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Component Processes in the Predictors of Reading Achievement: Direct and Indirect Effects

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COMPONENT PROCESSES IN THE PREDICTORS OF READING ACHIEVEMENT: DIRECT AND INDIRECT EFFECTS

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Abstract
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This study examined the relationships between the most reliable predictors of reading, possible factors of these predictors, and different aspects of reading achievement. Thirty six subjects were recruited from a reading clinic and administered measures of phonological awareness and rapid naming. They were also given measures of two constructs hypothesized to underlie these predictors, the constructs of working memory and processing speed. Each participant's sight word vocabulary, reading fluency, and reading comprehension were collected to represent reading achievement. Comprehension performance was not directly related to reading predictors but instead was indirectly influenced by sight vocabulary. Contrary to the presented hypothesis, phonological awareness was not found to mediate the influence of working memory in a sample of poor readers. However, working memory skills were closely related to sight vocabulary performance and support the hypothesis that memory affects long-term word associations. Processing speed was found to directly influence rapid naming, sight vocabulary, and reading fluency. It did not appear as an indirect influence but rather as the second best predictor in this poor reader sample. Phonemic analysis, which represents one-half of the phonological awareness construct, was the best overall predictor of reading achievement though it exerts less influence in this poor reader group compared to studies of typical students. Scores on phonological awareness were found to moderate the effects of rapid naming on vocabulary and reading fluency. Specifically, rapid naming did not influence reading achievement in students with average or above phonics skills but had an increasing influence as students' phonological skills were impaired. The double deficit subgroup of readers was thus supported by results of this study. Overall, the moderation findings also add support to phonological awareness being the core deficit in reading and processing speed affecting reading more strongly in those students with poor phonics. Findings also support the hypothesis that surface dyslexia is an expression of poor processing speed. Further study with working memory and processing speed measures is recommended to increase the application of these constructs to educational planning.

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CHAPTER 1

INTRODUCTION

The ability to read is considered one of the most amazing tasks in which human beings engage. Amazing because of the sheer volume of information we create and share through reading, and amazing because of the integration of a great many disparate cognitive skills that underlie this task. From visual perception, memory, and auditory analysis to finger dexterity and motor coordination of the mouth, a vast array of brain-based processes allow the skilled reader to follow a line of print, listen to a sentence of spoken words, name objects, and ultimately write down thoughts while engaged in a myriad of other activities. Reading is truly a spectacular process.

While reading acquisition occurs relatively easily for most children, a subset of individuals struggle to acquire the ability to read. For some children, this may be due to global cognitive deficits and mental retardation, but for others their reading ability is drastically impaired while their other cognitive skills are average or above. These individuals have dyslexia, which is defined by Critchley (1970) as "those who, despite conventional classroom experience, fail to attain the language skills of reading, writing, and spelling commensurate with their intellectual abilities" (p. 11). Those with dyslexia struggle in language learning, and often are subsequently labeled as having a reading disability in the classroom. As these terms are the most commonly used for reading deficiencies in comparison to ability, they will be interchangeable throughout the preceding chapters.

Dyslexia has been studied extensively for over a century. Early studies sought out quick, single factor causes with limited results. Later studies used empirical measures and factor analysis to show that different kinds of dyslexia do exist. Following this, information processing theories provided insight into the underlying deficits for different groups of individuals with dyslexia, and treatment programs were created to remediate these dysfunctions. Accurate predictors of reading problems were then discovered and used to research these underlying processes that cause different types of dyslexia. Neuropsychological models have been developed to describe these processes and pinpoint impairments.

Despite our knowledge about reading problems, many standard assessment practices do not provide categorization of reading problems or suggestions for intervention. Standard intelligence batteries such as the Wechsler series (Wechsler, 2003) have not been linked to specific impairments and thus lack an assessment for intervention linkage. This study examines such an evaluation through comparison of the new indexes of the *Wechsler Intelligence Scale for Children-Fourth Edition* (WISC-IV) with tasks that are predictive of reading achievement. Additional research questions examine the relationships among these predictors of reading.

Historical Views

Early research on dyslexia was conducted through case studies. These studies provided early clues about the basis of dyslexia as well as correlates of reading problems. Dysfunctional brain systems were suggested as causal agents (Wernicke, 1908) and genetic transmission implicated in development of dyslexia (Fisher, 1905; Hinshelwood, 1909). Different types of reading problems were noted in the early 20th century that would be replicated more than seventy years later (Castles & Coltheart, 1993; Hinshelwood, 1900; 1902).

After the original case studies, research on reading problems moved to single factor explanations of dyslexia. Global factors such as communication between brain hemispheres (Orton, 1937), visual perceptual deficits (Bender, 1959; 1961), auditory perceptual deficits (Wepman, Jones, Bock, & Van Pelt, 1960), and executive functions (Ackerman, Peters, & Dykman, 1971; Birch & Bridger, 1965; Cohen & Netley, 1981) were all suggested as the cause of the inability to read. These studies provided interesting avenues for later research on dyslexic subtypes, but none alone could account for the heterogeneity of reading problems.

With the failure of single factor theories to explain dyslexia, multiple factor theories were created. The majority of these theories centered on two types, a visual dyslexia pattern and an auditory dyslexia pattern (Boder, 1973; Johnson & Myklebust, 1967). These models suffered the same fate as single factor ones in that they could still not adequately explain the heterogeneous impairments of those with reading problems. Unlike earlier theories, however, the visual and auditory impairments had tremendous impact through their metamorphosis into the specific routes of lexical and sublexical reading (Mitterer, 1982).

Large-scale empirical studies appeared in the literature following the multiple factor theories. Mostly atheoretical in nature, the studies further established the heterogeneity of reading problems. Studies by Doehring & Hoshko (1977) found three clusters of reading problems and Morris, Blashfield, and Satz (1986) found five. Other cluster analysis studies found even more types of dyslexic readers (Hooper & Willis, 1989).

Reading Acquisition Theories

Although the heterogeneity of dyslexia appeared to confound researchers, a new avenue of study indicated that age may affect patterns of reading and explain much of this variability. Research in dyslexia had largely ignored developmental trends until the stage theory was presented by Frith (1985). She outlined three stages through which children acquire the ability to read. During preschool, children use salient features of words and context to read. This stage is referred to as the *logographic stage*. Around the entry to school, most children enter the *alphabetic stage* where they learn to develop grapheme to phoneme correspondences. This has been hypothesized to occur through development of a cipher that internalizes these correspondences (Gough & Tunmer, 1986). Finally, children pass into Frith's (1985) third stage called the *orthographic stage* or sight word reading (Ehri, 1992). At this point children read whole word or syllable units, allowing for dramatic increases in fluency.

The importance of these developmental stages cannot be underestimated. Any research on children with reading problems must consider the developmental period being examined, as the stages suggest that different components of reading are relatively more important at different stages.

Information Processing Theories

In the 1980's research on reading problems returned to its roots with the introduction of several high profile case studies. These studies attempted to show that patterns of reading problems found in acquired dyslexia (those who have suffered neurological insults) are similar to patterns found in developmental dyslexia. Temple and Marshall (1983) described HM, a 17 year-old girl whose pattern of reading was remarkably similar to that found in acquired phonological dyslexia (Marshall & Newcomb, 1973). In addition, Coltheart, Masterson, Byng, Prior, and Riddoch (1983) presented CD, another adolescent girl whose reading deficits resembled patterns common in acquired surface dyslexia.

The evidence that developmental dyslexia may have similar subtypes as acquired dyslexia led to the establishment of information processing theories of word reading. One of the two substantial theories of this period was the dual-route model (Castles & Coltheart, 1993). According to this model, individuals can read words by decoding through the sublexical route or accessing whole words through the lexical route. Phonological dyslexia occurs when the sublexical route to identifying words is deficient, usually identified through poor nonword reading. On the opposite side, surface dyslexia develops when the lexical route to word reading is deficient, usually being identified by poor exception word reading.

Castles & Coltheart (1993) tested this model by giving various reading tasks to 56 children with poor reading achievement and a matched control group. They found evidence of both patterns, but the most prominent pattern was a combination of both deficits. Replications of the study support that combined deficits in reading non-words and exception words are the most common type of reading problem (Manis, Seidenberg, Doi, McBride-Chang, & Peterson, 1996; Stanovich, Siegal, & Gottardo, 1997; Sprenger-Chrolles, Cole, Lacert, & Serniclaes, 2000). These studies, however, used reading level, matched control groups and found that individuals with surface dyslexia did not differ in reading patterns from their reading-level controls. The authors suggest that phonological awareness is the only core deficit (Manis et al., 1996) and that lack of print exposure may underlie surface dyslexia patterns (Stanovich et al., 1997).

The other influential information processing theory is the connectionist view. Based on computer models that simulate reading, these theories did not postulate the existence of different routes for reading (Seidenberg & McClelland, 1989). Instead they focused on the weighted connections between word information and the appropriate pronunciation. The computer programs were able to learn to read fluently, but had difficulty simulating the different patterns of reading problems (Coltheart et al., 1993). Newer models exhibited phonological dyslexia patterns by damaging the phonological receptors (Plaut, McClelland, Seidenberg, & Patterson, 1996), on the other hand removing processing units and decreasing power caused reading difficulties similar to surface dyslexia (Harm & Seidenberg, 1999).

Although the information processing theories disagreed on many theoretical points, they also provided converging evidence about reading problems. First, different patterns of dyslexia exist and are likely caused by different underlying problems. Second, phonological processing skills likely underlie the largest pattern of reading difficulties. Third, cognitive processes outside the language system such as processing speed may impede the functioning of these systems and lead to poor reading achievement.

