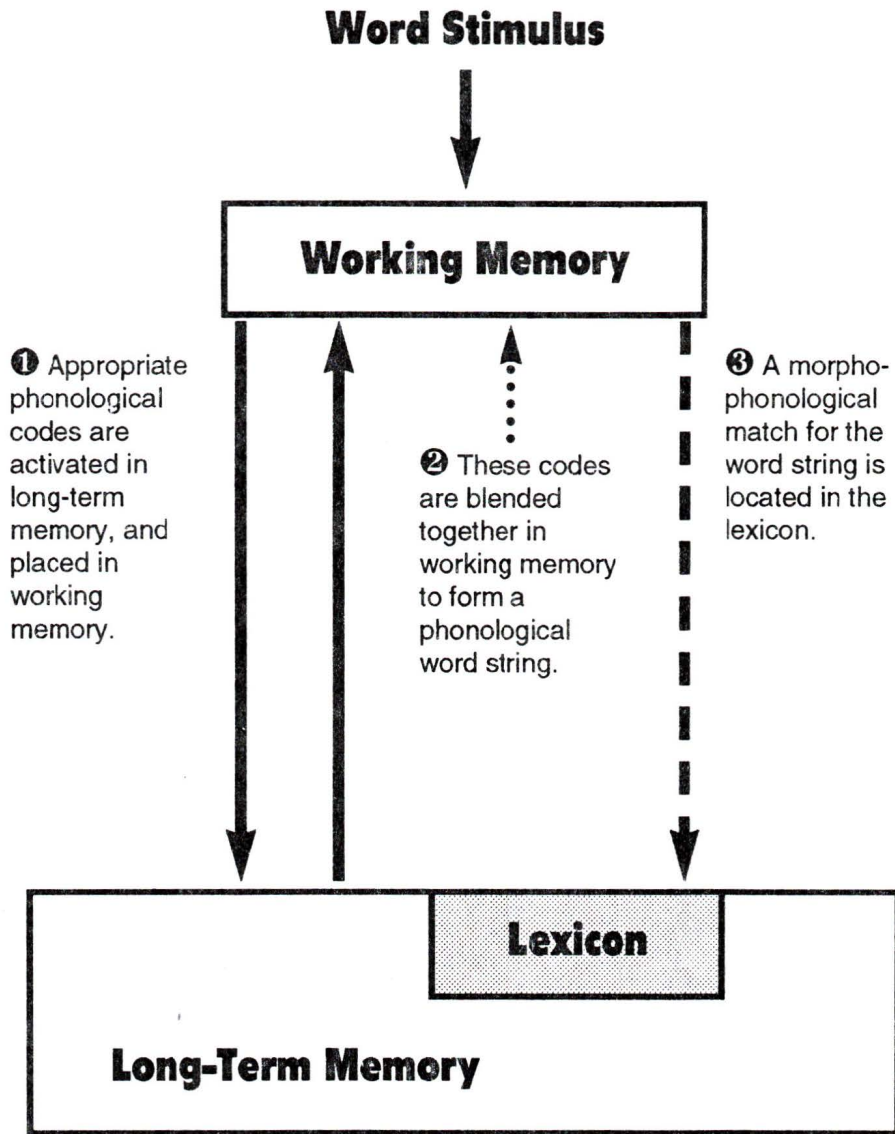


Figure 1 Phonological Processing Model of Word Decoding

representation of the original word stimulus (Stanovich, 1986).

3. The word is recognized by locating a morphophonological match for the word string in the lexicon. Morphophonological refers to the word's specific sound structure, along with its semantic and syntactic associative properties (Mann, 1985).

To facilitate an understanding of this thesis, it will be necessary to clarify these three areas of phonological processing research, along with their component terminology. This will be followed by an outline of research problems.

Phonological Coding In Working Memory

This is defined as the use of phonological codes in working memory. Working memory (Baddeley, 1986) corresponds to what is traditionally referred to as short-term memory. However, in addition to functioning as a temporary store, it is conceptualized as a limited capacity workspace in which cognitive processes are enacted.

It is thought to be comprised of a central executive and three sub-systems: the visual store, phonological store, and articulatory loop (see Figure 2). The central executive functions to operate cognitive processes, and to send information to the various sub-systems for temporary storage. Where information is placed depends upon its specific nature. Visual or spatial information is sent to the visual store, while the phonological store receives verbal information in the form of phonological codes. Although working memory functions as a temporary

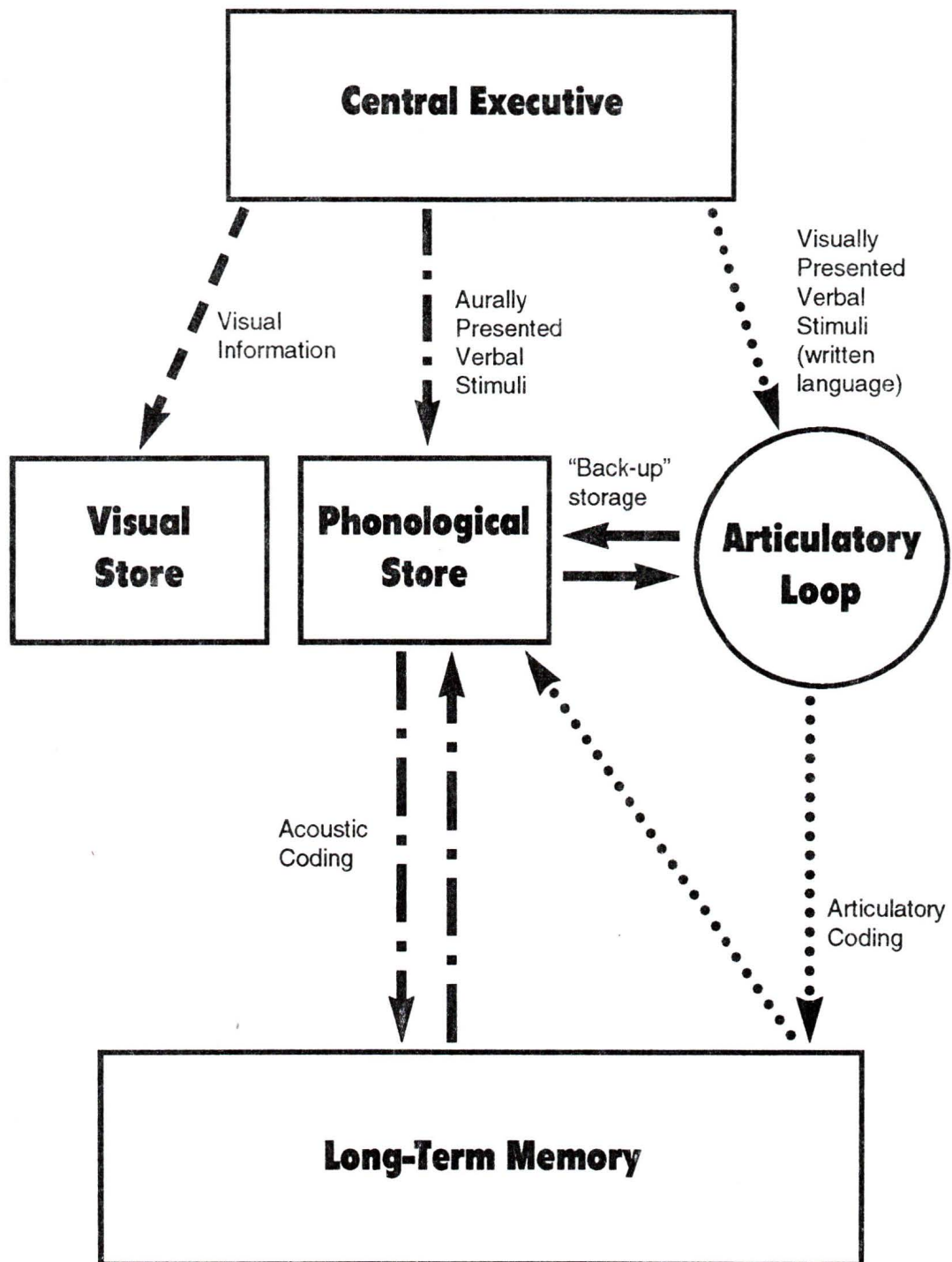


Figure 2 Working Memory

storage for both visual and verbal stimuli, there is much evidence to suggest that it is the specific use of phonological codes that are important in the development of beginning reading skills (Cohen, Netley, & Clarke, 1984; Mann, 1984; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979; Siegel & Linder, 1984; Torgesen, Rashotte, Greenstein, & Portes, 1987).

As shown in Figure 2, how phonological codes are activated in long-term memory, and placed in working memory depends upon how information is presented (Baddeley, 1986; Dempster, 1985). For verbal stimuli that are presented visually (i. e. written language), this process is undertaken by the articulatory loop. This is defined as articulatory coding. In contrast, for aurally presented language, phonological codes are automatically activated and placed in the phonological store. This is defined as acoustic coding.

Regardless of how verbal stimuli are presented, the articulatory loop also acts as a "back-up" storage system (see Figure 2). As verbal information in the phonological store has a short duration (i. e. 1.5-2 seconds), sub-vocal rehearsal processes in the articulatory loop function to hold a limited amount of phonological codes indefinitely. This is thought to be necessary for the enactment of ongoing cognitive processing (Baddeley, 1986).

Phonological Coding In Lexical Access

Phonological coding in lexical access involves the following

two-stage sequence (steps 1 and 3 shown in Figure 1). First, phonological codes are activated in long-term memory and placed in working memory. Second, these codes are used to obtain a morphophonological match in the lexicon (Perfetti, Beck, & Hughes, 1981; Wagner & Torgesen, 1987).

A substantial body of research has determined that there are at least two common means of lexical access (Crowder, 1982; McCusker, Hillinger, & Bias, 1981). One is phonological coding. The other is defined as visual access, which involves directly pairing the visual characteristics of the word with its lexical match without using phonological codes.

The majority of researchers now favour a "dual access" model of word decoding in which both phonological and visual access occur in parallel (c. f., Baron, 1979; McCusker et al, 1981; Stanovich, 1986). According to this model, phonological coding is used in varying degrees by all readers, but is thought to be especially important during the early stages of reading skill acquisition. As children develop through the late primary and middle school years, they are thought to rely less on phonological coding and more on visual lexical access as reading becomes more fluent and automatic (Crowder, 1982).

Phonological Awareness

Phonological awareness, also known as metalinguistic awareness, is generally defined as an understanding of the sound

structure of oral and written language. More specifically, it is thought to represent knowledge that there exists an ordered connection between speech sounds and the written word, reflected by a tacit awareness that oral language is comprised of syllables and phonemes, and that these are in turn represented by alphabetic script (Mann, 1985).

It is the position of a number of researchers (e.g., Mann, 1985) that phonological awareness is of unique importance in early reading skill acquisition. Specifically, a metacognitive understanding of the sound structure of language is thought to be a necessary precursor of phonological processes in both working memory and lexical access.

Research Problems

These three areas of phonological processing have each established close theoretical ties with reading skill acquisition (c.f., Baddeley, 1986; Stanovich, 1986). Moreover, numerous tasks from each area of research have shown significant concurrent and predictive correlations with early reading ability, relatively independent of IQ. In addition, tasks within each research area have been shown to be highly correlated (Bradley & Bryant, 1985; Mann & Liberman, 1984; Stanovich, Cunningham, & Cramer, 1984; Wagner & Torgesen, 1987; Wolf, 1984).

It is however neither theoretically nor empirically clear that they are representative of three distinct types of phonological processing. This issue is of practical significance regarding both the identification of children at high risk of reading failure, and the development of

appropriate intervention strategies (Blachman, 1984; Wagner & Torgesen, 1987).

The lack of theoretical clarity is related to concerns regarding what respective tasks from each area of research actually measure. Specifically, phonological awareness and phonological coding in lexical access measures which account for the greatest variance in reading ability can also be classified as theoretical measures of working memory (Ackerman, Dykman, & Gardner, 1990; Baddeley, 1986; Torgesen, Wagner, Simmons, & Laughton, 1990).

Similarly, there have been few empirical studies that have undertaken correlational comparisons between representative tasks from these different areas of phonological processing research, and the degree they concurrently account for the reading performance of primary children. Moreover, the majority of these have included comparisons between only two research areas, and are collectively characterized by inadequate numbers of tasks, subjects, and reading measures.

There are two research problems for this study. First, are tasks used to measure phonological awareness, phonological coding in lexical access, and phonological coding in working memory representative of three distinct abilities, which each function as determinants of reading ability? Second, can representative tasks from these areas of research be classified empirically as working memory measures that involve either articulatory or acoustic coding, and to what degree do each contribute

uniquely to our understanding of reading?

LITERATURE REVIEW

Introduction

A brief summary of the literature will be undertaken for each of three areas of phonological processing- phonological coding in working memory, phonological coding in lexical access, and phonological awareness. Within each area of research the following will be discussed: a) theoretical connections with early reading skill acquisition, b) correlational relationships between representative tasks and reading achievement, c) longitudinal studies, d) relationships between representative tasks, and e) theoretical concerns. This will be followed by an analysis of comparison studies that have investigated relationships between these different areas of phonological processing research. An outline of research hypotheses will conclude the review.

Phonological Coding In Working Memory

Theoretical Connections To Early Reading Skill Acquisition

Phonological coding in working memory has been posited to play an important role in the reading process at two levels. First, much evidence suggests that a phonological short-term store may play an integral role in the development of word decoding skills (Baddeley, 1986). Upon translation of the written word into component sounds, efficiency in storage is thought to be important in enabling the beginning reader to devote the maximum amount of cognitive processing capacity to the complex task of blending phonemes to form words (Baddeley,

1986; Torgesen, Kistner & Morgan, 1987).

Second, skill at phonological coding in working memory is thought to confer another processing advantage in addition to word recognition. Subsequent to lexical access, sequences of words must be held in temporary storage, while comprehension processes operate to integrate them into a semantic-based conceptual structure in long-term memory. Although some researchers have questioned the importance of post-lexical phonological coding in reading (e.g., Torgesen, Rashotte, Greenstein, & Portes, 1987), there is evidence that disabled readers have a reading comprehension deficit independent of their problems at the word decoding level, provided by the high correlations obtained between reading and listening comprehension measures (e. g., Stanovich, 1986).

Correlational Studies

There is considerable evidence that groups of reading disabled children, as compared to normal readers, perform poorly on a number of short-term memory tasks (Bauer, 1977; 1979; Cohen, 1982; Cohen & Netley, 1978, 1981; Koppitz, 1975; Rugel, 1974; Torgesen et al, 1990). Span tasks have traditionally been used as measures of short-term memory proficiency, and reduced memory span for strings of digits, letters, words, and sentences, presented visually or aurally, has frequently been found to correlate significantly with reading ability during the primary school years.

For example, Heulsman (1970) and Rugel (1974) reviewed the WISC profiles of reading disabled children and found, in the majority of studies, that disabled readers were significantly ($p < .05$) poorer on the Digit Span sub-test than IQ matched controls. Similar results have been obtained in a more recent studies (e.g., Byrne & Arnold, 1981).

These findings have been extended by other investigations. Spring (1976) found that performance on a digit span test similar to the WISC-R significantly ($p < .01$) discriminated groups of good and poor readers. Similarly, Koppitz (1975) tested the digit span of reading disabled and normally achieving children using either visual or auditory presentation. With overall IQ controlled for, the performance of poor readers was significantly ($p < .001$) worse on both measures.

Siegel & Linder (1984) obtained comparable results for short-term letter span. Subjects, 7-9 year-old children ($N = 67$) divided into reading disabled and non-disabled groups, were administered tasks that involved the visual or auditory presentation of letter strings. With overall IQ controlled for, the disabled readers performed significantly ($p < .001$) poorer on both tasks. Similar results have been reported for words (Byrne & Shea, 1979), and verbatim recall of sentences (Mann, Liberman, & Shankweiler, 1980; Mann & Liberman, 1984).

Other studies have shown that even within the normal skill range of reading, short-term memory span performance correlates with reading ability in young children. For example, Hulme (1988) tested 7-8 ($n = 40$)

and 9-10 ($n = 43$) year old children on an auditory word span memory test, and found that in both groups performance correlated significantly ($r = .57$ for 7-8 age group and $.45$ for 9-10; $p < .01$) with reading comprehension ability. Moreover, with the effects of age, and overall IQ partialled out, these correlations ($r = .31$ and $r = .28$) remained significant ($p < .05$).

Although group differences in memory span have frequently been found, there is considerable performance overlap between disabled and normal readers and a memory span deficit is not found in all children who experience reading difficulties (e.g., Ellis, 1979; Hulme, 1988; Torgesen et al, 1990). In other words, short-term memory span problems may contribute to the reading problems of only some reading disabled children, and may be one source of variation in reading skill among normal achievers. Hence, although there appears to be an association between reading difficulties and deficient performance on short-term span tasks, this relationship is far from linear.

Longitudinal Studies

Performance on short-term span tasks has also been shown to predict later reading achievement (Cohen, 1982; Jorm, Share, Mclean, & Matthews, 1986; Mann & Liberman, 1984). For example, Mann and Liberman (1984) examined the relationship between memory span of kindergarten children ($N = 60$) for word lists and their reading skills at the end of first grade. With IQ controlled for, a correlation of $.39$ ($p < .01$) was

obtained.

Other longitudinal studies have essentially replicated these findings. For example, Cohen (1982) obtained a significant ($r = .47$; $p < .01$) correlation between an auditory digit span task administered in kindergarten ($N = 100$), and a standardized reading test given one year later. Similarly, Jorm et al. (1986) found that children classified as reading disabled at the end of the second grade had differed significantly ($p < .01$) from normals on a word span measure in kindergarten.

Comparisons Between Representative Tasks

Numerous studies (e.g., Torgesen & Houck, 1980; Cohen, 1982), despite involving a variety of stimuli, have shown high correlations among short-term span tasks. This is taken as evidence of the existence of a single latent ability. However, span tasks that differ in presentation mode tend to share less variance (Baddeley, 1986; Torgesen et al, 1990), thought to be the result of the differential role of sub-vocal rehearsal in aural and visual presentation.

Summary

A brief review of phonological coding in working memory research can be summarized as follows: a) Phonological coding in working memory is posited to play an important role in the development of both word decoding and reading comprehension skills; b) significant concurrent and predictive correlations have been obtained between a variety of short-term span measures and reading achievement, relatively

independent of IQ; and c) high correlations have been obtained between numerous span measures, thought to be evidence of a unitary construct.

Theoretical Concerns

As discussed earlier, short-term span tasks have been the most frequently used measure of phonological coding in working memory. However, as working memory is thought to involve both storage and cognitive processing functions, at best short-term span tasks measure only the storage component of working memory. In other words, a holistic measure of phonological coding in working memory should involve not only temporary storage, but also ongoing cognitive processing.

Phonological Coding In Lexical Access

Theoretical Connections To Early Reading Skill Acquisition

Phonological coding in lexical access is thought to be important in the acquisition of word decoding skills. First, as automaticity in "naming" the sound of a letter is considered vital for progress in learning to decode words (Jorm & Share, 1983; Laberge & Samuels, 1974; Stanovich, 1986), slow retrieval speed for letter sounds is thought to impair the development of sound blending in working memory. Second, difficulty in locating appropriate sound structures in the lexicon is thought to hinder the word recognition process. Collectively, these impairments would lead to fewer repetitions of whole words so that those newly encountered would have less opportunity to become overlearned and automatized

(Laberge & Samuels, 1974; Stanovich, 1982b).

Correlational Studies

Phonological coding in lexical access has traditionally been measured by rapid naming of visually presented: objects, colors, numbers, letters, words, and pseudowords (Wagner & Torgesen, 1987). There is some consensus that collectively these tasks measure the efficiency or speed in which phonological codes are activated in long term memory, and placed in working memory (Jorm & Share, 1983; Snowling, 1980). In addition, naming speed for words and pseudowords is thought to measure automaticity in locating appropriate sound structures in the lexicon (e.g., Crowder, 1982).

Rapid naming measures are typically classified according to the paradigm used (Stanovich, Freeman, & Cunningham, 1983; Wagner & Torgesen, 1987). Serial naming tasks involve measuring the rate which subjects can overtly articulate a series of items (i. e. digits or letters), with all items visible simultaneously. In contrast, isolated or discrete trial naming tasks measure the time or latency in which subjects can identify or name an individual item.

Serial Naming

Reading disabled children have repeatedly been found to be slower at naming series of verbal stimuli. For example, Denckla & Rudel, (1976) compared the ability of 7-11 year old dyslexic, non-dyslexic learning disabled, and normal control children ($N = 228$) to rapidly name

serially presented objects, colors, numbers, and letters. Overall IQ was controlled for. Although naming errors were rare for all groups of stimuli, the dyslexic group had significantly ($p < .001$) longer latencies for the serial naming of letters, digits, and objects, than either control group.

Similarly, Wolf (1982) investigated the relationship between serial naming of letters, numbers, and colors, and performance on standardized oral reading and comprehension tests. Subjects were 6-11 year old children ($N = 64$), classified as poor and average readers. The poor readers were found to be significantly ($p < .001$) slower on all serial naming measures.

However, other studies have indicated that serial naming of linguistic stimuli (ie. digits, letters and words), as compared to objects and colors, are more reliable discriminants of reading ability. For example, Spring (1976), using 7-12 year old boys ($N = 28$), found that poor readers were significantly ($p < .01$) slower than good readers in rapidly naming digits, colors, and objects. However, rapid serial naming of digits accounted for most of this variance. Similarly, Katz & Shankweiler (1983) investigated the ability of good and poor reading second graders to serially name objects, colors, letters, and words, and found significant differences for only linguistic stimuli.

Isolated Trial Naming

Perfetti, Finger, & Hogaboam (1978) and Stanovich (1981) used a isolated trial naming procedure in which subjects were asked to rapidly

name items one at a time. Perfetti et al. (1978) found no difference between good and poor reading third graders, the latter averaging one year below grade level, for pictures, colors, and digits. Stanovich (1981) replicated these findings, in failing to distinguish good and poor readers on letter naming.

However, Stanovich, Freeman, & Cunningham (1983) did obtain significant ($p < .01$) correlations between discrete trial naming of letters and reading achievement. Subjects were groups of third ($n = 56$) and fifth ($n = 50$) graders, classified as good and poor readers. These contradictory findings were explained as the result of the extreme ranges of reading impairment in the Stanovich et al (1983) study that may have been absent in previous investigations. Stanovich also pointed out that despite the significance of these correlations, they were substantially less than those obtained in studies that utilized a serial naming paradigm. Lorschach & Grey (1985) replicated these findings.

However, one discrete trial task on which robust correlations with reading ability are consistently obtained is naming speed for pseudowords (Hogaboam & Perfetti, 1978; Stanovich, 1982a, 1986). Perfetti & Hogaboam (1975) investigated the relationship between reading comprehension ability and isolated naming rate for a set of stimuli comprised of real words and pseudowords. Subjects were 32 third graders and 32 fifth graders, classified within groups as good or poor readers. Although poor readers differed at both grade levels in

having significantly ($p < .01$) longer latency times, simple effects tests revealed that the rate of naming pseudowords was a significantly ($p < .05$) better discriminant of reading comprehension ability than vocalization latency for words.

These results were replicated in a follow-up study (Hogaboam & Perfetti, 1978). Subjects were third ($n = 36$) and fourth ($n = 30$) graders, similarly classified as good and poor readers. Stimuli were 1 and 2 syllable real words and pseudowords. The good readers at both grade levels had significantly ($p < .001$) shorter vocalization latencies than the poor readers, although again pseudoword naming was found to be a significantly ($p < .01$) better discriminant of reading comprehension ability than discrete trial naming of words.

Longitudinal Studies

Wolf (1984) investigated the relationships between a variety of rapid naming and reading ability measures. Subjects were 115 kindergartners, 98 of whom remained participants at the end of the second grade. The rapid naming tasks, administered at the end of the kindergarten year, included the serial naming of letters, numbers, objects, and colors. Reading measures included the Gates-MacGinitie Reading Test, and the Grey Oral Reading Test, given at the end of kindergarten, first grade, and second grade school years.