Causal Agent Theories

Research into the best predictors of reading attempted to locate causal influences through assessment tasks as opposed to reading routes. The most influential of these models has been the phonological core variable difference model (Stanovich, 1988). Based on longitudinal studies conducted over a four-year interval, the model postulated that phonological awareness was the core impairment of dyslexia, with other comorbid cognitive deficits causing the different patterns found across research groups. Other longitudinal studies replicated the finding that phonological awareness tasks were among the best predictors of reading achievement (Bradley & Bryant, 1987; Torgesen, Wagner, & Rashotte, 1994)

Wolf & Bowers (1999) agreed that phonological awareness was one of the best predictors of reading, but argued that rapid naming ability also contributes significant variance to reading achievement. They proposed the double deficit hypothesis, which suggests that these two variables each explain primary deficits in two groups of individuals with dyslexia, and that individuals with both impairments have the most severe reading difficulties. Earlier longitudinal research had found rapid naming to be a reliable predictor of reading achievement almost two years after the measures were administered (Wolf, Bally, & Morris, 1986). In addition, these deficits appeared to be independent of phonologically-based stimuli (Wolff, Michel, & Ovrut, 1990) and serial presentation (Fawcett & Nicolson, 1994). Meanwhile, other studies found tentative support for the existence of reading deficit subgroups based on phonological and rapid naming deficits (Ackerman & Dykman, 1993; Manis, Doi, & Bhadha, 2000).

The predictive power of phonological awareness and rapid naming tests has thus been well established, but the independence of these variables is still a matter of protracted debate (Meyer, Wood, Hart, & Felton, 1998; Wolf, Bowers, & Biddle, 2000). Longitudinal research by Torgesen, Wagner, Rashotte, Burgess, and Hecht (1997) found rapid naming to contribute variance only during the alphabetic stage of reading. This research team also found rapid naming shared the majority of its effect on reading achievement with phonological awareness. Meyer et al. (1998) meanwhile suggested that phonological awareness is a moderating variable for rapid naming, as those with poor levels of this skill had between 18% and 22% of their reading achievement variance explained by rapid naming. Studies using structural equation modeling have also suggested that the influence of rapid naming on reading achievement is mostly indirect (Holland, McIntosh, & Huffman, 2004). Considering these findings, the interaction of phonological awareness and rapid naming skills in predicting reading is important as both skills are becoming commonly assessed constructs that prescribe interventions (Wagner, Torgesen, & Rashotte, 1999).

These studies led to the first research question in this study. Specifically, it was hypothesized that rapid naming skills do have indirect effects on reading achievement through the moderation of phonological awareness. If this hypothesis were true, then difficulties in rapid naming would have different effects on reading achievement that are dependent on an individual's level of phonological skills.

Processes in Phonological Awareness

Although the interaction of the predictors of reading achievement is important, deeper analysis of the core cognitive processes that underlie phonological awareness and rapid naming tasks would provide even more information about assessment and intervention for reading difficulties. Phonological awareness tasks have historically been broken into two main components; phoneme analysis and phoneme synthesis (Torgesen et al., 1994). Many studies have found phoneme analysis to be an independent skill that is based on the ability to discriminate the different phonemes in spoken language (Ackerman & Dykman, 1993; Cornwall ,1992). Additionally, studies that predict reading achievement have historically found phoneme analysis to contribute the most unique variance (Torgesen et al., 1997; Velluntino, 1987).

The cognitive components that make up phoneme synthesis skills have been more elusive. One hypothesis that has gained support over two decades of research is the importance of phonological working memory in combining phonemes into words (Jorm, 1979). According to this hypothesis, the capacity of phonological working memory to store and manipulate phonemes has explained a large portion of the variance in phoneme synthesis skills (Catts, 1986; Daneman & Carpenter, 1980).

Phonological Working Memory

Studies have implicated phonological working memory in many cases of dyslexia (Baddeley, 1986), as well as a factor that differentiates struggling from fluent readers (Stanovich et al., 1997). Applying the Baddeley and Hitch (1974) model of phonological working memory, Gathercole, Willis, and Baddeley (1991) reported this model accounted for significant variation in reading. Specifically, nonword repetition measures of working memory accounted for 6.4% of the variance in word reading, digit span 15.1%, and rhyme detection 11.8%. Apparently phonological working memory becomes important as children move into Frith's (1985) alphabetic stage and begin decoding and recoding words. Gathercole et al. (1991) concluded that phonological working memory dissociates at school entry from phoneme analysis as individuals develop sensitivity to sounds. Nonetheless, phonological working memory may contribute significantly to phoneme synthesis skills.

This hypothesis was tested through a mediation model. Specifically, the use of regression analysis was used to differentiate if phonological working memory effects reading achievement through the ability to blend words. This question is the second analysis in this study.

Processes in Rapid Naming

The cognitive processes that underlie phonological awareness are now being studied rigorously, but studies of rapid automatized naming are just emerging. First, some researchers have argued against a cognitive processing basis to rapid naming and suggested that lack of exposure to print underlies these deficits (Perfetti, 1992; Stanovich, Nathan, & Zolman, 1988; Stanovich et al., 1997). However, Wolf and Bowers (1999) reported that only modest correlations exist between rapid naming and print exposure. Other studies found rapid naming is predictive only when stimuli are familiar, thus negating the effects of print exposure (Katz, 1986, Meyer et al., 1998). Other research teams have tested the hypotheses that visual processing deficits are the culprit in naming speed impairments (May, Williams, & Dunlap, 1988; Wolff et al., 1990), but most research supports that language processes underlie the majority of variance in rapid naming (Blank, Berenzweig, & Bridger, 1975; Manis et al.,2000).

Processing Speed

One promising hypothesis proposed by Kail (1994) is that processing speed causes large portions of the variance in rapid naming. Defined as the global speed of information processing, processing speed has been found to be consistent across many decision and reaction time measures (Kail & Bisanz, 1982). Further, processing speed has also been implicated in various patterns of dyslexia (Harm & Seidenberg, 1999; Lovett, 1992). The exact process through which processing speed effects reading has been investigated in only two studies. In the first, Kail (1992) found evidence that processing speed may impact articulation rate and phonological working memory. Results from the second study indicated that processing speed effects rapid naming, which then effects reading achievement (Kail, 1994).

They hypothesis that processing speed effects rapid naming is the third and final hypothesis in this study. Specifically, the mediation model discussed previous was utilized and regression equations calculated to determine if rapid naming mediates the effect that processing speed has on reading.

Data Analysis

The study thus had three main research questions. The first was whether phoneme analysis, phoneme synthesis, and rapid naming contribute independent variance to reading achievement or form some interaction amongst themselves. This is easily investigated through a test for moderator variables (Keith, 1998; Loehlin, 1992). The second and third hypotheses suggest that the effect of phonological working memory and processing speed on reading achievement is mediated by phoneme synthesis and rapid naming, respectively. These questions were researched through a series of mediator models that include the two cognitive processes and three predictors of reading achievement (Baron & Kenney, 1986).

Measures

Identifying the cognitive processes behind the varying types of reading problems enables us to better understand and intervene in reading problems. None of this information can be of practical importance, however, unless common measures of both the cognitive processes and reading predictors are used. As such, the operationalization of constructs was extremely important in this study and reliable instruments of practical importance were required.

The two cognitive processes in this study are phonological working memory and processing speed. Both of these constructs were measured using the WISC-IV. This test includes a Working Memory Index score (WMI) and Processing Speed Index score (PSI). Both indexes are composed of two reliable and valid subtests (Wechsler, 2003).

The three predictors of reading achievement were measured through a subtest from the *Comprehensive Test of Phonological Processing* (CTOPP; Wagner, Torgesen & Rashotte, 1999). Based on over ten years of longitudinal research (Torgesen et al., 1997), the CTOPP subtests have excellent reliability and validity (Wagner et al., 1999). Phoneme analysis was measured by CTOPP Elision, phoneme synthesis by CTOPP Blending Words, and rapid naming by CTOPP Rapid Naming subtests. While single measure operationalizations have been criticized in equation modeling (Keith, 1998), the use of highly reliable and popular tests outweigh these concerns.

Historically reading achievement has been measured in many ways over the history of research (Hooper & Willis, 1989), but a current consensus exists since the report of the National Reading Panel (2000). They conclude that phonemic awareness, phonics, vocabulary, fluency, and comprehension are separate but equally important areas of reading achievement. Phonemic awareness and phonics skills were measured as causal variables in this study, but the remaining three areas were all measured as part of reading achievement. Vocabulary was defined through sight word knowledge as recommended by Rudel, Denkla, and Broman (1981) and Torgesen et al. (1997). The *Test of Oral Word Reading Efficiency* (TOWRE) was used for this measurement as it provides reliable and valid scores of vocabulary (Torgesen et al., 1997). Comprehension and fluency were measured by separate subtests of the same assessment device, the *Gray Oral Reading Test-Fourth Edition* (GORT-4; Wiederholt & Bryant, 2001). The GORT-4 provides scores on passage reading fluency and comprehension questions, and has a long history of sound psychometrics properties.

All measures in this study account for the problem of developmental age in reading research as all scores are based in comparison to same-age peers in the standardization groups of each test. To account for appropriate ranges in general cognitive ability the WISC-IV Similarities subtest was administered. This test provides reliable estimates of general verbal ability (Wechsler, 2003).

Procedures

The power of measures to predict reading achievement is often restricted in typical students unless a large sample size is obtained. As such this study examined reading in those with poor achievement. Although this restricts the range of generalizable findings, most reading tests are given to those who are beginning to struggle with reading. As such, subjects recruited from a local reading clinic provided an appropriate sample for study. Reading measures were collected from files and WISC-IV administrations conducted. Approximately 50 subjects were recruited in the summer and fall semesters of 2005 to examine the before-mentioned research questions.