For the reading tests administered in kindergarten, all four naming tasks were significant ($p < .001$) correlates. At the end of grade 1, each

variable was also found to be a significant ($p < .001$) predictor of performance on each of the reading measures. By grade 2, however, only rapid serial naming for letters and numbers remained significant predictors of performance on the oral reading ($p < .001$), and reading comprehension ($p < .05$) tests. Wolf, Bally, & Morris (1986) replicated these results.

Comparisons Between Representative Tasks

High correlations have typically been obtained between rapid naming tasks that varied in type of stimuli (i. e. letters, digits, pseudowords), and experimental paradigm (serial vs. isolated trial). For example, Wolf et al. (1986) found that latency in pseudoword naming was significantly ($r = .49$; $p < .001$) correlated with rapid serial naming of digits and letters. A similar finding was obtained (Torgesen et al,1990) for serial and isolated trial naming of digit and letters ($r = .46$; $p < .001$).

Summary

A brief review of phonological coding in lexical access research has revealed the following: a) The use of phonological codes in lexical access is thought to be important for the development of word decoding skills; b) significant concurrent and predictive correlations between rapid naming measures and reading ability have been obtained, largely independent of IQ; c) the most reliable correlations with reading achievement involve the serial naming of linguistic stimuli, and discrete trial naming of pseudowords; and d) there is some evidence that rapid

naming measures are representative of a unitary construct, as provided by the high correlations obtained among the various tasks.

Theoretical Concerns

Although rapid naming tasks have been found to highly correlate, there are two related concerns regarding what these tasks actually measure. First, phonological coding in lexical access should be measured by the degree of automaticity in which: a) strings of phonological codes are activated in long-term memory, and placed in working memory; and b) a morphophonological match for the string of retrieved phonological codes can be located in the lexicon (Stanovich, 1986; Wagner & Torgesen, 1987). Based upon this position, none of the tasks previously outlined can be considered holistic measures of phonetic coding in lexical access. Although all conceivably involve the retrieval of phonological codes, only naming rate for words involves lexical access. However, latency in word reading is confounded by visual access (especially among skilled readers) and cannot be considered a "clean" measure of phonological coding. Similarly, while rapid naming of pseudowords is thought to avoid this limitation, pseudowords cannot have a lexical referent because they are not real words.

Second, rapid naming tasks which correlate most highly with reading achievement, rapid serial naming for digits or letters and latency for pseudoword naming, can be theoretically considered as measures of

working memory. Although serial naming of digits and letters involve the retrieval of phonological codes, they are also considered by some researchers (e.g., Ackerman et al, 1990; Baddeley, 1986) to be an overt measure of the rate in which phonological codes can be rehearsed in the articulatory loop. Some evidence for this position is provided by the large amount of variance accounted for in serial naming tasks by counting rate (i. e. the rate subjects can repeatedly count from 1 to 10), considered by many researchers to be a relatively pure measure of sustained rehearsal speed (e.g., Spring & Perry, 1986).

According to the phonological processing model of word reading skill acquisition (Perfetti et al, 1981), pseudoword reading would arguably require both the storage and blending of phonemes to form a phonological word string. As working memory is thought to involve both storage and ongoing cognitive processing, and no lexical access can occur, rate of pseudoword naming can be considered to holistically measure the efficiency of phonological coding processes in working memory (Baddeley, 1986).

Moreover, the robust correlations obtained between rapid serial naming tasks and latency in pseudoword reading (ie. Wolf et al, 1986) could be explained by the working memory model as follows. First, as pseudowords are visually presented, phonological codes must undergo articulatory coding before being blended. Second, sub-vocal rehearsal is thought to be necessary to maintain information in working memory in

order for ongoing cognitive processes (i. e. blending) to be enacted. In summary, inefficiency in utilizing rehearsal, as measured by slow articulation of a series of verbal stimuli, would impair both the storage and maintenance of phonological codes in working memory (Baddeley, 1986).

Phonological Awareness

Theoretical Connections To Early Reading Skill Acquisition

It is the position of a number of researchers (Bradley & Bryant, 1985; Fox & Routh, 1980; Jorm & Share, 1983; Liberman & Shankweiler, 1979; Mann, 1985; Stanovich, 1986) that phonological awareness is important in the acquisition of word decoding skills, specifically for the enactment of both working memory and lexical access processes. First, unless phonological awareness is achieved, the alphabet will make no sense as representative language, making difficult the blending of syllables and phonemes (Stanovich, 1986). Second, without knowledge of the phonological units of oral and written language, children would be unable to access the morphophonological representation of words in the lexicon, and the phonetic rules which relate phonological word strings to these morphophonological representations (Mann, 1985).

Correlational Studies

Numerous tasks have been used to measure phonological awareness. All are aural in presentation, and involve the manipulation of syllables or phonemes. Examples of phonological awareness measures

include segmenting a word into component phonemes or syllables, reversing their order, or blending together syllables or phonemes presented in isolation to form a word (Lewkowicz, 1980). Phonological awareness proficiency is also measured by sound categorization and rhyme production tasks.

Considerable evidence from widely diverse subject populations shows that a strong positive relation exists between children's awareness of the phonemic and syllabic structure of speech and their success in learning to read (Fox & Routh, 1975; Lundberg, Olofsson, & Wall, 1980; Perfetti, Beck & Hughes, 1981; Rosner & Simon, 1971). Collectively, these studies have shown that phonological awareness develops at about the same time children begin to read, and that phonological awareness is highly correlated with reading achievement during the primary school years.

In a sample of 4-6 year-olds, Liberman, Shankweiler, Fisher, & Carter (1974) found that none of the nursery children and only 17% of the kindergartners could identify the number of phonemes in an aurally presented word. About half the 4-5 year old children could distinguish the number of syllables. At age 6 however, 70% could segment phonemes and 90% could identify syllables. Similar results were reported by Calfee, Chapman, & Venezky (1972) for 5 year old subjects required to distinguish whether two words sounded the same at the end, and to provide a rhyming word for a presented word.

Rosner and Simon (1971) studied the relationship between ability to say a word without one of its sounds and scores on the Stanford Achievement Test, involving randomly selected Kindergarten ($n = 50$), Grade 1 ($n = 53$), and Grade 2 ($n = 41$) children. The relationship, with overall IQ controlled for, was significant ($p < .01$) at all grade levels. Similar relations have been found between other measures of phonological awareness and reading achievement (e.g., Fox and Routh, 1980; Zifcak, 1981).

Longitudinal Studies

There is a substantial body of evidence indicating that phonological awareness tasks are moderate to strong predictors of the speed with which children acquire reading fluency in the early grades (Bradley & Bryant, 1985; Fox & Routh, 1980; Jorm & Share, 1983; Liberman & Shankweiler, 1979; Liberman, 1982; Trieman & Baron, 1981; Williams, 1980). For example, Calfee, Lindamood, & Lindamood (1973) found that more than half of the total reading variance in Grades 1-2 could be predicted from performance on the Lindamood Auditory Conceptualization Test which measures phonemic segmentation skills. Similarly, Liberman et al. (1974) found a syllable segmentation task administered in kindergarten to be a significant discriminant of Grade 1 reading ability. They noted that 85% of a population of kindergarten children who went on to become good readers in the first grade correctly counted the number of syllables in aurally presented words, whereas

only 17% of the future disabled readers could do so. Finally, Fox & Routh (1980) tested a group of first graders on a simple phoneme segmentation task. A longitudinal follow up study indicated children who had difficulty with this task showed marked deficits in reading ability three years later.

Other studies have extended these findings. Lundberg et al. (1980) examined the nature of the relationship between phonological awareness skills in kindergarten and later reading achievement. However, it had a number of advantages over the majority of previous studies as it included a larger number of subjects and phonological awareness tasks, along with both Grade 1 and Grade 2 reading measures.

Kindergarten children ($N = 200$) were administered blending, segmentation, rhyme production, and reversal tasks, involving the manipulation of both syllables and phonemes. One year later, students remaining in the study ($n = 146$) were given tests of intelligence, and word reading, with the same measures administered in Grade 2 ($n = 133$). With IQ partialled out, the majority of correlations between the phonological awareness tasks and reading achievement in both Grade 1 and 2 were significant ($p < .001$), with the highest correlations obtained for phoneme blending and phoneme reversal.

Other studies have provided similar evidence that deficient performance on phonological awareness measures can presage future reading difficulties. For example, Bradley and Bryant (1985) examined

relations between phonological awareness and reading achievement in a 3 year longitudinal study involving nonreaders, 4-5 years of age at the beginning of the study. Phonological awareness was measured with a sound categorization task in which children listened to lists of three or four words, all but one of which shared an initial, medial, or final sound, and then indicated which word was the odd one out. Approximately 3 years later, these children were given two standardized reading tests. Holding constant the variables of age, IQ, and memory for word lists, the sound categorization task contributed significant ($p < .001$) unique variance to both reading measures.

Comparisons Between Representative Tasks

Stanovich, Cunningham, & Cramer (1984) examined the nature of the relationship between various phonological processing tasks, and how these measures compared as predictors of reading ability. Ten phonological awareness tasks were administered to 49 kindergarten students. These included three rhyme production, and four multiple choice sound categorization tasks, along with phoneme deletion and addition measures, with a standardized reading test (Metropolitan Achievement Test) given 1 year later.

Moderate to high correlations were obtained between phonological awareness measures. Moreover, a principal factor analysis yielded only one significant factor. Similarly, when these same tasks were entered into a stepwise regression with reading ability in grade 1

($n = 31$) as the dependent variable, they were highly redundant.

Collectively, this was taken as evidence that despite the differing task requirements there was every indication that these tasks were tapping a similar construct. This conclusion was supported by Wagner & Torgesen (1987) who showed that the majority of phonological awareness tasks used in the Lundberg et al (1980) study were representative of a single latent ability.

Summary

A review of phonological awareness research can be summarized as follows: a) Phonological awareness is postulated as playing an important role in the acquisition of word decoding skills; b) strong relations have been reported between performance on various measures of phonological awareness and early reading ability, largely independent of IQ; c) longitudinal studies have revealed that performance on phonological awareness tasks significantly predicts subsequent reading performance; d) tasks involving the manipulation of phonemes (i. e. phoneme blending and sound categorization), as opposed to syllables, appear to yield the most substantive correlations with reading ability; and e) there is evidence from factor analytic studies which suggests that phonological awareness tasks are representative of a unitary construct.

Theoretical Concerns

Although there is evidence to suggest that the large number of phonological awareness tasks utilized are measuring a single cognitive

ability, those which account for the greatest amount of reading variance can also be theoretically classified as measures of working memory. In other words, in the sense that these tasks rely on a combination of storage and ongoing cognitive processing, it can be posited that the crucial performance determinant is the use of phonological codes in working memory rather than phonological awareness (Baddeley, 1986; Wagner & Torgesen, 1987).

For example, to complete the sound categorization task, arguably the subject must temporarily store four aurally presented words, while simultaneously determining which word does not rhyme. Similarly, phoneme blending would seem to involve the temporary storage of aurally presented phonemes, with the parallel process of blending them to form words. Hence, regarding the working memory model, these measures would necessarily involve the storage of phonological information through acoustic coding, with rehearsal in the articulatory loop functioning to maintain stimuli until task completion.

In contrast, while proponents of phonological awareness (Bradley & Bryant, 1985; Mann, 1985) generally concede that temporary memory processes are involved in tasks such as phoneme blending and sound categorization, its role is viewed as facilitative. In other words, both working memory and phonological awareness are thought to be uniquely important in reading skill development. However, based upon available empirical evidence, this argument is equivocal.

Comparison Studies

The literature has been reviewed for each of three areas of phonological processing. Within each area of research: a) There are theoretical connections to the development of reading skills during the primary school years; b) numerous studies have been undertaken using a variety of tasks, subjects, and experimental designs, and significant concurrent and predictive correlations with various reading measures have been obtained; and c) representative tasks have been found to be highly correlated, often taken as evidence of a unitary construct.

Nevertheless, numerous theoretical concerns remain regarding what these tasks actually measure. Moreover, there have been few empirical studies specifically designed to investigate the nature of possible relationships between tasks representing different kinds of phonological processing, and the vast majority of these have included comparisons between only two research areas.

These comparison studies will be outlined, followed by a discussion of their collective limitations. Research hypotheses for this study will then be summarized.

Working Memory And Lexical Access

Torgesen et al. (1990) investigated the relationship between serial naming of digits and letters, and visual and aural digit span measures. Subjects ($N = 79$) were randomly selected second graders. Significant correlations were obtained between visual and aural digit

span ($r=.52$; $p < .001$), and between serial naming of digits and letters ($r=.77$; $p < .001$). However, the relationship between the serial naming tasks and visual digit span was also significant ($r= .25$; $p < .05$). Despite this shared variance, the higher correlations between representative tasks within each area of research were taken as evidence of the existence of two largely separate cognitive abilities.

Working Memory And Phonological Awareness

In a two-year longitudinal study, Mann & Liberman (1984) administered tests of phonological awareness (syllable segmentation), short-term memory (word span), and IQ (Peabody Picture Vocabulary Test) to randomly selected kindergarten children. One year later subjects ($n = 62$) were again administered the short-term memory test, along with a measure of reading ability (Woodcock Reading Mastery Test).

An ANCOVA was undertaken with age and IQ as covariates, the phonological awareness and short-term memory measures as independent variables, and reading as a three way categorical dependent variable. The main effects of syllable counting ($p < .001$) and word string memory ($p < .01$) were both found to be significant predictors of first grade reading ability.

Performance on the syllable counting task correlated ($p < .05$) with word span. However, a regression analysis of reading ability for data collected in kindergarten revealed that both contributed significant unique variance. An analogous regression for first grade data replicated

kindergarten results. Mann & Liberman (1984) concluded that, despite sharing some variance, these tasks were representative of two relatively distinct types of processing.

Phonological Awareness And Lexical Access

Blachman (1984) investigated the possibility that phonological awareness tasks and rapid naming measures were representative of a global phonological processing factor. Subjects were 34 kindergartners and 34 first graders. Phonological awareness tasks included rhyme production (Calfée et al, 1972) and syllable and phoneme segmenting (Liberman et al, 1974), while serial naming of objects, colors, and letters comprised the rapid naming measures. The rapid naming of letters and phoneme segmentation tasks were administered only to the first grade.

For the kindergarten sample, out of four possible correlations between rapid naming and phonological awareness skills, only the relationship between the rapid naming of colors and syllable segmentation was significant ($p < .05$). The four predictor variables were entered into a stepwise multiple regression, with the word reading subtest of the WRAT serving as the dependent variable. The rapid naming of colors and rhyme production both contributed significant ($p < .001$) unique variance.

For the first grade sample, there were no significant relationships between the rapid naming and phonological awareness measures. Similarly, a stepwise multiple regression analysis revealed that both

rapid naming of letters and the phoneme segmentation task contributed significant ($p < .001$) unique reading variance.

It was concluded that phonological awareness and rapid naming ability are representative of two largely distinct factors. However, the author also noted that an inadequate number of subjects were used, and that generalizations should be limited to the low-average group of children the subjects represented.

Stanovich, Cunningham, & Freeman (1984) investigated the relationship between latency naming for pseudowords and two phonological awareness tasks- strip initial consonant (Calfee et al, 1972) and sound categorization (Bradley & Bryant, 1985). Subjects were randomly selected first graders ($N = 56$).

The two phonological awareness tasks were robustly ($r = .52$; $p < .01$) correlated. However, the relationship between pseudoword naming and the sound categorization task was also significant ($r = -.33$; $p < .05$), with the correlation ($r = -.24$) between pseudoword naming and the strip initial consonant task approaching significance.

In a hierarchical regression analysis with reading scores from the Metropolitan Achievement Test as the dependent variable, the two phonological awareness tasks produced a multiple correlation of .494 when entered first. The pseudoword naming task, however, accounted for 14.2 % additional variance beyond that accounted for by the two phonological awareness tasks. A "bottom-up" regression analysis

produced a similar result in finding that the two phonological awareness measures accounted for significant variance when entered after pseudoword naming. Moreover, a pathway analysis indicated that both phonological awareness measures and pseudoword naming were directly related to reading ability. These results were interpreted as evidence that although the phonological awareness and pseudoword naming tasks shared significant variance, they were largely representative of unique factors.

Working Memory, Lexical Access, And Phonological Awareness

Mann (1984) administered measures of phonological awareness (phoneme reversal), working memory (short-term word span), lexical access (serial letter naming), and IQ (Peabody Picture Vocabulary Test) to 44 randomly selected kindergartners. One year later, reading ability was measured by the word recognition and word attack sub-tests of the Woodcock Reading Mastery Test.

With IQ held constant, significant relationships with first grade reading ability were attributed to phoneme reversal ($\beta = .61$, $p < .001$), and short-term word span ($\beta = .39$, $p < .001$), with the partial correlation between serial letter naming speed and reading ability approaching significance ($p < .1$). It was concluded by the authors that these measures were tapping different aspects of phonological processing.

In summary, the limited number of comparison studies have resulted in somewhat contradictory findings. On one hand, there is some

support for the position that each research area is distinct, as evidenced by the higher correlations obtained within as opposed to between research areas, and the unique reading variance accounted for by representative tasks. However, the majority of comparison studies have also revealed significant correlations between tasks from each area of phonological processing. Moreover, the nature of this shared variance remains unexplained.

There are a number of concerns with these comparison studies. To date, only one (Mann, 1984) has actually involved comparisons from all three research areas, and their concurrent relationship to reading achievement. In addition, there are three collective limitations with these comparison studies regarding the inadequate number of representative tasks, reading measures, and subjects utilized. First, many (i. e. Mann & Liberman, 1984; Stanovich, Cunningham & Freeman, 1984) used only one representative task from each research area. Although tasks within each body of research have been found to be highly correlated, it is possible they may show differential relationships with tasks from other areas of phonological processing. Second, all but one of these comparison studies used a single criterion measure. As there is a general consensus that the developmental reading process involves the acquisition of both decoding and comprehension skills (c.f., Stanovich, 1986), it is the position taken here that the relationship between phonological processing tasks and reading achievement may be

dependent upon the specific type of reading skill measured. Third, too few subjects were used in the majority of comparison studies (e.g., Blachman, 1984; Mann & Liberman, 1984). Given the heterogeneity of performance on phonological processing tasks and criterion measures, this may invalidate extant conclusions regarding the nature of the relationship between phonological processing variables.

In contrast, this present investigation is thought to be the first to examine relationships between multiple measures of phonological coding in working memory (auditory digit span and visual digit span), phonological coding in lexical access (discrete trial naming of pseudowords and serial naming of digits), and phonological awareness (sound categorization and sound blending), and the degree they concurrently account for variability in performance on both decoding and comprehension measures. Moreover, unlike many previous comparison studies a statistically adequate number of subjects were utilized.

Research Hypotheses

The position that these research areas represent three separate cognitive abilities is shown in Figure 3. Each area of phonological processing is measured by two criterion tasks.

In contrast, the working memory model of phonological processing (shown in Figure 4) classifies these tasks as involving either articulatory or acoustic coding. Specifically, pseudoword naming, rapid serial naming, and visual span (as these involve visual presentation) are

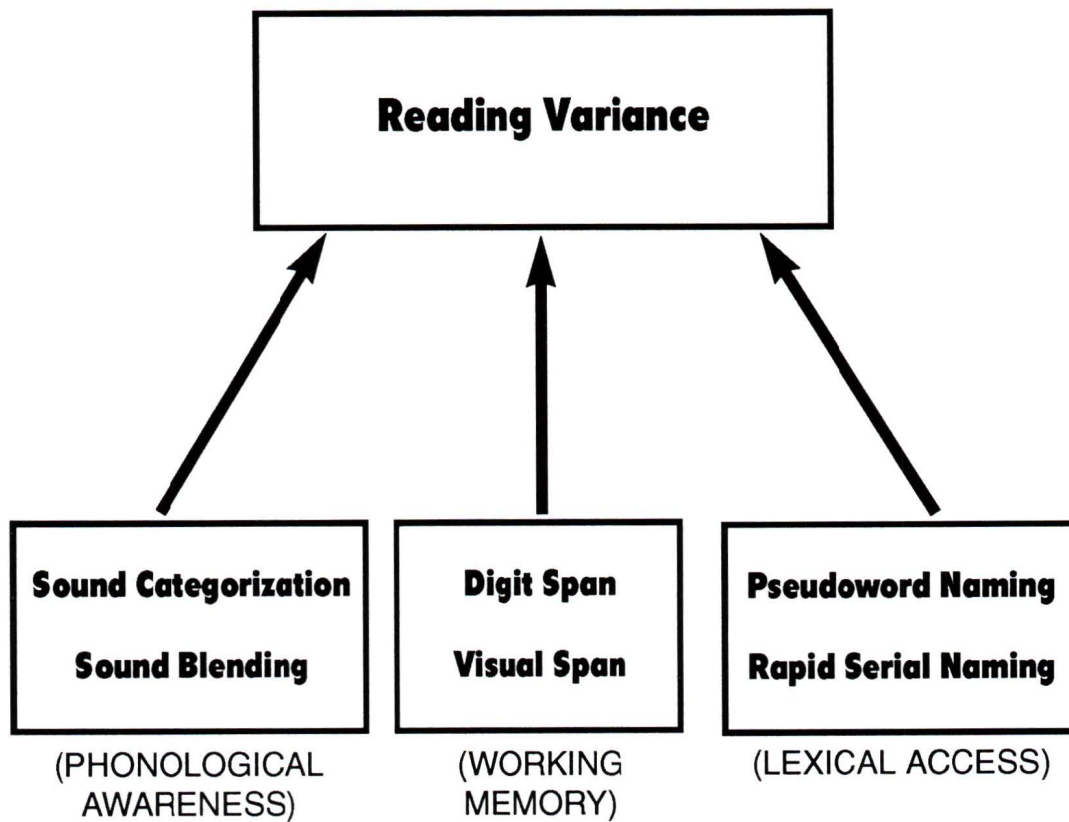


Figure 3 Phonological Processing as Three Separate Cognitive Abilities

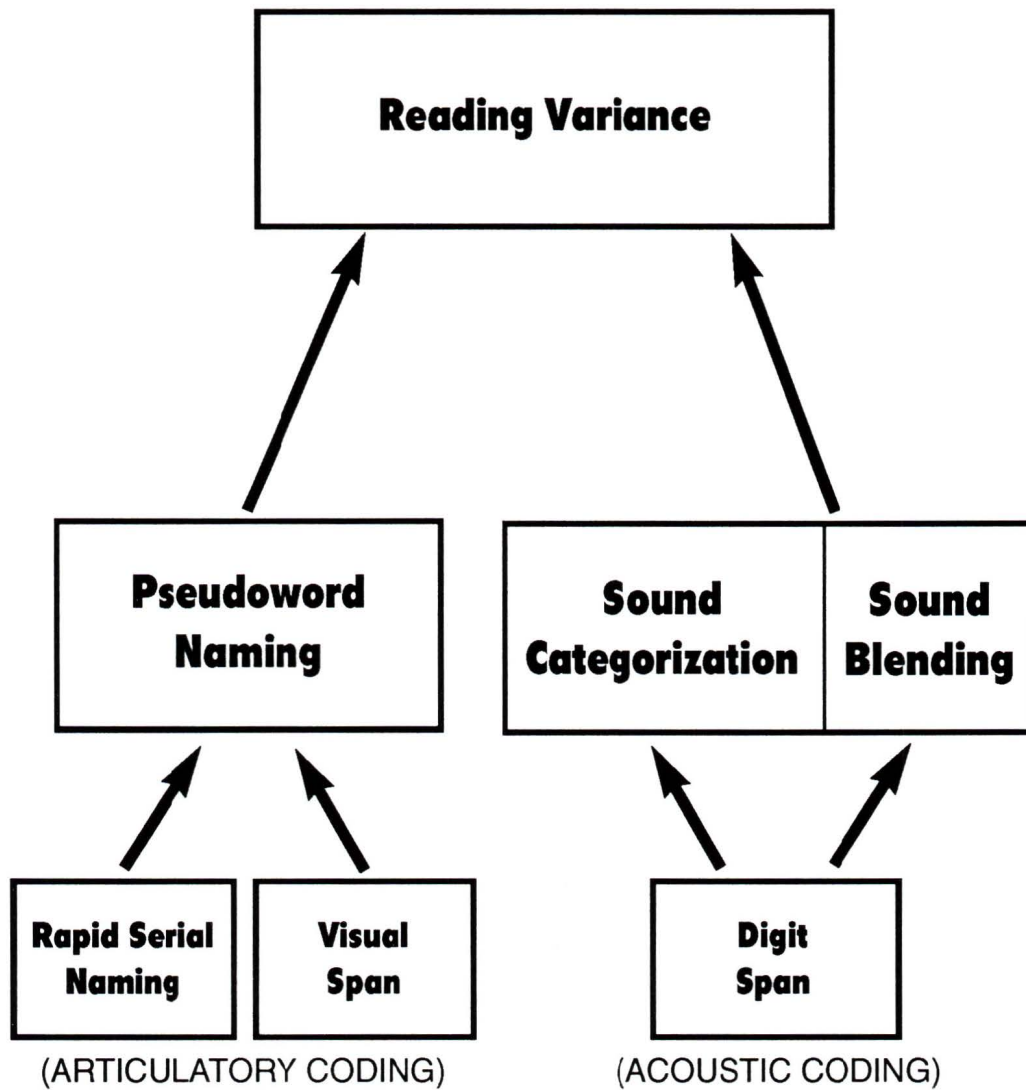


Figure 4 Working Memory Model of Phonological Processing

considered articulatory coding tasks. Similarly, sound categorization, sound blending, and digit span (as these involve aural presentation) are classified as measures of acoustic coding.