CHAPTER II

LITERATURE REVIEW

This chapter describes the research on dyslexia, starting with historical studies and continuing through modern research. Through this process, different routes for reading will be described and different underlying deficits explained. From these routes and deficits, the review proceeds to the most accurate predictors of reading achievement. Discussion of these predictors will examine how the three main predictors may contribute direct influence, or may effect reading achievement indirectly through each other. Finally, the most empirically supported component processes of these predictors will be discussed. How these components effect reading achievement through the possible mediation of the predictors concludes this chapter.

Historical Views

Skilled reading is a complicated ability that requires the harmonious functioning of several cognitive components during crucial developmental periods. Because of this, research into the development of skilled reading, and likewise the problems that may arise, has been vast yet only begun to elucidate the mechanisms behind this task. Early studies showed that word reading was impaired in children with dyslexia. Later studies attempted to arrive at single causes underlying this impairment, followed by empirical studies that began suggesting subtypes of dyslexia related to differing causes. These areas of research are described in the following sections.

Early studies

When neurology and neuropsychology emerged as promising fields, the explanations for children's reading problems began to congeal on brain-related factors.

Reading problems were thought to be related to dysfunctional brain systems by prominent authors such as Wernicke (1908). Several case studies illustrated profound reading difficulties while other cognitive abilities remained intact. The term *word blindness* gained in popularity as two early case studies illustrated the profound difficulty dyslexics have in reading individual words (Morgan, 1896).

Following the initial cases, Hinshelwood (1900, 1902) described two child cases of word blindness that showed different presentations. One child showed excellent alphabet and naming skills, but could recognize only a few letters and words by sight. The other child was proficient in naming letters and words, but performed poorly on reading exceptional, monosyllabic words. Unbeknownst to the author, this was the first observed indication of reading problems and would be replicated in many future studies.

Other case studies found that reading problems were genetic and more prevalent in certain populations, such as males (Fisher 1905; Hinshelwood, 1909). In general, these studies provided several guiding principles in research on reading achievement. As reviewed by Hooper and Willis (1989), these principles were that reading disorders were present at all ages, had a familial component, were quite heterogeneous, require comprehensive assessment, and are often unresponsive to intervention attempts.

Research began to diverge between those individuals who never develop skilled reading and those with brain insults that lose the ability to read. These distinct groups were referred to as “developmental dyslexics” and “acquired dyslexics” (Patterson, 1981, p. 151). While studies of acquired dyslexia continued to examine cognitive routes described in early case studies, research on developmental dyslexia began looking for unilateral causes.

Single factor models

As case study and brain localization techniques fell out of favor, theorists began to propose unified theories on the cause of dyslexia that were related to unified, global deficits in the process of reading (Satz, Rardin, & Ross, 1971). Most of these theories are now considered obsolete, but their influence extends into the prominent subtypes of reading disability today.

The delayed cerebral dominance theory was the first single factor model to emerge for reading problems. According to Orton (1937), individuals with reading problems tend to show more left-handed and ambidextrous patterns than normal readers. He proposed that in normal individuals the left hemisphere becomes dominant in information processing abilities, and for dyslexics this dominance never fully develops. While this theory is now completely refuted, the delayed cerebral dominance theory helped focus attention on the communication between hemispheres and cognitive processes as a culprit in reading difficulties (Hooper & Willis, 1989).

Bender's groundbreaking studies (1959; 1961) on visual perceptual deficits in reading led to theories that specific visual deficits cause poor reading achievement. Later studies posited that visual motor integration was the primary culprit behind poor reading (Kephart, 1971). Perhaps most influential to later research were the eye movement studies of Pirozzolo (1979). These studies found reading difficulties and faulty eye movements to be present in only readers with specific visual dyslexia. Poor readers identified with auditory linguistic problems did not exhibit these eye movements. This finding coalesced nicely with the surface and phonological subtypes of Marshall and

Newcomb (1973) discussed later, and also supports the distinctions found as far back as Hinshelwood (1902).

The most resilient single factor theory is clearly that of auditory perceptual deficits. Begun by Wepman et al.'s (1960) proposal that delays in auditory perception and discrimination were paramount in reading disorders, these theories had difficulty explaining why dyslexics did not have poor speech perception. Nonetheless, this theory has ongoing influence in current models of phonological dyslexia that will be discussed in later sections (Stanovich, 1988).

Several other single factor theories have been put forward that encompass more executive function areas. Theories such as sensory integration deficits (Birch & Bridger, 1965), attention deficits (Ackerman et al., 1971), and memory deficits (Cohen & Netley, 1981) were all related to reading disabilities. As research progressed, these functions came to be seen as correlated or component functions rather than primary causes, and two executive function areas, working memory and processing speed, will be returned to later in this chapter.

Following the single factor theories, more comprehensive approaches such as clinical models and empirical studies were developed. Before turning to these, it is important to realize the continued legal contribution single factor theories have had. During this the period when single and multiple factor theories were prevalent, the passage of PL 94-142 was completed. This law was far-reaching in its consequences for several reasons. First, the reading problems evidenced by dyslexics were now legally defined as a reading disability (RD), and schools were required to individually tailor instruction and education for those children with these disabilities. Although reading disability was now an accepted educational handicap, the federal law provided a definition based on underachievement compared to predictions from ability. This discrepancy model was basically atheoretical, and provided no basis for a scientifically defined model of reading. Nonetheless, ability-achievement discrepancies remain the criteria of choice in almost all studies of dyslexia in the past few decades (Stanovich, 1988).

Multiple factor models

Dissatisfaction with the explanatory power of single-factor models and a need to account for more heterogeneous groupings led to renewed interest in use of neuropsychological, ability and achievement measures to identify reading subtypes. The earliest and most prevalent subtypes were based on visual and auditory deficits. As described by Johnson & Myklebust (1967), visual dyslexics had problems in connecting whole words with their meanings, and made many visual similarity errors and replacements (i.e. big for dig). Individuals with auditory dyslexia had problems discriminating sounds and blending them together to form words. They may associate whole words with meanings, but exhibit difficulty reading components or unfamiliar material.

These types of reading problems formed the basis of the most prevalent multiple factor model described by Boder (1973). He renamed auditory problems as dysphonic dyslexia and visual problems as dyseidetic dyslexia, but essentially the same causal paths and syndromes identified by previous researchers were supposed. Later studies by Mattis, French, and Rapin (1975) described a third type with associated problems in both graphological domains and motor coordination deficits. Following the publication of

Vellutino's (1979) rigorous rebuttal of visual deficits, these types became more focused on processes of word reading such as recoding and whole word deficits (Mitterer, 1982). In this format they influenced the growth of information processing theories.

Empirical models

The advent of multivariate statistics and advanced computer programs allowed empirical studies to flourish in the reading disability literature. Doehring & Hoshko (1977) found three types of poor readers using Q-type factor analysis. The largest group had deficits in oral reading as opposed to silent reading, the second largest had deficits in grapheme to phoneme correspondences, and the third group showed problems with orthographic material. These results were later replicated (Doehring, Trites, Patel, & Fiedorowicz, 1981).

Data from the Florida Longitudinal Project was subjected to cluster analysis to derive subtypes of reading disabilities prevalent in school populations (Satz & Morris, 1981; Morris et al., 1986). Results indicated a continuum of verbal deficits in interaction with a continuum of visuo-spatial impairments. Another factor in defining groups was change in cognitive ability over time, as two of the five groups showed fluctuations in their cognitive performance compared to average readers. These studies point to the importance of considering development in research, a variable discussed later in this paper.

Other studies were conducted using common intelligence and achievement measures to classify dyslexics (Joschko & Rourke, 1985; Vance, Walbrown, & Blaha, 1978). Although these studies showed clear subtypes, most authors view their results as reflections of the Wechsler factors more than true group differential variables (Hooper &

Willis, 1989). Caution in using single measures must be exerted when evaluating deficits in dyslexics, and this precaution is further addressed in chapter three.

Summary

Historical views of dyslexia have a long and rich tradition. Beginning with the early case studies, subtypes of dyslexia were hypothesized (Fisher 1905; Hinshelwood, 1909). Single factor theories helped to point to the prominent deficits in dyslexic children and pave the way for more complicated dual and multiple factor models (Bender, 1959; Hooper & Willis, 1989; Orton, 1937; Wepman et al., 1960;). Many of these factors were incorporated into the newer models of dyslexia and continue to exert influence today (Castles & Coltheart, 1993; Seidenberg & McClelland, 1989; Stanovich, 1988; Wolf & Bowers, 1999).

Despite the rich research tradition of dyslexia, several methodological difficulties continued to plague the field. As reviewed by McKinney (1984), the research had relied on two problematic techniques. Inferential techniques relied on different ability measures to group dyslexic children into ill-defined categories based on visual matching of children across multiple measures. This led to poorly constructed groups, who then either did not respond to instruction or had negative outcomes. Concurrently, other studies looked for single syndromes and causal agents to account for all dyslexic problems, thus leading to groups of children with widely different causal agents for their dyslexia. Improving research would require applying multivariate statistics to theoretically grounded groups of readers (McKinney, 1984).

These new procedures were integral parts of two research fields that emerged in the early 1980’s. First, a handful of authors outlined possible stages in reading development that helped to explain conflicting findings about dyslexia. Second, information processing theories emerged that reshaped thinking on reading disabilities and facilitated the development of predictors of reading achievement currently in use.

Reading Acquisition Theory

Research into subtyping of dyslexia often resulted in conflicting results. One explanation for this was given by Frith (1985), who stated that different cognitive processes might underlie reading at different stages of development. According to her model, individuals pass through three distinct phases of reading based on how they decipher print. During the logographic phase, young children identify whole words by sight, without concern for the phonological structure. This sight recognition often relies on only one salient cue per word, leading to many errors with increasing vocabulary development (Gough, Juel, & Griffith, 1992). Direct visual connections are made, allowing children to develop an impressive sight vocabulary before actually using the alphabet to read.