Moreover, as discussed earlier, pseudoword naming and the two phonological awareness measures are classified as holistic measures of working memory. This is based on the position that both theoretically involve the storage of phonological information and ongoing cognitive processing. In contrast, rapid serial naming, visual span, and digit span are thought to measure only storage components of working memory.

There are two general research hypotheses for this study. The first involves an investigation of the relationship among phonological processing variables, which can be stated as three directional sub-hypotheses.

Regarding the separate abilities position:

1) Robust ($p < .001$) correlations between tasks within each area of research will be obtained .

2) The correlations among tasks within each area will be significantly greater than those between tasks representing different phonological processing research.

In terms of the working memory model:

3) The correlation between sound categorization and sound blending will not differ significantly from their respective correlations with pseudoword naming.

The second general research hypothesis involves an investigation of the concurrent relationship of these phonological processing tasks to reading achievement. Specifically, this can be stated as four directional sub-hypotheses.

Regarding the position that these three areas of phonological processing are representative of three distinct cognitive abilities:

1) Representative tasks from each area of research will make independent contributions to both oral reading and reading comprehension.

The predictions of the working memory model can be stated as follows:

2) Regarding the articulatory coding variables, only pseudoword naming will contribute uniquely to oral reading and reading comprehension. Visual span or rapid serial naming will not account for significant additional variance beyond that shared with pseudoword naming.

3) In terms of the acoustic coding variables, digit span will not make a contribution to oral reading or reading comprehension beyond that accounted for by sound categorization or sound blending. In contrast, both sound categorization and sound blending will contribute significant variance above that shared with digit span.

4) Pseudoword naming will make a unique contribution to oral reading and reading comprehension beyond that shared with sound

categorization or sound blending. Conversely, sound categorization and sound blending will each account for significant variance, above that attributed to pseudoword naming. This is based upon the position that despite being similarly classed as holistic measures of working memory, different modes of presentation are involved, and hence different coding processes.

METHOD

Subjects

The sample included 90 second-grade children (48 females and 42 males) recruited from two Winnipeg, Manitoba school divisions. Four regular classrooms from three elementary schools were involved in the study, representing the lower to upper middle range of socioeconomic status families. English was the first language of all participants and none possessed physical, emotional, or intellectual handicaps. Means and standard deviations for age, reading percentile scores, and Verbal and Performance IQ's are shown in Table 1.

Measures

Sound Categorization (Bradley & Bryant, 1985)

This task involves an "oddity" measure, divided into three sections of 6 trials each. Within each set of words contains a common sound that the fourth lacks, with the subject's job to isolate the odd word. In Section 1, the odd word does not rhyme with the others because the first sound is different (e.g., bud, bun, bus, **rug**). In Section 2, the odd word has a different ending sound (e.g., leg, peg, **hen**, beg). In Section 3, the odd word has a different middle sound (e.g., pat, bat, **fit**, cat).

The procedure is entirely verbal in presentation. Prior to each condition the child was administered two test trials. If she was not correct on either, the child was told so and given another try. If still incorrect, the odd word was given at the end of the string and emphasized. The

Table 1

Descriptive Means and Standard Deviations for Sample ($n = 90$)

	Mean	SD
Age (in months)	92.3	3.3
GMRT (reading comprehension %)	56.4	25.8
Gort-3 (passage %)	60.4	30.6
SDRT (word-attack %)	66.0	22.0
Verbal IQ	107.7	17.1
Performance IQ	111.2	15.9

examiner then repeated the string with the odd word at the beginning, and asked the child to pick it out. The test trials for each condition were then administered.

Sound Blending (Kirk, McCarthy, and Kirk, 1969)

This standardized sub-test of the Illinois Test of Psycholinguistic Abilities (ITPA) measures the degree isolated sounds, presented aurally at a rate of 1/second, can be blended together to form words and pseudowords. There are 32 stimuli (24 words and 8 pseudowords). Test-retest reliability is .80.

Standard protocol was followed. Subjects were instructed they would be listening to strings of isolated sounds, and would be required to blend the sounds together to form words or pseudowords. Practice trials were given for both categories.

Digit Span (Wechsler, 1974)

The Digit Span sub-test of the WISC-R (Wechsler, 1974) involves 14 forward and 14 backward trials ranging from 2 to 9 digit sequences, presented aurally at a rate of 1/sec. Test-retest reliability is .84.

Standard protocol was followed for both digits forward and backward. Subjects were told that the experimenter would be reading them some numbers, and they would be required to immediately repeat the series. Stimuli started with three digits forward and two digits backward. If a sequence was failed, a second trial of the same length was given. Testing was terminated when subjects failed both trials of a

given length.

Visual Digit Span (Torgesen et al, 1990)

This is identical to the Digit Span sub-test in that the same digit sequences were presented at a rate of 1/second, with both forward and backward series. However, this test involves visual presentation.

The procedure was identical to the standard Digit Span sub-test, with the following exceptions. Digits were presented on a Macintosh computer (with a refresh cycle of 20 msec) one at a time. Two practice trials were given prior to both forward and backward series, and the entire procedure was repeated over two sessions.

Serial Naming Of Digits (Torgesen et al, 1990)

This task measures the time required to name a series of 36 random single-syllable digits, typed six to a line on a sheet of paper measuring 20.5 X 28.1 cm.

Subjects were instructed to read digits out loud going down each line left to right, and were told to read stimuli as quickly as possible. Results were recorded with a Micronta digital stopwatch. One practice trial was administered, followed by at least two test trials. Test trials that involved uncorrected naming errors were not scored, and an additional test trial was administered. In each trial, a different series of digits was read.

Pseudoword Naming (Stanovich, Cunningham, & Freeman, 1984)

Stimuli were 12 one syllable pseudowords (ged, dar, lat, wuck,

pish, jun, breep, fob, rill, luss, trink, mip) comprised of acceptable English spelling patterns, individually presented on a Macintosh computer. This task involves the time required to name stimuli upon presentation.

Subjects were informed that a "fake" word is not a real word despite regular sound patterns, and that when the experimenter pushes the "return" key on the computer a "fake" word will come on the screen. They were instructed to try and say the word upon presentation as quickly as possible. Two practice trials were given, followed by 10 test trials. Upon presentation, a computer generated timing mechanism engaged. When the subject made an audible response into a unidirectional microphone, a "voice-key" connected between the computer and microphone simulated a "mouse-click" and stopped the timer. Trials on which the subject incorrectly named the stimulus, and those with a response time greater than 1000 msec, were scored as subject errors and dropped from the analyses. The mean error rate was 1.6 %.

Vocabulary (Wechsler, 1974)

This sub-test functioned as a Verbal IQ measure. For 7.5 year old children, the intercorrelation between Vocabulary sub-test scaled scores and Verbal IQ is .72. Test -retest reliability is .70.

Block Design (Wechsler, 1974)

This sub-test functioned as a Performance IQ measure. For 7.5 year old children, the intercorrelation between Block Design subtest

scaled scores and Performance IQ is .68. Test -retest reliability is .82.

Gates-McGinitie Reading Comprehension Sub-Test

(MacGinitie & MacGinitie, 1988; form: Level B)

This test was designed to measure silent reading comprehension and consists of short paragraph passages with one multiple-choice question following each passage. It is standardized with scaled scores. Equivalent-forms reliability is .91.

Standard protocol was followed, which involved group administration to each classroom. Following instructions and practice trials, subjects were given 35 minutes to complete 46 multiple choice silent comprehension questions.

Grey Oral Reading Test-3 (Bryant, & Wiederholt, 1992; form: A)

This was designed to measure connected oral reading ability. The student reads aloud graded and timed passages until a ceiling is reached. Scaled scores are given for both rate, accuracy, and passage (i. e. combined rate-accuracy). Equivalent-forms reliability is .88.

Standard protocol for individual administration was followed. Students were instructed that they would be reading short timed paragraphs, and told to read as they would normally. The experimenter recorded the time taken to read each paragraph, as well as the number of errors. Testing began at the Grade 1 passage and was discontinued when the child's ceiling performance was reached. Rate, accuracy and passage scaled scores were recorded.

Stanford Diagnostic Word Attack Sub-test

(Karlsen, Madden, & Gardner, (1984; form: H)

This sub-test was used a measure of the child's ability to locate beginning and ending sounds in aurally presented words. Scaled scores are provided. Equivalent-forms reliability is .86.

Standard protocol was followed. This test consists of two parts. In Part A, children were read a series of 20 words, and were instructed to choose the correct beginning sound for each word from 4 multiple choice answers. In Part B children were instructed to identify the correct ending sound.

Procedure

Two people conducted the research, the experimenter and a research assistant. The GMRT and SDRT sub tests were given first to each classroom group and took a total of 1 hour. The other tasks were administered individually and took approximately 40-50 minutes per subject to complete.

Three sessions were used to administer the individual measures. In one session, the experimenter administered tasks in the following order: Serial Naming Of Digits, Vocabulary, Digit Span, Block Design, Visual Span, and Pseudoword Naming. Similarly, the research assistant concurrently administered the GORT-3, Sound Categorization, and Sound Blending measures. In a third session one week later, the experimenter again administered the Visual Span task. No student

received more than one session per day, including the group administered reading measures.

RESULTS

A total of 97 Grade 2 children were tested. Prior to analyses, both phonological processing and criterion measures were examined for accuracy of input and missing values, and evaluated for assumptions of normality, linearity, and homoscedasticity.

Phonological Processing Tasks

Means and standard deviations, along with skewness, kurtosis, and reliability values for each of the phonological processing variables are shown in Table 2. Raw score means and standard deviations were judged reasonable for a Grade 2 sample.

Four subjects were unable to complete the pseudoword naming task, despite being able to perform the other measures. They provided correct responses for only 2-5 of the 10 trials, and were excluded from the study as a result. An additional twelve children did not provide correct responses for 1 or 2 pseudoword items. However, these subjects were included in the analyses, with missing data estimated from performance on the successfully completed trials (Cohen & Cohen, 1975).

As commensurate with a large sample, the decision to transform variables was based upon the following: a) conservative significance tests for skewness and kurtosis ($p < .001$), b) an examination of the respective histogram distributions, and c) meaningfulness of variable scale (Cohen & Cohen, 1975; Tabachnick & Fidell, 1989). As shown in

Table 2, pseudoword naming was found to have significant positive ($p < .001$) skewness. Moreover, an investigation of the histogram distribution showed an obvious departure from normality. Hence, a decision was made to transform the pseudoword naming raw data into normalized standard scores prior to analyses, despite the difficulty of interpretation.

None of the other phonological processing measures showed significant ($.001$) skewness or kurtosis, although skewness values for rapid serial naming and sound categorization approached significance. An inspection of histograms also revealed some departure from normality. However, raw data was utilized in the analyses to facilitate interpretation.

Pairwise influence plots were used for residual analyses of the relationships between phonological processing variables. With a $p < .001$ criterion for Mahalanobis distance, 1 outlier was identified and subsequently removed. Assumptions of normality, linearity, and homoscedasticity were met.

Reliability measures ranged from moderate (.72) to high (.94). The relatively low value for the visual span task can be explained partially by the use of test-retest reliability which generally yields lower estimates than the split-half method. Nevertheless, visual span reliability was lower than the test-retest estimates for the two standardized measures (sound blending and digit span).

Table 2

Phonological Processing Measures: Descriptive Statistics

Task	Mean	SD	Skewness	Kurtosis	Reliability
PS (sec.)	2.9	1.4	1.4*	1.6	.94 ¹
RS (sec.)	21.7	4.7	.76	.55	.94 ¹
SC	13.0	3.4	-.71	-.41	.84 ¹
SB	24.7	4.1	-.21	-.97	.80 ²
DS	8.9	2.2	.16	-.40	.84 ²
VS	6.9	2.5	.51	-.27	.72 ³

Note. All data represent raw scores: PS = Pseudoword naming

RS = Rapid Serial Naming SC = Sound Categorization

SB = Sound Blending DS = Digit Span VS = Visual Span

¹ Split-half with Spearman-Brown correction

² Test-retest

³ Test-retest

* $p < .001$

Criterion Measures

Descriptive statistics for each of the reading tests are displayed in Table 3. Plausible scaled score means and standard deviations for a high-average Grade 2 sample were obtained. There was no missing data, and no task showed significant ($p < .001$) skewness or kurtosis.

The word-attack sub-test of the SDRT was found to be at ceiling. The modal raw score was 40/40 (achieved by 22 subjects), with the next most frequent value 39/40 (achieved by 18 subjects). A decision was made to exclude this variable from further analyses. In addition, the rate and accuracy scaled scores of the GORT-3 were highly correlated ($r = .89$), and showed similar relationships with the other criterion variables (see Table 4). Hence, a standardized passage score, a combination of rate-accuracy (Bryant & Wiederholt, 1992), was chosen as a representative measure of oral reading proficiency.

Residual analyses for both dependent measures (GORT-3 passage and GMRT reading comprehension scaled scores) involved a series of hierarchical multiple regressions, with the six phonological processing tasks serving as independent variables. Two multivariate outliers with significant Mahalanobis distance ($p < .001$) were located and removed, leaving a sample of 90 children. The assumptions of multivariate analysis were met.

Table 3
Criterion Measures: Descriptive Statistics

Task	Mean	SD	Skewness	Kurtosis	Reliability
GMRTSS	421	55.8	.05	-.19	.94 ¹
RATE	10.0	2.7	-.07	-.86	.92 ¹
ACC	11.6	3.8	.18	-.78	.89 ¹
PASSAGE	10.8	3.2	.03	-.94	.92 ¹
SDRTSS	454	47.3	-.43	-.84	.88 ²

Note. All data represent scaled scores:

GMRTSS = Gates-MacGinitie reading comprehension

RATE = GORT-3 oral reading rate ACC = GORT-3 oral reading accuracy

PASSAGE = GORT-3 oral reading combined rate-accuracy

SDRTSS = Stanford Diagnostic word-attack

¹ Internal consistency (KR-20)

² Equivalent-forms

Table 4
Intercorrelations Between Criterion Measures

Task	GMRTSS	RATE	ACC	PASSAGE	SDRTSS
GMRTSS	1.0	.76	.82	.81	.67
RATE		1.0	.89	.95	.68
ACC			1.0	.98	.64
PASSAGE				1.0	.65
SDRTSS					1.0

Note. All correlations significant ($p < .001$)

Research Hypotheses

Relationships Among Phonological Processing Tasks

Table 5 displays the correlations between phonological processing tasks. Note when interpreting Table 5 that superior performance on the timed measures (pseudoword naming, rapid serial naming) is indicated by lower scores, and thus their correlations with the other tasks are negative. All correlations above .20 are significant at the .05 level.

Relationships among tasks within each area of research, pseudoword and rapid serial naming ($r = .44$), sound blending and sound categorization ($r = .47$), and visual span and digit span ($r = .42$) were all highly significant ($p < .001$). These results replicated earlier findings (e.g., Blachman, 1984; Stanovich, Cunningham, & Cramer, 1984; Torgesen et al, 1990).

However, similar relationships were obtained between representative tasks from different research areas. As shown in Table 5, the correlations between rapid serial naming and sound categorization ($r = -.45$), visual span and pseudoword naming ($r = -.40$), and digit span and sound blending ($r = .53$) were equally robust ($p < .001$).

Fisher's Transformation z tests (with all correlations considered positive) revealed that out of 24 comparisons of correlations among tasks within each research area, and correlations between tasks representing different phonological processing research, only 3 were found to

Table 5

Intercorrelations Between Phonological Processing Measures

		LA		PA		WM	
		PS	RS	SC	SB	DS	VS
LA	PS	1.0	.44*	-.66*	-.50*	-.31**	-.40*
	RS	.44*	1.0	-.45*	-.18	-.05	-.20***
PA	SC			1.0	.47*	.30**	.35*
	SB			.47*	1.0	.53*	.34*
WM	DS					1.0	.42*
	VS					.42*	1.0

Note. LA = Lexical Access PA = Phonological Awareness

WM = Working Memory PS = Pseudoword Naming

RS = Rapid Serial Naming SC = Sound Categorization

SB = Sound Blending DS = Digit Span VS = Visual Span

* $p < .001$

** $p < .01$

*** $p < .05$

significantly differ in accordance with the separate abilities position.

Although the correlation between pseudoword and rapid serial naming differed significantly ($p < .01$) from that between pseudoword naming and sound categorization, it was in the opposite direction to what the separate abilities position predicted.

Moreover, commensurate with the working memory model, the correlation between the two phonological awareness tasks did not differ significantly from that between pseudoword naming and sound categorization ($r = -.66$) or pseudoword naming and sound blending ($r = -.50$).

Relationships Between Phonological Processing And Criterion Measures

As shown in Table 6, the correlational pattern between phonological processing tasks and the two reading tests was quite similar. Although sound blending, digit span, and visual span showed somewhat higher correlations with reading comprehension than with oral reading, these differences were not significant.

Pseudoword naming was found to be the most highly correlated with reading achievement, followed by sound categorization, replicating the results of Stanovich et al, 1984. Moreover, the correlations obtained for rapid serial naming, sound blending, and the two span measures were typical of earlier studies (e.g., Torgesen et al, 1990; Wolf et al, 1986).

Table 6

Correlations Between Criterion and Phonological Processing Measures

Task	PS ¹	RS	SC	SB	DS	VS
GMRTSS	-.77	-.36	.68	.52	.37	.42
PASSAGE	-.78	-.41	.68	.40	.32	.29**

Note. All correlations significant at $p < .001$ unless otherwise noted.

¹ Normalized standard scores

** $p < .01$

Separate Abilities Position

The possibility that these research areas represent three distinct cognitive abilities, each of which uniquely contribute to reading, was investigated via a series of grouped hierarchical regressions. The predictor variables were paired and analyzed as sets. The digit span and visual span tasks were used as representative measures of phonological coding in working memory (WM), rapid serial naming and pseudoword naming as measures of phonological coding in lexical access (LA), and sound categorization and sound blending as measures of phonological awareness (PA).

The extent to which these sets contributed shared or unique variance was investigated by alternating the order of entry. Two groups of analyses were undertaken. The first involved the relationship between the three sets of phonological processing tasks and oral reading. The second involved the relationship between these phonological processing variables and reading comprehension. In all regressions, a significance criterion of $p < .05$ was used.

Oral Reading.

The results of regression sequences for the sets of phonological processing variables (WM, LA, PA), and the GORT-3 passage scores are illustrated in Table 7. As indicated in A, when working memory was entered first, it produced a significant multiple correlation (R^2 increase = .131; $p < .001$). Entered at Step 2, the lexical access variables explained

Table 7
 Hierarchical Multiple Regressions for Phonological Processing
 Variables and Oral Reading

Order	Step	Variables	R	R ² *	P (2 Tail)
A	1.	WM	.362	.131	.001
	2.	LA	.791	.495	.001
	3.	PA	.818	.043	.01
B	1.	WM	.362	.131	.001
	2.	PA	.690	.346	.001
	3.	LA	.818	.192	.001
C	1.	LA	.783	.614	.001
	2.	WM	.791	.012	NS
	3.	PA	.818	.043	.01
D	1.	PA	.684	.469	.001
	2.	WM	.690	.008	NS
	3.	LA	.818	.192	.001
E	1.	PA	.684	.469	.001
	2.	LA	.810	.188	.001
	3.	WM	.818	.012	NS
F	1.	LA	.783	.614	.001
	2.	PA	.810	.043	.01
	3.	WM	.818	.012	NS

Note. WM= Working Memory LA = Lexical Access

PA= Phonological Awareness NS = Not Significant

* R² increase

a substantial amount of additional variance (R^2 increase = .495; $p < .001$). Likewise, phonological awareness made a significant contribution (R^2 increase = .043; $p < .01$) beyond that accounted for by the previous measures. Collectively, these pairs of tasks, representing the three areas of phonological processing research, accounted for 66.9% variability in oral reading performance.

A similar pattern was obtained when the order of entry for lexical access and phonological awareness was reversed. As illustrated in B, phonological awareness made a substantial contribution (R^2 increase = .346; $p < .001$) beyond working memory. Similarly, lexical access accounted for significant unique (R^2 increase = .192; $p < .001$) variance.

In contrast, despite being robustly correlated with oral reading, the working memory measures did not account for significant variability above that shared with lexical access or phonological awareness. As displayed in C, the contribution of working memory failed to reach significance (R^2 increase = .012) when entered after lexical access. In D, after phonological awareness was forced, working memory again did not account for significant additional variance (R^2 increase = .008). Orders E and F elucidate the collective failure of the two span measures to account for unique oral reading variance.

In summary, only lexical access and phonological awareness made independent contributions to oral reading. However, 64% of the variance contributed by these two sets of variables was shared between

them.

Reading Comprehension.

An analogous set of hierarchical regressions were undertaken with reading comprehension scaled scores from the Gates-MaGinitie Reading Test as the dependent measure (see Table 8). Results of these regression sequences replicated those obtained for oral reading.

Orders A and B illustrate the multiple correlation of working memory (R^2 increase = .219; $p < .001$), and the independent contributions of phonological awareness (R^2 increase = .045; $p < .01$) and lexical access (R^2 increase = .130; $p < .001$). Together 66.5% variability in reading comprehension was explained by the three groups of phonological processing measures.

As displayed in C and D, working memory explained a small amount of additional variance when entered after lexical access (R^2 increase = .026; $p < .05$) and phonological awareness (R^2 increase = .023; NS). However, as illustrated in E and F, the two span measures did not account for significant unique variance.

In summary, only lexical access and phonological awareness made independent contributions to reading comprehension. However, of the total variance attributed to these two variable sets, only 26.3% was unique.

Table 8

Hierarchical Multiple Regressions for Phonological Processing
Variables and Reading Comprehension

Order	Step	Variables	R	R ² *	P (2 Tail)
A	1.	WM	.468	.219	.001
	2.	LA	.787	.401	.001
	3.	PA	.816	.045	.01
B	1.	WM	.468	.219	.001
	2.	PA	.731	.316	.001
	3.	LA	.816	.130	.001
C	1.	LA	.771	.594	.001
	2.	WM	.787	.026	.05
	3.	PA	.816	.045	.01
D	1.	PA	.716	.512	.001
	2.	WM	.731	.023	NS
	3.	LA	.816	.130	.001
E	1.	LA	.771	.594	.001
	2.	PA	.811	.061	.01
	3.	WM	.816	.008	NS
F	1.	PA	.716	.512	.001
	2.	LA	.811	.145	.001
	3.	WM	.816	.008	NS

Note. WM= Working Memory LA = Lexical Access

PA= Phonological Awareness NS = Not Significant

* R² increase

Working Memory

To address the predictions of the working memory model, three sets of hierarchical regression analyses were undertaken for each dependent variable. The first involved the relationship between those classified by the working memory model as articulatory coding measures: pseudoword naming, visual span and rapid serial naming. The second involved those classified as acoustic coding variables: sound blending, sound categorization, and digit span. This was followed by a similar analyses involving the three variables classed as holistic measures of working memory: pseudoword naming, sound categorization, and sound blending.