As this procedure becomes burdensome and leads to many errors, children then progress into using the alphabet. Here the young reader applies grapheme to phoneme instruction and phonological processing to sound out words and begin “true reading.” Children internalize the phonological rules of language, matching specific graphemes to oral phonemes (Gough et al., 1992). Frith (1985) referred to this process as the alphabetic stage of reading acquisition.

The primary task of this stage later came to be known as word decoding (Gough & Tunmer, 1986). These authors preferred to term the grapheme-phoneme converter a cipher. This cipher operates on four principle areas. First, children must intend to apply the rules of the language. Second, they must be aware of the letters in any given word. Third, they must be aware of the component phonemes in the word. Finally, they must have pairs of spoken and written words to develop the rules (Gough et al., 1992). Any problems with these principles will lead to a deficient processing cipher, and poor visual analysis, phoneme awareness, or print exposure will all cause similar detrimental effects. This cipher is the basis for all reading and, similar to Frith (1985), these authors believe all orthographic skills as well as spelling abilities are built upon the cipher.

The alphabetic reading process remains available to readers afterward, but most individuals move on to the last stage called orthographic reading, or cipher sight word reading (Ehri, 1992). This last transition requires that readers use orthographic units in words to access semantic and phonological information in their memory lexicon. The main difference between this stage and the last is the unit used to access memory, in this case a sequence of letters versus blended phonemes (Ehri, 1992). This process allows for the drastic increases in fluency and reading rate that occur for normal readers around age seven.

Frith's (1985) theories on reading acquisition have strong explanatory power when interpreting research results. Studies that assess word decoding and grapheme-phoneme skills will likely find the strongest relationship during the alphabetic phase. Phonological skills may not exhibit as much effect at the earlier, logographic stage. Likewise, orthographic skills may not show relationships to reading until the cipher sight word stage is reached. Although correlations between underlying variables and reading achievement may fluctuate with age, any deficit during development may have profound impact on later stages. The next section outlines the information processing theories, which consider problems in development as core characteristics of dyslexia.

Information Processing Theories

Great strides in the understanding of dyslexia have occurred as a result of information processing theories. These models grew out of research conducted on individuals with acquired dyslexia, individuals whose reading problems occurred after neurological insults. Comparisons from acquired dyslexia syndromes allowed component processes of skilled reading to be isolated and studied when they become deficient. Leading researchers quickly noticed the similarities between many individuals with acquired dyslexia and developmental dyslexia, and thus advocated the generalization of subtypes already identified in the neuropsychological literature (Patterson, 1981).

The most common subtypes of acquired dyslexia, originally presented by Marshall and Newcomb (1973), were deep dyslexia, letter-by-letter reading, phonological dyslexia, and surface dyslexia. These four subtypes were studied extensively in the ensuing years and several qualitative descriptions developed (Patterson, 1981). Deep dyslexia was associated with phonological skill impairments that resulted in fairly accurate familiar content word reading, poor function word reading, and an almost nonexistent ability to read non-words. Letter by letter reading describes readers who can only process print by pronouncing out each letter and are unable to organize letters into syllables and words. Phonological dyslexia is similar to deep dyslexia except that familiar words are read very accurately and non-words can be read, but performance is drastically behind that of normal readers. Finally, surface dyslexia describes a syndrome where individuals have problems with irregular spellings. These individuals can use phonological information to decode words well, but have problems with unfamiliar exception words, or those that do not follow normal phonological rules. Problems with rate of reading also exist in this subtype of dyslexia.

Comparisons of individuals with acquired and developmental dyslexia revealed some discrepancies that called into question whether these four subtypes actually exist in poor readers without neurological insults. Baddeley, Ellis, Miles, and Lewis (1982) studied 32 individuals with developmental dyslexia and found that none fit the pattern of deep dyslexia, a finding that has been replicated (Baddeley, Papagno, & Vallar, 1988b). No evidence of letter-by-letter reading in individuals with developmental dyslexics was found either (Seymour & MacGregor, 1984). As such, these two types were not considered prevalent in developmentally poor readers.

Phonological and surface dyslexia met with greater success when studied in individuals with developmental dyslexia. This occurred through the presentation of detailed case studies conducted on developmentally poor readers. The first case study was presented by Temple and Marshall (1983), who described the case of HM, a 17 year-old female with profound difficulties in reading. Despite her word-reading being at a 10 year-old level, she evidenced above average verbal intelligence and a well-developed vocabulary. These researchers presented her with several lists of both nonsense words and real words of different usage frequency. While HM pronounced all the high frequency real words correctly, she only pronounced 36% of the non-words correctly. In subsequent lists, she showed deficits on non-words that were visually dissimilar to real words, and longer, multi-syllabic words were particularly difficult. She made derivational errors, or choosing other forms, on several words and also chose visually similar words on several occasions. However, HM did not make any regularization errors, defined by overapplying phonetic rules. The authors explain her difficulty as a problem in phonological analysis and synthesis, and termed her a "phonological dyslexic" (Temple & Marshall, 1983; p. 520).

The second seminal study was presented by Coltheart et al. (1983). In this study, the researchers provided several word reading measures to an adolescent girl named CD. Of particular importance, CD pronounced almost all regular words correctly but showed difficulty pronouncing words that did not follow regular phonetic rules (termed irregular words). She made many regularization errors, applying phonetic rules when inappropriate. She also showed difficulty in spelling irregular words and the stressing of appropriate syllables in speech. Her non-word performance was mixed, which the authors attribute to the combination of phonetically correct and incorrect pronunciations of non-words.

Coltheart et al. (1983) used the term coined by Marshall and Newcomb (1973) of surface dyslexia to describe CD's performance. They hypothesize that poor orthographic skills lower the encoding and retrieval of whole-word representations in lexical memory. Thus, surface dyslexics use phonological decoding to read most words. This results in their defining symptoms of poor irregular word reading, many regularization errors, syllable stress errors, and phonetic spelling.

Despite the important contribution of these case studies to the development of word reading subtypes, several critics of their techniques emerged. Bryant and Impey (1986) gave the same list of measures to a small group of normally achieving students. They found many of these students showed as many deficits as the case studies, yet read at an age-appropriate level. As such, these authors concluded that phonological and surface strengths and impairments exist on a more dimensional level for all readers, and are not a sure diagnostic sign of dyslexia (Bryant & Impey, 1986). Although the case study method has obvious drawbacks, the influences of these cases are clear on the models of reading disability that emerged.

Dual-route model

Following the finding that phonological and surface types of dyslexia may exist in developmental cases, a model was proposed that these two types of reading problems reflect the two cognitive routes to accessing words. Deficiencies in either route will result in different types of dyslexia. In their seminal study and literature review, Castles and Coltheart (1993) provided the full dual route model. They described the commonalities between reading patterns in individuals with acquired dyslexia and developmental dyslexia, and pointed out the similar presentations between acquired and developmental versions of phonological and surface dyslexia. They postulated that phonological dyslexia occurs when the sublexical route to identifying words is deficient. On the other hand, surface dyslexia develops when the lexical route to words is deficient.

According to Castles and Coltheart (1993) these two deficiencies will result in different patterns of reading disability. First, phonological dyslexics with damaged sublexical routes will have difficulty pronouncing words they have no visual representation of in the lexicon. Because they have no phonological processing skills they have great difficulty pronouncing non-words. On the other hand, individuals with surface dyslexia who have damaged lexical routes will be unable to identify exception words that do not follow phonological rules applied by the sublexical system. As their visual, lexical access system is impaired they cannot retrieve visual representations of these words and incorrectly apply phonological analysis to them.

In order to test the dual-route model, Castles and Coltheart (1993) studied 56 children that were at least a year and a half behind in reading (RD group), and 56 normally achieving readers. Each participant read a list of 90 words that contained regular words, exception words, and non-words. On this task, half the RD group was below average on both non-words and exception words. Despite difficulties in both surface and phonological reading, most of the participants showed discrepancies when regression equations were used to predict performance of non-words from exception words and vice versa. As such, many of the RD group could still be classified as “soft” phonological or surface dyslexics.

Of the remaining RD participants, 34% showed a deficit for only non-words or exception words, with the majority of this group being phonological dyslexics. The results supported the distinction between phonological dyslexia and surface dyslexia, but individualized skills were more dimensional than cluster based (Castles & Coltheart, 1993). Generalizing these findings, a very small minority of dyslexic children will show pure surface dyslexia with intact phonological encoding, while a larger group will show pure phonological dyslexia. However, the largest group of reading disabled children will have difficulties in both areas and individuals with “soft” phonological and surface dyslexics will exist within this combined group.

Replications of the Castles and Coltheart (1993) study have found similar results, but with different interpretations (Manis et al., 1996; Stanovich et al., 1997; Sprenger-Charolles et al., 2000). The replication by Manis and colleagues (1996) used the same measures with concurrent tasks of phonological awareness and orthographic skill, and also compared children with dyslexia to a reading-age matched control group. Several theorists describe the importance of comparing children with dyslexia to reading age controls, assuming that they should show a deviation from the reading patterns of normal learners (Stanovich et al., 1997; Torgesen et al., 1994 Sprenger-Charolles et al., 2000). Results of the study found a larger than predicted percentage of dyslexics exhibited significant deficits in reading both nonwords and exception words. For those with discrepancies between the two skills, the phonological dyslexic group scored poorly on both phonological awareness and orthographic skill. The surface dyslexic group only did poorly on orthographic skill. Although this finding partially supports the dual route model, the authors point to the poor performance of phonological dyslexics as evidence of the supremacy of this deficit in reading disabilities (Manis et al., 1996).