The extent to which individual variables contributed shared or unique variance was investigated by entering the stronger measure first, and alternating the order of entry. As with the previous regression analyses, a significance criterion of $p < .05$ was used.

Oral Reading.

The results of regression sequences for the articulatory coding variables and the GORT-3 passage scores are illustrated in Table 9. As indicated in A, rapid serial naming did not account for additional variance beyond pseudoword naming, despite being robustly correlated ($p < .001$) with oral reading. However, in B, pseudoword naming continued to contribute significantly (R^2 increase = .446; $p < .001$) when entered after rapid serial naming.

Table 9
 Hierarchical Multiple Regressions for Articulatory Coding
 Variables and Oral Reading

Order	Step	Variables	R	R ² *	P (2 Tail)
A	1.	PS	.780	.608	.001
	2.	RS	.783	.006	NS
B	1.	RS	.410	.168	.001
	2.	PS	.783	.446	.001
C	1.	PS	.780	.608	.001
	2.	VS	.780	.001	NS
D	1.	VS	.290	.084	.01
	2.	PS	.780	.530	.001

* R² increase

Similarly, in C, visual span did not contribute additional variance despite being significantly ($p < .01$) correlated with GORT-3 passage performance. Again, as shown in D, the independent contribution of pseudoword naming was substantial (R^2 increase = .530; $p < .001$).

Results for the acoustic coding variables are shown in Table 10. After sound categorization entered first (A), digit span did not contribute to oral reading. In contrast (B), sound categorization accounted for substantial variance (R^2 increase = .375; $p < .001$) independently of digit span. As illustrated in C and D, similar results were obtained for sound blending and digit span, in that only the former was found to contribute uniquely (R^2 increase = .077; $p < .01$) to oral reading.

The results of hierarchical regression analyses involving the holistic working memory variables are shown in Table 11. As illustrated in A and B, both pseudoword naming (R^2 increase = .195; $p < .001$) and sound categorization (R^2 increase = .047; $p < .01$) were found to contribute unique oral reading variance, despite the substantial correlation ($r = .66$; $p < .001$) between these independent variables. However, 62% of the variability in oral reading performance they accounted for was shared.

In contrast, as illustrated in C, when sound blending entered at Step 2, its contribution failed to approach significance. On the other hand, pseudoword naming contributed substantial variability in oral reading performance (R^2 increase = .447; $p < .001$) beyond that

Table 10
 Hierarchical Multiple Regressions for Acoustic Coding Variables
 and Oral Reading

Order	Step	Variables	R	R ^{2*}	P (2 Tail)
A	1.	SC	.678	.460	.001
	2.	DS	.689	.015	NS
B	1.	DS	.317	.100	.001
	2.	SC	.689	.375	.001
C	1.	SB	.402	.162	.001
	2.	DS	.421	.015	NS
D	1.	DS	.317	.100	.001
	2.	SB	.421	.077	.01

* R² increase

Table 11
 Hierarchical Multiple Regressions for Holistic Variables
 and Oral Reading

Order	Step	Variables	R	R ² *	P (2 Tail)
A	1.	SC	.678	.460	.001
	2.	PS	.810	.195	.001
B	1.	PS	.780	.608	.001
	2.	SC	.810	.047	.01
C	1.	SB	.402	.162	.001
	2.	PS	.780	.447	.001
D	1.	PS	.780	.608	.001
	2.	SB	.780	.000	NS

* R² increase

accounted for by sound blending.

Reading Comprehension.

Results for the reading comprehension scaled scores of the Gates-MaGinitie Reading Test were similar to those obtained in the previous set of regressions involving oral reading. Findings for the articulatory coding measures are shown in Table 12. In A, rapid serial naming again did not provide additional variance. In contrast, as shown in B, latency naming for pseudowords continued to contribute significantly (R^2 increase = .466; $p < .001$) when entered after rapid serial naming. As illustrated in C and D, similar findings were obtained for pseudoword naming and visual span in that only the former made a unique contribution to oral reading (R^2 increase = .434; $p < .001$).

Results for the acoustic coding variables are shown in Table 13. As shown in A and C, digit span did account for a small amount of significant variance when entered after sound categorization (R^2 increase = .032; $p < .05$), but not sound blending. In contrast, as illustrated in B and D, substantial contributions were attributed to both sound categorization (R^2 increase = .355; $p < .001$) and sound blending (R^2 increase = .147; $p < .001$) independent of digit span.

Results of hierarchical regression analyses for pseudoword naming, sound categorization and sound blending are shown in Table 14. As with oral reading, both pseudoword naming (R^2 increase = .185; $p < .001$) and sound categorization (R^2 increase = .051; $p < .01$)

Table 12
 Hierarchical Multiple Regressions for Articulatory Coding Variables
 and Reading Comprehension

Order	Step	Variables	R	R ^{2*}	P (2 Tail)
A	1.	PS	.771	.594	.001
	2.	RS	.771	.000	NS
B	1.	RS	.358	.128	.001
	2.	PS	.771	.466	.001
C	1.	PS	.771	.594	.001
	2.	VS	.779	.013	NS
D	1.	VS	.416	.173	.001
	2.	PS	.779	.434	.001

* R² increase

Table 13
 Hierarchical Multiple Regressions for Acoustic Coding Variables
 and Reading Comprehension

Order	Step	Variables	R	R ² *	P (2 Tail)
A	1.	SC	.678	.460	.001
	2.	DS	.701	.032	.05
B	1.	DS	.370	.137	.001
	2.	SC	.701	.355	.001
C	1.	SB	.521	.272	.001
	2.	DS	.533	.012	NS
D	1.	DS	.370	.137	.001
	2.	SB	.533	.147	.001

* R² increase

Table 14
 Hierarchical Multiple Regressions for Holistic Variables
 and Reading Comprehension

Order	Step	Variables	R	R ² *	P (2 Tail)
A	1.	SC	.678	.460	.001
	2.	PS	.803	.185	.001
B	1.	PS	.771	.594	.001
	2.	SC	.803	.051	.01
C	1.	SB	.522	.272	.001
	2.	PS	.786	.346	.001
D	1.	PS	.771	.594	.001
	2.	SB	.786	.024	.05

* R² increase

accounted for significant unique variance. However, again the majority (63.7%) of variability accounted for by these measures was shared between them.

Likewise, pseudoword naming contributed significantly (R^2 increase = .346; $p < .001$) after sound blending had been forced into the analysis. However, in contrast to the results for oral reading, sound blending also made a significant unique contribution (R^2 increase = .024; $p < .05$).

Path Analyses

Path analyses were undertaken to further explore the implications of the working memory model by: a) elucidating the structure of the relationship between phonological processing variables, and b) their concurrent association with reading achievement. Figure 5 displays a path diagram in which Gort-3 Passage scores serve as the criterion measure. The arrows represent directional relationships between variables, as measured by path coefficients. Only coefficients with a minimum significance criterion ($p < .05$) were included.

In accordance with the working memory model, pseudoword naming, sound categorization, and sound blending were considered causally prior to rapid serial naming, digit span, and visual span. Within the first grouping, causal priority was determined by the magnitude of the respective correlations with the criterion measure. Hence, pseudoword naming was classified as causally prior to sound categorization, which in

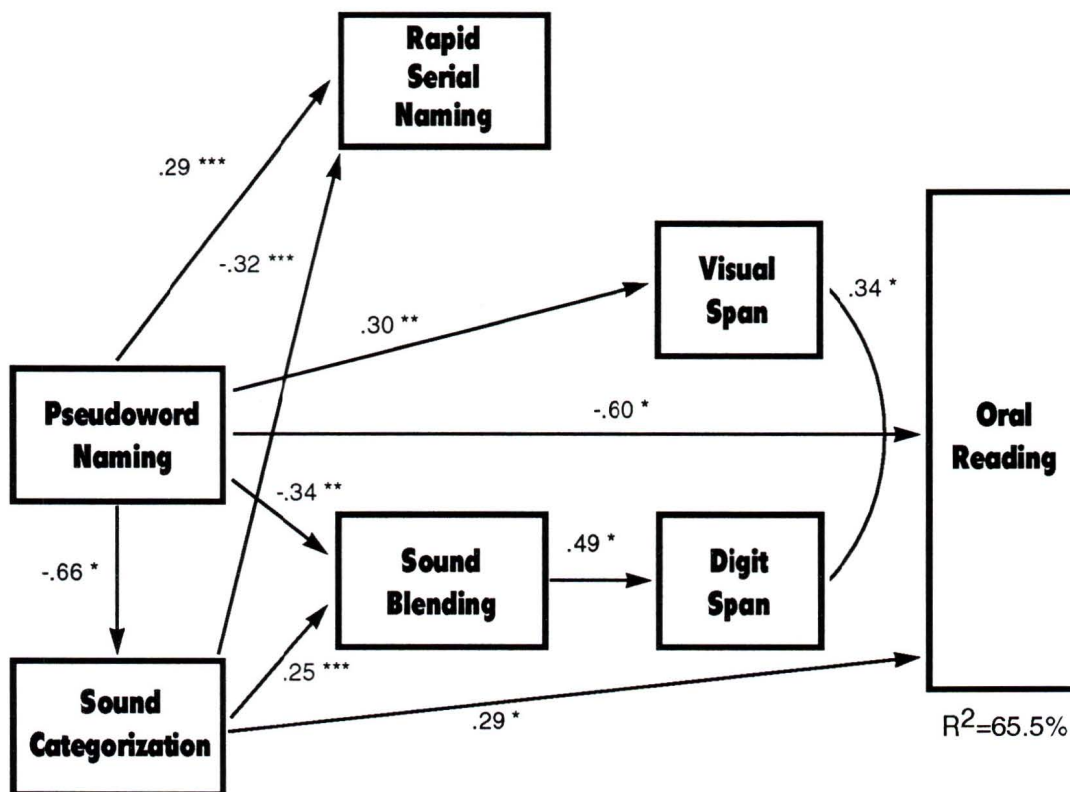


Figure 5 Path analysis with GORT-3 Passage scores as the last dependent variable. Only significant coefficients are shown.

- * $p < .001$
- ** $p < .01$
- *** $p < .05$

turn was causally prior to sound blending. The standardized path coefficients were estimated from a series of multiple regressions in which each variable in turn becomes the criterion variable for all prior measures.

The relationship among phonological processing variables in the path diagram verified the findings of the correlational analyses, in that equally significant relationships were obtained within and between research areas. Pseudoword naming was found to be a significant predictor of both sound blending and sound categorization, as well as rapid serial naming and visual span. Considered causally after pseudoword naming, sound categorization predicted both sound blending and rapid serial naming. Moreover, sound blending was found to be the only significant predictor of digit span.

The robust path coefficient ($\beta = .34$; $p < .001$) between digit span and visual span is considered to be non-directional, as indicated by the curved line connecting these measures. In other words, while the shared variance between these tasks is theoretically accounted for by the working memory model (i. e. they both measure the storage component of working memory), one is not considered to cause the other.

The final regression indicated that only pseudoword naming ($\beta = -.60$; $p < .001$) and sound categorization ($\beta = .29$; $p < .001$) made significant independent contributions to oral reading. Rapid serial naming, digit span, and visual span failed to contribute unique variance,

evidenced by the failure of their respective path coefficients to reach significance. In addition, pseudoword naming made an indirect contribution to Gort-3 Passage performance through sound categorization. Collectively, these findings are similar to those obtained in the series of hierarchical regressions discussed earlier, in that despite sharing substantial variance, only pseudoword naming and sound categorization measures contributed uniquely to oral reading.

Results of path analysis with the Gates-MaGinitie reading comprehension scores as the dependent measure are shown in Figure 6. As with the earlier hierarchical regression analyses, the pattern for oral reading and reading comprehension was very similar. Only pseudoword naming ($\beta = .57$; $p < .001$) and sound categorization ($\beta = .30$; $p < .001$) were found to contribute independently to reading comprehension, with pseudoword naming again explaining indirect variance through sound categorization. None of the other variables had significant direct or indirect pathways to reading comprehension, although the beta weight of digit span via sound blending approached significance ($\beta = .14$; $p < 1$).