More importantly, the performance of the reading disabled group compared to reading-age matched controls was analyzed. Results indicated that 71% of the group with phonological dyslexia performed significantly more poorly than younger readers on reading non-words, and showed a trend of poorer performance on phonological awareness tasks. In comparison, only 7% of the surface dyslexic group performed differently than the younger readers. Manis et al. (1996) interpreted these findings as evidence that different groups do exhibit phonological and orthographic deficits, but that phonological deficits represent a true reading disorder, while surface deficits represent a general delay in word recognition.

Another study conducted by Stanovich and colleagues (1997) replicated this finding using 68 children with dyslexia and a group of chronological-age and reading-age matched individuals. They found that both individuals with phonological and surface dyslexia (defined by performance on non-words and exception words) scored below chronological-age peers on most reading measures. However, only children with phonological dyslexia differed from reading-age controls. These groups differed on both measures of phonological awareness and orthographic skill, while surface dyslexics differed on neither. The authors postulate the same argument as Manis et al. (1996) that surface dyslexics represent a developmental delay and not a true reading disability. They also view orthographic deficits as a true reading problem, but one that only manifests dyslexia when phonological deficits are already present. The authors' hypothesize that surface deficits may be due to lower print exposure and environmental influences (Stanovich et al., 1997).

A final replication of the Castles and Coltheart (1993) study was conducted on a French-speaking sample (Sprenger-Charolles et al., 2000). This study agreed with the findings of Stanovich and colleagues (1997) that only individuals with phonological dyslexia differed from reading age controls. They also found concurrent evidence that those children with surface dyslexia resembled a delay, however many of their children with surface dyslexia exhibited phonological deficits compared to same-age normal readers. In addition to reading, this study included orthographic and phonological spelling measures. Interestingly, Sprenger-Charolles and colleagues (2000) reported that orthographic problems became more pronounced with age in individuals with surface dyslexia compared to both groups of normal readers and phonological dyslexics. Unfortunately, the confounding variable of different language systems in this study must be further investigated.

In summary, research findings on the dual route model have drawn two conclusions. First, the phonological deficits apparent in phonological dyslexia are unequivocally present. Second, the presence of a smaller surface dyslexia group based on irregular word reading does exist, but whether it is a true deviation and form of dyslexia requires further research. Most individuals with surface dyslexia resemble younger readers in their component skills, though orthographic deficits may become more apparent with age. To explain these results, two theories have been issued: 1) They have a lack of print exposure and word knowledge and 2) Surface dyslexia is actually a category of readers who progress normally but are delayed in their reading. These hypotheses are addressed by the other major theory that grew out of information processing theories, that of the connectionist view.

Connectionist models

Seidenberg and McClelland (1989) took advantage of the new power of computer models to simulate human reading in developing the connectionist view. Their first model created vast research interest in that after training on almost 3,000 words, the model was able to simulate learning and flawlessly provide correct pronunciations of words. Mistakes were infrequent and resembled those often made by normal readers.

The model was quickly hypothesized as representing the architecture of language processes of the brain. The structure, however, was profoundly different than the dual route theory of Castles and Coltheart (1993). First, orthographic, phonological, and semantic properties of words were combined in one system to elicit the correct word. This combined information is processed by hidden units that map onto the correct word by a series of weighted connections. Weights between combined information and words are created by practice and exposure to the words in different contexts. Finally, accurate mapping is influenced by the computational capacity of the hidden units, thus damaged connections or missing units result in decrements in reading skill (Seidenberg, 1993). These concepts are inherent properties of the computer model, and Seidenberg and McClelland (1989) were able to compare the computer performance to behavioral data on normal and dyslexic readers.

The largest deviation from standard thinking was that the system had no explicit rules, where all other models assumed a set of grapheme-phoneme correspondence rules in word decoding (Stanovich, 1988). This lack of rules and reliance on weighted connections did pose problems for the model. When Seidenberg and McClelland (1989) attempted to simulate dyslexic patterns they found the model performed much worse on non-words than normal readers and even phonological dyslexics. Likewise, they were unable to simulate more than very mild patterns of surface dyslexia by altering the model.

Updated versions were able to overcome many of the limitations of the first connectionist model (Harm & Seidenberg, 1999; Plaut et al., 1996). First, new models were able to learn to pronounce non-words when a series of exemplars were added to the hidden units. When the phonological representation units were altered through random disconnection or addition of noise, the model showed performance similar to phonological dyslexics. Interestingly, further damage to the phonological structure caused a pattern that resembled a mixed disorder with problems in pronouncing non-words and exception words (Plaut et al., 1996). As previously discussed, this mixed pattern was the most prevalent syndrome found in dual route studies.

The most recent connectionist model was also able to simulate surface dyslexia through different procedures. First, models that were not trained as well performed poorly on exception words. Secondly, damage to orthographic input devices caused decrements in exception word reading. Finally, removing hidden units and decreasing the computational power of the model created patterns similar to the word reading of individuals with surface dyslexia (Harm & Seidenberg, 1999). These findings create several hypothesized links between components of the reading process and surface dyslexia.

Research from the connectionist models expanded the understanding of system interactions in skilled reading, but many limitations were outlined by Coltheart and colleagues (1993). The models' limited training vocabularies do not simulate automatic and higher level reading found in skilled readers. Furthermore, lexical decisions and the influence of semantic information are given less importance than phonological input. Thus the models cannot make decisions between different pronunciations of multiple meaning words. Finally, the inability to directly simulate patterns of dyslexia (especially surface dyslexia) clearly questions the completeness of the causal interpretations for reading disability based on the model (Coltheart et al., 1993).

Although limitations of connectionist models exist, several important concepts have arisen. The first involves the role of phonological representations. These representations are able to learn and grow through connections and weighted interactions with various orthographic patterns. This phenomenon has been termed the self-teaching mechanism of phonology by Share (1995), and helps explain the improved phonological abilities of those with increased print exposure and reading practice. The second point is that damage to the phonological representations causes an output pattern strikingly similar to phonological dyslexia, with increased destruction leading to a mixed disorder performance (Plaut et al., 1996). Thus these models provide converging evidence that phonological processing underlies the major patterns of dyslexia. Finally, attempts to replicate surface dyslexic patterns resulted in several theories of how this occurs, and many of these hypotheses converge with those from the studies of dual-route theory (Harm & Seidenberg, 1999).

The first hypothesis that surface dyslexics have less exposure to print has been investigated in several studies. The Harm and Seidenberg (1999) computer model showed performances similar to surface dyslexics when it was exposed to less words. Recently, Bailey and colleagues (Bailey, Manis, Pederson, & Seidenberg, 2003) trained 230 children on reading regular, exception, and non-words. As their study was based on responses to intervention they hypothesized a link would exist with previous reading practice, however they found print exposure and environmental influences to not be a likely candidate in surface deficits. As such, the print exposure hypothesis remains tentative.

The second hypothesis, drawn by Stanovich and colleagues (1988), was supported by replicating the findings that individuals with surface dyslexia perform exactly like younger readers matched for reading age (Bailey et al., 2003; Manis et al., 1996; Sprenger-Charolles et al., 2000; Stanovich et al., 1997). Developmental delay is the most parsimonious explanation for this apparent match, and as such these authors have proposed developmental delays as the cause of surface dyslexia. Interestingly, these reading patterns were also obtained in connectionist models when computational power was decreased (Harm & Seidenberg, 1999). Thus delays in human processing mechanisms such as processing speed could underlie the surface pattern of delayed reading. This view is discussed later in this chapter and the final important information processing theory is discussed next.

Accuracy vs rate model

Lovett (1984) introduced the concept of fractionated dyslexic groups based on accuracy and rate deficits. She reported children with accuracy problems tend to have oral language deficits, while rate deficient children exhibit more difficulties in visual naming (Lovett, 1992). In addition, children with reading accuracy problems had poor phonological analysis and synthesis, poor comprehension, poor spelling, and deficient word recognition. The children classified as rate disabled produced more decoding errors and had markedly slower word identification times. These groups show many similar characteristics to phonological and surface dyslexics in the impaired phonological skills of accuracy deficient children and slower reading speeds of rate-disabled children. In addition, Lovett, Ransby, and Barron (1988) showed modest treatment gains when phonological skills training was given to the accuracy deficient group. Despite this evidence, these categories have not received much empirical support. Influences on the literature were more profound, however, in continuing to propagate processing deficits as a possible core factor in surface dyslexia and existing models (Nicolson & Fawcett, 1994; Kail & Hall, 1994; Wolff et al., 1990).

Summary

Information processing theories have contributed a wealth of information about the reading problems of dyslexic children. These theories have helped to elucidate different patterns and subtypes of dyslexia, and began the drive for appropriate treatments tailored to these deficits. Two distinct patterns of reading disability emerged from these theories, those of phonological dyslexia and surface dyslexia. Research on phonological dyslexia has shown this to be the largest pattern of deficits in reading, and have unequivocally pointed to impairments in phonological processing skills as a core feature of this disability. Surface dyslexia has remained a more elusive subgroup, with different researchers ascribing these difficulties to phonological problems, developmental delays, and low print exposure. Nonetheless, the surface pattern of reading disability has brought to light the possible consequences of low print exposure and various processing deficits on reading ability.

Causal Agent Theories

While the above models have focused on different patterns of word reading as the basis of reading models, other researchers have focused on the causal agents and predictors of achievement (Stanovich, 1988; Torgesen, 1996; Wolf & Bowers, 1999). Using longitudinal methods and rigorous designs, these research groups have centered efforts around the strong relationship between phonological awareness and rapid naming as factors in subsequent reading achievement. Interestingly, the underlying processes of these two skills may also explain the reading patterns discovered by information processing theories. This hypothesis will be discussed as part of the research questions of this study, but before this section can continue both phonological awareness and rapid naming must be defined.