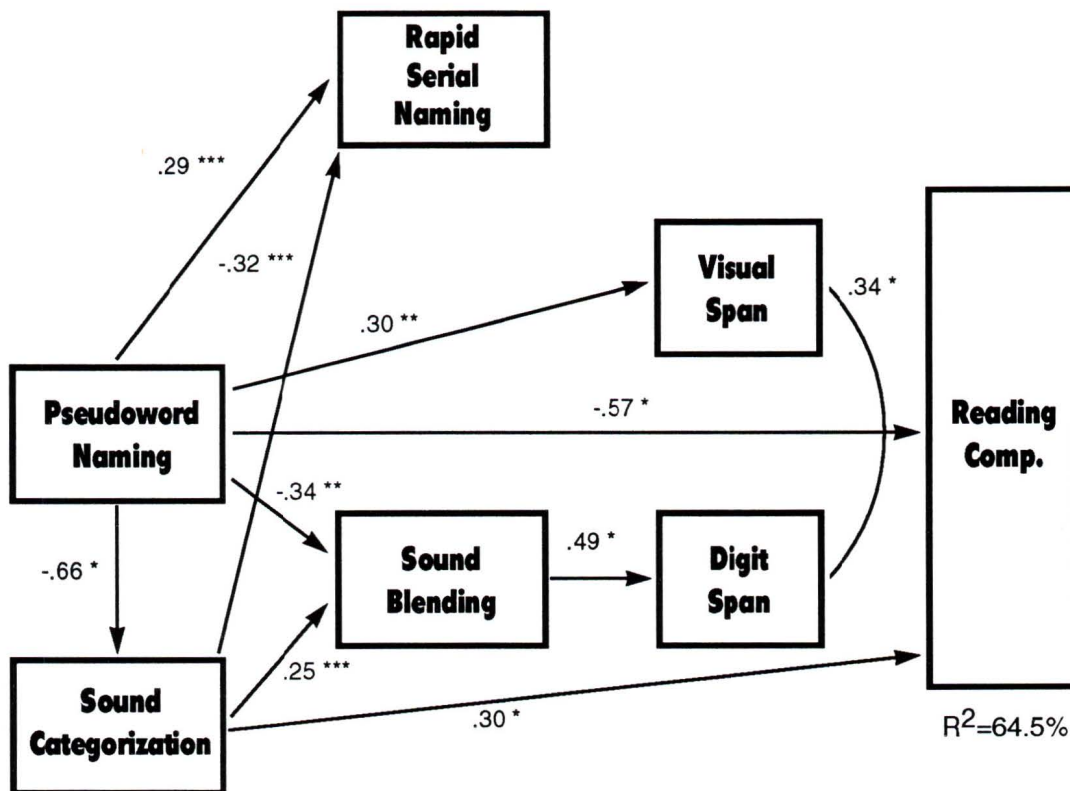


Figure 6 Path analysis with Gates-MaGinitie reading comprehension scores as the last dependent variable. Only significant coefficients are shown.

- * $p < .001$
- ** $p < .01$
- *** $p < .05$

DISCUSSION

Introduction

As outlined earlier, the three areas of phonological processing research have each shown significant correlational relationships with reading ability during the primary school years. Although similar findings were obtained in this study, there was little evidence for the position that these research areas represent distinct cognitive abilities. In contrast, results from the investigation of relationships between phonological processing variables, and their concurrent association with reading achievement were highly supportive of the working memory model.

Relationships Between Phonological Processing Variables

The correlations obtained between phonological processing tasks did not substantiate the position that these three research areas are representative of three separate cognitive abilities. For this to be supported, then as previously outlined the correlations among tasks within research areas should be significantly greater than those between tasks representing different phonological processing research. Although tasks within each area were found to be robustly correlated ($p < .001$) as this position predicted, 21 of 24 correlations between tasks from different research areas were of equal or greater significance.

In comparison, the working memory model can accommodate both of these findings. Regarding the highly significant relationships between tasks within research areas: a) Visual span and digit span are

thought to measure the storage component of working memory; b) sound blending and sound categorization are classed as holistic measures of working memory that involve acoustic coding; and c) both rapid serial naming and pseudoword naming involve articulatory coding, and are thought to be causally related through the supportive role of sub-vocal rehearsal in the blending of phonemes (Baddeley, 1986).

Similarly, the robust ($p < .001$) correlations between tasks from different research areas can be explained by the working memory model as follows. First, although rapid serial naming and sound categorization involve different presentation modes, sub-vocal rehearsal is thought to be necessary to maintain information in working memory during ongoing cognitive processing (Baddeley, 1986). Similarly, visual span is thought to measure the storage component of working memory and involve articulatory coding, hence its high correlation with pseudoword naming. Finally, as digit span is taken to measure the storage component of working memory and involve acoustic coding, the large variance it shared with sound blending can be accounted for.

The specific prediction of the working memory model was also verified. Commensurate with their classification as holistic measures of working memory, the correlation between sound categorization and sound blending did not differ significantly from their respective correlations with pseudoword naming. Moreover, these relationships were highly significant ($p < .001$).

Relationships Between Phonological Processing Variables
And Reading Achievement

The relationship between phonological processing and reading achievement did not appear to depend upon the criterion measure utilized. This is congruent with the findings of other studies which have found oral reading and reading comprehension to share a substantial amount of common variance during the primary school years (c.f., Jorm & Share, 1983; Stanovich, 1986; Torgesen, Rashotte, Greenstein, & Portes, 1987).

Results from the series of hierarchical regressions analyses were not supportive of the separate abilities position. First, variance directly explained by working memory, as represented by the two span measures, failed to approach significance. Second, although lexical access and phonological awareness made independent contributions to both oral reading and reading comprehension, the majority of variance collectively accounted for by these measures was not unique.

In contrast, the predictions of the working memory model were largely substantiated. Consider first the two sets of regressions centring upon the relationship between articulatory coding variables. The working memory model predicted that only pseudoword naming would account for unique reading variance (see Figure 4). In contrast, regarding the separate abilities position, the two naming tasks, and visual span should make independent contributions, as these measures

are from different research areas (see Figure 3). Clearly, the former position is supported here. Neither visual span nor rapid serial naming accounted for significant variance beyond that shared with pseudoword naming, while the latter made a sizeable unique contribution. Whereas the separate abilities model could accommodate the relationship between naming measures (i. e. the pseudoword naming task is thought to measure efficiency in locating a lexical match in addition to the activation of phonological codes), it cannot account for the failure of visual span to contribute uniquely to reading. In summary, for both criterion measures, all eight regressions between articulatory coding variables were congruent with the working memory model.

Results from the series of hierarchical regressions involving acoustic coding variables were also supportive of the working memory model. As predicted, although digit span contributed significant oral reading variance when entered first, it did not when entered subsequent to sound blending or sound categorization. The separate abilities position, in contrast, cannot explain these results. Digit span, taken as being distinct from the two phonological awareness measures, should have contributed unique variance beyond sound categorization or sound blending.

Regarding the analyses for the acoustic coding variables and reading comprehension, the only regression not in agreement with the working memory model was that involving the independent contribution

($p < .05$) of digit span beyond sound categorization. The failure of digit span to account for unique variance beyond sound blending, and the large contribution of both sound blending and sound categorization independent of digit span support the working memory position. That is, as sound blending and sound categorization are classed as holistic measures of working memory, digit span should not make a unique contribution to reading achievement beyond either of these tasks.

Although the unique reading comprehension variance accounted for by digit span was possibly spurious (R^2 increase = .032; $p < .05$), the failure of sound blending to explain any additional variance ($R^2 = .000$) beyond pseudoword naming is surprising given the different modes of presentation involved.

A possible explanation of this finding relates to the nature of the sound blending task. This measure consisted of 24 real words and only 8 pseudoword stimuli. It is feasible that the blending of phonemes to form real words, as a lexical referent is available, requires less maintenance in working memory than blending phonemes to form pseudowords. This position is supported by the significantly higher ($p < .01$) correlation obtained between rapid serial naming and pseudoword naming (.44), compared to rapid serial naming and sound blending (.18).

Hence, if rapid serial naming can be taken to measure efficiency of sub-vocal rehearsal in the articulatory loop, the sound blending task may not have accounted for unique oral reading variance because the

blending of phonemes to form real words does not rely upon rehearsal processes. Some support for this position is provided by the fact that sound categorization made a unique contribution to oral reading beyond the pseudoword task, and was also robustly correlated ($r = .45$; $p < .001$) with rapid serial naming.

Although sound blending did not account for additional oral reading variance above that attributed to pseudoword naming, results of the other regressions involving the holistic measures went as the working memory model predicted. The separate abilities model would explain these findings as pertaining to the fact that tasks from different research areas were involved, phonological coding in lexical access and phonological awareness. In contrast, the working memory model predicted these results based upon the different modes of presentation. However, only the working memory model can explain the high correlations between these tasks, a finding that was substantiated by the large amount of shared oral reading and comprehension variance attributed to these measures.

The results of path analyses largely replicated the findings of the hierarchical regressions. With those classified as holistic measures of working memory considered causally prior to the other phonological processing variables, only sound categorization and pseudoword naming made direct contributions to oral reading or reading comprehension. Moreover, the close relationship between these

measures was revealed by the indirect variance accounted for by pseudoword naming through sound categorization.

In conclusion, the separate abilities position is not supported by the nature of the relationships among the phonological processing tasks used in this study, or their concurrent association with reading achievement. The specific predictions of the working memory model were however largely verified.

Implications For Future Research

There are three implications for future research. First, the results of this study must be replicated. Second, the developmental relationship between working memory and reading achievement should be examined. Third, it must be determined that articulatory and acoustic coding processes in working memory are causally related to early reading achievement.

Replication And Extension Of Findings

As this investigation is believed to be the first to examine relationships between multiple measures from the three areas of phonological processing, and their concurrent relationship with reading achievement, caution should be exercised in interpreting these results. In other words, although the role of working memory as a possible determinant of reading achievement was supported, without replication any conclusions are attenuated.

Regarding the failure of sound blending to account for unique oral

reading variance, the possibility that this is due to the differential role of rehearsal in working memory should be investigated. This would involve examining the relationship between pseudoword naming and the auditory blending of phonemes to form pseudowords, and the degree they concurrently account for reading variance. The association between pseudoword naming and other phonological awareness tasks (i. e. phoneme reversal) should also be explored.

Developmental Relationship Between Working Memory And Reading Achievement

There is considerable evidence to suggest that the relative importance of the various cognitive processes of reading change with the general developmental level of the sample (Cohen, 1982; Stanovich, 1986; 1990). One apparent trend is that skills and abilities measured in primary school years become increasingly correlated as the age of children increases. Hence, it is possible that the administration of the same phonological processing and reading measures in kindergarten and Grade 1 would result in significantly different findings. Alternatively, the high correlations obtained between tasks from these three research areas may be an artifact of the age and developmental reading level of the sample.

As it is possible that the same pattern of relationships between phonological processing variables and reading achievement may not be obtained at earlier developmental stages, similar multi-variate studies

should be conducted in Kindergarten and Grade 1. To facilitate casual inference, both concurrent correlational and longitudinal studies should be implemented.

Working Memory As A Causal Determinant Of Reading Ability

By providing a tenable explanation of the relationship between phonological processing and reading achievement, the working memory model can be viewed as a possible means of unifying diverse research. This may in turn result in better methods of identifying children at risk of reading failure before reading instruction begins. Moreover, as the speed of early reading skill acquisition is substantially correlated with reading performance in the middle and secondary school years (e.g., Stanovich, 1990), determining the etiology of reading failure among primary children could result in both the prevention and remediation of reading disabilities at more advanced levels of schooling. However, as this study only involved concurrent correlational investigations, this alone cannot be taken as evidence that working memory and reading skill are casually linked.

To determine if a causal relationship exists, conclusive evidence ultimately must be provided from experimental studies. These would involve dividing pre-reading children into experimental and control groups, with the experimental group given training on a variety of working memory tasks.

However, premature action on an unproven hypothesis hinders

the implementation of effective remedial instruction. In other words, a clearer understanding of the specific nature of the relationship between working memory and reading achievement, along with its developmental implications, is imperative before such experimental studies should be undertaken.

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