Phonological processing skills have had a long history in relation to reading disability (Hooper & Willis, 1989). As reviewed earlier, case studies found phonological skill deficits to be a core problem in certain dyslexic groups (Temple & Marshall, 1983). Likewise, word recognition and pronunciation models have used non-word reading as a measure of phonological processing skill. However, better ways of analyzing phonology may exist. As described by Torgesen (1994), phonological processing requires two key components. First, phoneme analysis is the process of extracting the specific phonemes from different graphemes in words. At the basic level, this skill requires identification of specific letter sounds in words. The second skill is phoneme synthesis. This skill requires a reader to combine letter-sound combinations to form phonemes, which in turn lead to word pronunciations. Taken together, these skills form the more common term phonological awareness. Torgesen et al. (1994) provides the definition of phonological awareness as “one's sensitivity to, or explicit awareness of, the phonological structure of the words in one’s language” (p. 276). Considering this dual role of phonological awareness, tasks that measure it (as opposed to non-word reading) require analysis and synthesis of sounds and phonemes.

A separate factor in reading achievement has been termed rapid naming. Commonly measured by rapid automatized naming (RAN) tasks, these were first developed by Denckla and Rudel (1976) and require the individual to name objects that are presented in a rapid, serial fashion. This serial order usually consists of five rows of ten items, with the reader instructed to name each item as fast as possible. RAN tasks usually require the naming of letters, digits, colors, and objects separately (Wolf et al., 2000). Significant relationships between RAN and dyslexia have been discovered, and researchers utilize the task as it approximates the process required in skilled reading (Wolf & Bowers, 1999; Denckla & Rudel, 1976).

Phonological core variable difference model

The first longitudinal study to produce predictive agents in reading achievement was by Stanovich (1988). He reviewed the comparison of poor readers and normal readers within and across ages. The largest predictor of reading comprehension was word naming scores, and the largest contributor to word naming was phonological awareness (Stanovich, 1992). As for rapid naming skills, these scores were more predictive of chronological age and appeared to improve with each successive grade. Stanovich (1988) used these results to create the phonological-core-variable difference model. According to this model, phonological awareness is at the core of all dyslexia (although he admits to a rare dyslexia based on surface, orthographic origins) and all other deficits are secondary. As children exhibit deficits in RAN or other reading-related skills, they will also show other areas of learning disability and become more cognitively challenged through grade school. Likewise, children with early reading failure may develop cognitive deficits that are caused by their reading problems, thus impairments at later ages may be influenced by prior reading achievement (Stanovich, 1992). Individuals with these multiple cognitive deficits have lower intelligence and generalized learning difficulties, and in terms of reading are termed "garden variety" poor readers (Gough & Tunmer, 1986; Stanovich, 1988).

Historically, various studies have found phonological skills to be impaired in dyslexic children (Bradley & Bryant, 1987; Hooper & Willis, 1989). Since the proposal of the phonological core variable difference model, several studies have replicated the finding that phonological awareness is the core deficit in reading disability. The longitudinal studies of Torgesen et al. (1994) included 244 children on a wide variety of variables from kindergarten to grade three. Stability coefficients for phonological and rapid naming skills were all between .5 and .7. In comparison to isolated naming and memory skills, only phonological awareness and rapid naming predicted future reading ability. However, when entered into a structural equation, only phonological awareness (and specifically phoneme analysis) contributed independent variance to future reading achievement. As such, these authors stipulate that phonological awareness skills underlie most reading processes and remain the core deficit in dyslexia (Torgesen et al., 1994). Many research teams that have used cross sectional analysis agree with these findings (Bailey et al., 2003; Gough & Tunmer, 1986; Manis et al., 1996; Sprenger-Charolles et al., 2000)

Cluster analysis results also support the phonological core variable difference model (Morris et al., 1998). Examining 376, seven to nine year old elementary students, these authors found seven clusters of learning disability. Of the seven, six had phonological deficits as part of the discrepancy scores that defined the group. Only children with global rate deficits (equivalent to processing speed impairments) exhibited no phonological impairments.

Double deficit model

Although the importance of phonological awareness as a factor in development of skilled reading and dyslexic patterns can no longer be questioned, some authors have found the reliance on just phonology to be incomplete. These researchers have also focused on rapid naming skills as a causal factor in reading disabilities, and foremost among them have been the proponents of the double deficit hypothesis outlined by Wolf & Bowers (1999). Their review of the literature points to phonological awareness problems and naming speed problems as contributing independent variance to reading ability. As such, children with only single deficit phonological or naming speed deficits will show poor reading achievement, but those with both problems, or a double deficit, will show the most severe difficulties.

Wolf and Bowers (1999) review the separate contributions of these deficits. Phonological awareness problems affect tasks such as decoding and word attack tests. Naming speed problems affect orthographic tasks, timed reading, and fluency measures. Both cause delays in reading comprehension, and together both create severe problems across all reading tasks. The double deficit theory may also explain the distinction between phonological dyslexics and surface dyslexics, as well as the profound reading problems of those children who exhibit both deficits (Castles & Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997). According to their meta-analysis, Wolf and Bowers (1999) reported correlations between naming speed and phonological awareness are only .1 to .4, showing the independence of these skills. They posit that phonological awareness is related to underlying auditory processing while naming speed either relates to visual or temporal processing, a stance somewhat aligned to the dual route theory of Castles and Coltheart (1993).

The question remains if rapid naming, as measured by RAN tasks, truly predicts reading performance. In an earlier study of 83 children, rapid naming was found to significantly differentiate those who developed dyslexia from controls at the start of kindergarten (Wolf et al., 1986). Specifically, the reading disabled group showed large latency times between viewing the stimulus and repeating the appropriate name. This discrepancy between later-defined normal and poor readers remained for letters, numbers, colors, and objects. As such, the naming speed deficit appeared independent of grapheme-based stimuli and has been replicated in other studies (Wolff et al., 1990). When the RAN tasks were administered one year later, interesting results were obtained. The dyslexic group made substantial gains in rapid naming times, while the normal readers only made small gains. Nonetheless, the reading disabled group still remained substantially behind the normal readers, who had attained fluency levels. This difference remained stable when measured one year later. From these results, Wolf et al. (1986) concluded that rapid naming speed contributes significant variance to early reading abilities and differences between normal and dyslexic groups.

Ackerman and Dykman (1993) used rapid naming and phoneme analysis tasks in conjunction with memory span and articulation to examine the differences between Attention Deficit Disorder (ADD) children, normal readers, poor readers with below average intelligence (garden variety poor readers), and readers with a 17-point discrepancy between achievement and ability measures (identified as the reading disabled group). Using a sample of 119 children they found the reading disabled group scored significantly poorer on phoneme analysis and rapid naming tasks compared to both normal and garden variety poor readers. This distinction provides evidence that rapid naming tasks are not only related to reading achievement, but also differentially predict the presence of dyslexia when compared to children with more global cognitive deficits.

While it appears that rapid naming differentiates children with dyslexia from those with global deficits, others have objected that lack of exposure to print and poor early literacy may contribute to naming deficits (Stanovich et a., 1988). One study of readers at age 8, 13, and 17 found that individuals with a reading disability had equivalent RAN scores to earlier, age matched children (Fawcett & Nicolson, 1994). Interestingly, the reading disabled and slow learner groups did poorly on all rapid naming tasks and discrete trial naming tasks. This study thus presents mixed results in that dyslexics and same reading level, normal readers have similar rapid naming scores but that the naming speed deficits for dyslexic children present across modalities and in isolated naming tasks. These results contradict those of Ackerman and Dykman (1993) who found only serial naming differentiated dyslexics from garden-variety poor readers.

The ability for rapid naming tasks to differentiate dyslexics from normal readers was further replicated with 100 adolescents (Wolff et al., 1990). In this study, groups were also given discrete trial naming tasks via film exposures with varying rates. Interestingly, dyslexics were significantly poorer at discrete naming tasks compared to normal readers, a finding that supports that of Fawcett & Nicolson (1994). However, the faster discrete trial presentations with shorter exposures were much more impaired in individuals with dyslexia. Whether only rapid serial naming is deficient in dyslexia, or a more global naming problem is present in discrete trials requires further research.

Although the above studies were concerned with reading level effects and degree of naming deficits, the longitudinal studies of Torgesen et al. (1994) found reading skills to create stronger effects on phonological awareness. These studies also replicated the finding that phonological awareness and naming speed contribute the best prediction of future reading achievement, as well as the stability of naming speed measures (.62 across one year). In a later follow up of this group, naming speed no longer contributed any predictive influence to subsequent reading, though phonological awareness continued to predict achievement. Torgesen et al. (1997) thus concluded that naming speed contributed variance only before grade three and ceases to predict the achievement of older readers. Studies of adulthood substantiate this claim (Wolff et al., 1990).

Meyer et al. (1998) administered both phonological processing measures and rapid naming tasks to a large group of normally-distributed readers, and then to a smaller group of readers performing in the 10th percentile or lower. Their results indicated that rapid naming indeed provides no predictive value in a normal distribution like that of Torgesen et al. (1997). In contrast, when the poor reader group was analyzed, rapid naming contributed 18-22% of the variance in reading within this group. All participants in the poor reader group performed badly on measures of phonological awareness, as such these measures provided no within group variance. The authors use these findings as evidence that naming speed contributes variance on top of phonological skills, and not independent of them (Meyer et al., 1998).

Although numerous studies have found the importance of rapid naming tasks to predictions of reading achievement, the relative independence of these groups continues to find mixed results. One study found that phonological awareness and naming speed shared variance, so that only phonological awareness contributed independently (Torgesen et al., 1994). This finding is in contrast to the 23% shared variance found in other studies (Meyer et al., 1998). Recently, Manis et al. (2000) took 85 children and administered both phonological awareness and rapid naming tasks, using these to create groups with no deficit, phonological deficits, naming deficits, and double deficits. Using performance on word reading and comprehension, they found moderate delays in reading achievement for the single deficit groups and severe delays for the double deficit group.

The relative importance of phonological awareness and rapid naming was recently studied through structural equation modeling (Holland et al., 2004). Measures of orthographic skill were also included for this sample of 100 elementary students. The different models tested whether rapid naming contributes directly to reading achievement or through the variance in phonological awareness and orthographic skills. One model also tested if orthographic and phonological skills have indirect effects on reading achievement through rapid naming.

The model that fit the data best had rapid naming contributing to variance in reading achievement indirectly. Specifically, rapid naming had a .31 direct effect on reading achievement (for every standard deviation change in rapid naming, there is a .31 standard deviation change in reading achievement) and a .28 indirect effect through phonological awareness skills. When rapid naming was directed through orthographic skills, the total effect jumped to .56 and when it was directed through both the phonological and orthographic skills the total effect was .68. In this last model orthographic skills actually contributed the most effect at .70, while phonological processing skills contributed the least total effect at .51 (Holland et al., 2004).

Two tentative conclusions and two precautions can be drawn from this study. First, rapid naming appears to contribute directly to phonological awareness and orthographic skills, and thus will have indirect influence on reading achievement whether it contributes directly or not. Second, rapid naming appears to be as strong a predictor of reading achievement as phonological awareness considering the .68 and .51 total effects from the best model. The finding that orthographic skills contributed the most variance is contradictive of results from many larger studies (Meyer et al.; 1998; Torgesen et al., 1994)

The two precautions concern the operationalization of phonological and orthographic skills. One of the orthographic measures in this study was receptive coding, which includes visual scanning and matching. Visual matching skills, when used in a timed fashion, are often used to measure processing speed and the potential confounding influence of this variable will be discussed later in this chapter (Wechsler, 2003). The other weakness of the Holland et al. (2004) study is their operationalization of phonological awareness. All three measures used for this construct are deletion tasks (syllable, phoneme, and rhyme deletion). As such, no measure of phoneme synthesis or word blending was utilized, an important component of reading (Torgesen et al., 1997). Whether use of these measures would alter results remains a viable research question.

Summary

Combining the studies on phonological awareness and rapid naming difficulties in dyslexia requires interpretation, and recent reviews have drawn different results (Wolf et al., 2000). However, several key conclusions can be drawn from the literature. First, phonological awareness problems remain a core deficit in reading disabilities. A separate group with rapid naming speed deficits has been found, but several studies find this may not be an independent group of dyslexics. One finding that is consistent is the combination of phonological awareness deficits and rapid naming speed deficits causes the most severe reading problems. This combination also provides the most predictive power in reading achievement, though a few studies have found orthographic skills to do likewise. Whether phonological awareness (as defined by phoneme analysis and phoneme synthesis) and rapid naming contribute direct effects on reading achievement is a research question considered in this study.

Processes in Phonological Awareness

As earlier defined by Torgesen et al. (1994), phonological awareness is the sensitivity to the smallest parts of a language called phonemes. A volumous history of research has shown phonological awareness to be a core deficit in the majority of individuals with dyslexia, with estimates on the overall variance in reading ability to be 25% to 60% (Wagner & Torgesen, 1987). Despite the importance of phonological awareness, the underlying processes remain elusive. Recent studies have found that all phonological awareness tasks load on one factor, and defining this factor is a current research initiative (Wagner, Torgesen, & Rashotte, 1994). Three major hypotheses have been forwarded in this regard, these being that the largest variance in phonological awareness skills is the analysis of phonemes in a word, the awareness of rhyme and analogy, and phoneme synthesis or sound blending.

Phoneme analysis

The early longitudinal studies of Bradley and Bryant (1983) found analysis of phonemes to be a major contributor to dyslexia, and this hypothesis has grown empirically stronger since. Cornwall (1992) found tasks such as auditory analysis were stronger correlates of reading when compared to phonological memory and rhyme measures. Other studies have replicated that simple sensitivity to the phonemes in a word, as measured by locating an incorrect phoneme, are the strongest correlates of word reading ability (Ackerman & Dykman, 1993). This phonological analysis ability was referred to as phoneme segmentation skill by Olson, Wise, Connors, Rack, & Fulker

(1989) in their twin studies on dyslexia. They found that phoneme segmentation was the only reading skill that exhibits the characteristics of a heritable disability, thus providing evidence of deficient processing not due to general intelligence, a core characteristic of dyslexia (Stanovich, 1988).

Vellutino (1987) studied 265 kindergartners and 300 older students in a longitudinal study of dyslexia and treatment for reading disability. Correlations between phoneme analysis ability and later reading achievement were stronger than any other relation, including vocabulary and intelligence scores. The identification of sounds from specific word letters provided the greatest variance in this measure, and classroom training in sound-letter identification and phoneme segmentation showed the greatest gains in reading skills. In another longitudinal study, 244 kindergartners were assessed for their abilities in phonological analysis, synthesis, memory, and various naming and intelligence measures (Torgesen et al., 1994). By second grade, ability to analyze phonemes was the biggest predictor of reading from all the measures, also remaining relatively stable over time (stability coefficient = .66).

Phoneme analysis and sound-letter correspondence may not exhibit the same difficulty throughout words either. Studies have found that consonants pose more difficulty than vowels as they undergo more changes due to neighboring vowels and word stems (Reed, 1989). Likewise, large consonant clusters at the beginning and end of words (such as –sch or –tch) appear to pose greater problems than single or double consonant clusters, indicating that segmenting these types of phonemes is difficult for individuals with dyslexia (Bruck & Treiman, 1990). These studies and those above indicate that phoneme analysis, or the segmentation of phonemes in words, appears impaired in readers with dyslexia.

Rhyme and analogies

Another area of phonological awareness that may underlie reading problems is rhyme and analogies. Through several studies and writings, Goswami & Bryant (1990; 1992) have shown that perception of rhyming letters, phonemes, and words is correlated with future reading ability. They theorized that ability to create and perceive rhymes and analogous phonemes represents a form of phoneme segmentation and blending. These studies support a role of rhyme for ability, however other studies have indicated that rhyme and analogy are predictive only during Frith's (1985) logographic stage and lose sensitivity as children enter school (Cornwall, 1992).

Phonological working memory

In his often-cited review of the research on dyslexia, Jorm (1979) described the hypothetical relationship between phonological awareness and phonological working memory. He theorized that individuals with dyslexia have difficulty integrating the phonological information contained in words, and likewise have secondary difficulty in reorganizing that information for speech or spelling. These abilities were referred to as phonological decoding and recoding, but are now popular under the names of phoneme analysis and synthesis (Torgesen et al., 1997). Jorm (1979) then described part of these deficiencies as due to problems in working memory. The relation of phoneme analysis and synthesis to phonological working memory has grown to become a focus of research in dyslexia, with researchers suggesting an overlap in these abilities (Daneman & Carpenter, 1980).

An important hypothesized relationship is that ability to analyze phonemes is actually subsumed by working memory's ability to decode words into "chunks" of information (phonemes), and to process this information in phonological working memory. In a study of speech and reading problems, Catts (1986) found children with dyslexia had greater difficulty with multisyllabic words that appeared to indicate problems in decoding the information. In addition, Daneman and Carpenter (1980) gave adult readers a reading span task that required recall of the last word in different sentences. They found that reading span and comprehension correlated .84, the strongest relationship between component skills and reading achievement.

One study compared 68 students with a reading disability to a matched group of younger children performing at the same reading level (Stanovich et al., 1997). Of all the measures, verbal working memory was only one of two that differentiated children with dyslexia from same-level peers (syntactic processing was the other). Perhaps most convincing, factor analysis in the large longitudinal studies of Torgesen and colleagues (1994) found phonological working memory and phoneme analysis continued to load as the same factor until second grade, at which time they differentiated. Thus during the alphabetic stage, these abilities may be the same. Taken together, these studies lend much support to the theory of phonological working memory and phonological awareness sharing variance.

If the ability to synthesize or analyze phonemes is influenced by phonological working memory, then the relationship between phonological working memory and reading achievement may be linked by this process. The one side of this hypothesis would suggest that phonological working memory directly affects the segmentation of phonemes, and thus indirectly affects reading achievement. However, some studies found phoneme analysis to be independent of phonological working memory, and this hypothesis lacks empirical support (Torgesen et al., 1994). The other side of this research question would suggest that phonological working memory directly affects the ability to synthesize phonemes or blend sounds together. This phoneme synthesis ability then affects reading achievement. While research on working memory and word recoding is unfortunately lacking, measures such as digit span are correlated with reading achievement (Ackerman & Dykman, 1993), and estimates of shared variance between working memory and word reading are between 11% and 20% (Bowers, Steffy, & Tate, 1988).

Despite this empirical support and suggestive hypothesis, some long standing reservations must be considered. If blending phonemes through phonological working memory is directly influenced by an individual's ability to analyze and segment words, then the phoneme analysis skills may be the original cause of reading problems, with working memory simply not receiving the proper information to encode. Cohen and Netley (1981) studied this assumption by preventing the operation of the phonological loop during encoding of stimuli. They found that readers with dyslexia performed worse than controls whether working memory was operating efficiently or not, indicating that impairments occur in the representations, not memory, of phonological information. A later study showed that children with dyslexia showed a much larger impairment in remembering rhyming compared to nonrhyming words (Siegel & Ryan, 1988). This discrepancy can be interpreted as indicating poor phoneme analysis prior to synthesis when compared to normal readers.

Research of underlying processes in phonological awareness is not conclusive, but certain trends can be identified. First, the ability to analyze phonemes in words appears to be one of the two largest factors in phonological awareness. Second, the ability to synthesize phonemes is the second large factor in phonological awareness. Phonological working memory abilities may underlie a large portion of variance in this last skill, a research question that will be investigated in this study.

Phonological Working Memory

The previous section introduced research that suggests phonological working memory may explain some of the variance in phoneme synthesis and the more encompassing process of phonological awareness. The construct of phonological working memory thus remains to be discussed in this section. First the model of working memory will be discussed. Following this, studies on phonological working memory and reading achievement will be reviewed.

Research on memory and information processing was drastically changed by the introduction of the working memory model by Baddeley and Hitch in 1974. According to their theory, working memory contains three primary components; a phonological memory system, a visual-spatial memory system, and a central executive system. The phonological system contains a storage buffer that can maintain several pieces of phonological information in order for integration with long-term memory or transformations with other stimuli to occur. This storage buffer is refreshed by an articulatory loop that requires voluntary rehearsal. By using this rehearsal system, the phonological information is maintained in the storage buffer and not lost. The visual-spatial memory system is a similar system that maintains purely visual stimuli, and the central executive allocates processing resources to these secondary systems.

This working memory model has remained relatively intact, with a few minor updates and revisions since its introduction (Baddeley, 1986; 1992). Articulation does not appear related to the working memory system, so the rehearsal system was renamed the phonological loop. Also, it has been empirically shown that any stimuli that can be encoded phonologically is quite often done so, even when presented in picture format. As such, the phonological working memory system has grown to encompass many types of stimuli and experimental tasks (Brandimonte, Hitch, & Bishop, 1992)

Only one study has rigorously examined the links between phonological working memory and reading achievement. Gathercole et al. (1991) conducted longitudinal studies of skilled and poor readers during the reading acquisition period. They found no relation between phonological working memory tasks (non-word repetition, digit span, and rhyme detection) and naming in four-year olds. However, when the children were five years old, phonological working memory and naming were now significantly related. Specifically, non-word repetition shared 6.4% of variance in word reading, digit span 15.1%, and rhyme detection 11.8%. Apparently working memory became important as children moved into Frith's (1985) alphabetic stage and began decoding and recoding words. Gathercole et al. (1991) conclude that phonological skills dissociate at school entry, with phonological awareness and working memory creating unique variance in reading achievement (and thus causal influences in dyslexia).

Some studies have declared that working memory is not related to reading ability. Lovett (1987) found no differences in measures of memory between ability levels of readers. Likewise, Cornwall (1992) found average to high scores on sentence memory tasks in readers with dyslexia. Despite these findings, the results do not refute phonological working memory as a process in phoneme synthesis, because sentence reading and recall tasks given in each study likely measured long term and semantic memory systems, which are hypothesized to remain unimpaired in those with reading disabilities (Gathercole & Baddeley, 1993).

Processes in Rapid Naming

As previously discussed, rapid naming tasks have consistently been found as the second best predictor of reading achievement when coupled with phonological awareness. Unfortunately, the processes that influence the speed and accuracy of rapid naming have not been fully outlined, leaving a space in our knowledge of dyslexia. Stanovich (1988) hypothesized that reading exposure may be a culprit and Wolf (1991) theorized that processing variables such as visual deficits, global processing mechanisms, and working memory may underlie speed in rapid naming. Each of these hypotheses will be discussed in this section.

Print exposure

Developmental lag theory postulates that surface dyslexia and slow rapid naming are both manifestations of delayed reading, perhaps due to low exposure to print at an early age (Stanovich et al., 1988; 1997). Likewise, connectionist models such as that by Perfetti (1992) simulate poor naming by reducing training and exposure to print in their models. Converging evidence is surprisingly provided by Wolf et al. (1986) in their study using RAN tasks. Dyslexics performed substantially worse on naming of graphological symbols compared to non-graphological material. Only two explanations can explain this difference; problems with phonological awareness or lack of experience with graphological, print-based information.

Although these few studies provide support for the theory that slowed rapid naming is due to print exposure, other studies have criticized this claim. Wolf and Bowers (1999) showed that only modest correlations exist between rapid naming and other language tasks that are influence by reading experience. One study of third graders found that size of vocabulary, a measure very dependent on reading experience, showed no relationship with naming speed or accuracy (Katz, 1986). Finally, Meyer and colleagues (1998) constructed predictive equations based on the rapid naming scores of 64 poor readers and found that reading speed of only familiar words predicted reading ability. As knowledge of words played no part in the predictive power of rapid naming, the authors state that lack of reading experience cannot underlie the deficits that dyslexics show.

Visual deficits

Visual deficits were perhaps the first popular explanation for slow rapid naming speeds in children with reading disabilities. According to this account, slow visual letter identification impairs orthographic pattern recognition, especially in familiar material such as that of RAN tasks (Wolf & Bowers, 1999). These deficits would explain the finding from cluster analysis studies that one group of poor readers evidence deficiencies in visual perception (Boder, 1973; Lyon & Watson, 1981). In her studies of rate and accuracy disabled subtypes of dyslexia, Lovett (1987) found that visual naming was deficient in both types and appeared to be a visual-based deficit only.

Latency for naming objects in rapid and discrete trials has been related to visual impairments also. One study by Wolff and colleagues (1990) conducted RAN tasks and film-based naming tasks, which allowed for exposure and presentation times to vary. Results of this study indicated that dyslexics were poor not only at rapid naming tasks, but also at naming the film stimuli presented with short exposure time or fast presentation time. Normal readers did not show these deficits. The authors concluded that individuals with dyslexia have a longer registration time for visual material that impairs fluid reading. A similar study presented words in different orders and required subjects to identify the word that appeared first (May et al., 1988). Results supported a temporal processing deficit in that longer intervals between word presentations were required for individuals with dyslexia to respond correctly.

While a few studies have presented evidence for a visual deficit in rapid naming tasks, most research does not support this view. In his comprehensive review of dyslexia, Vellutino (1979) examined all research on visual problems in dyslexics and found most empirical evidence does not support this hypothesis. Studies have found that slowed visual perception only appears for reading disabled individuals when they view phonologically-based symbols (Blank et al., 1975), implicating a language-based system in these deficits. More recently, Manis et al. (2000) replicated the finding that RAN tasks predict reading ability, but found that rapid naming times were not related to orthographic (visual-based) skill measures. This research questions the validity of the visual deficit hypothesis, and points to language systems as a potential culprit. In addition, most study results supporting visual deficits can be explained by processing speed, the next variable discussed.

Processing Speed

The third hypothesized variable in rapid naming speed is global processing speed. According to this theory, deficits in processing all information impede the rapid perception and articulation of reading words. If individuals with dyslexia exhibit slower speeds in a variety of tasks, then a global mechanism would be a likely cause of the impairments. In a study of auditory perception, participants with dyslexia showed slowed speed of access for both phonological and non-phonological material. Reaction time did not differ between poor and normal readers, running contrary to a perceptual explanation (Nicolson & Fawcett, 1994). Fawcett and Nicolson (1994) later showed that effort and articulation do not influence rapid naming times either, and as speed of access to several types of stimuli is impaired, they posit that processing speed must underlie the slowed naming speed of individuals with dyslexia. Related studies have found that individuals with dyslexia are deficient in processing rapidly presented auditory tones and sounds also (Reed, 1989).

Global processing deficits in individuals with dyslexia would influence isolated word reading, and whether children with reading disabilities show impairments on discrete trial naming tasks continues to be debated. Wolf and colleagues (2000) state that most discrete naming tasks do not show predictive power for reading ability, but those requiring choice and integration of information are predictive. Ackerman and Dykman (1993) gave a variety of reading related tasks and found impairments in retrieval of discrete names also. They attribute the deficits in discrete and rapid naming to processing speed variance. Perhaps most convincing, however, was the results of multiple regression equations created by Kail and Hall (1994). They found that speed of naming on RAN tasks was best predicted by popular processing speed measures on standardized intelligence tests. These results show that processing speed is a viable explanation for the deficits in rapid naming that individuals with dyslexia exhibit.

Two studies provide a cautionary addendum to processing speed explanations in rapid naming. First, in the longitudinal study of Wolf et al. (1986), poor readers made substantial gains in rapid naming times that were greater than predicted by increases in processing time with age. Likewise, Kail (1991b) has shown that many tasks that measure processing speed increase at a reliable rate with development. Many individuals with dyslexia, however, show deficits in rapid naming tasks with relatively normal performance on processing measures (Wolf et al., 2000). One possible explanation of these discrepancies is that processing speed is primarily impaired for only phonological information.

The equivocal findings in regard to processing speed and naming speed provide an interesting research question. Like phonological working memory, processing speed may affect reading achievement indirectly, in this case through rapid naming skills. According to this hypothesis, slowed processing speed impedes the ability to rapidly retrieve phonological information, and thus causes delays in reading achievement. This mediation model is further discussed in the conclusion and chapter three. Before conclusions are drawn, however, the concept of processing speed must be further defined.

Processing Speed

During the 1970’s the creation of computer systems led to the advent of information processing models of cognitive functioning. These models had a tremendous impact on reading research, as evidenced by the earlier models of Castles & Coltheart

(1994) and Seidenberg & McClelland (1989). They also had an impact on the construct of executive function, helping to create models of working memory (Baddeley & Hitch, 1974) as well as processing speed (Kail & Bisanz, 1982). Defined as a global speed of information processing, spatial processing speed was measured in adults and found to decrease exponentially by age. This decrease was orderly and tied to several types of tasks, leading Kail (1991a) to question if processing speed's decay occurs in the reverse order for children.

In his first of many experiments on processing speed, Kail (1986) gave spatial processing tasks to a group of eight year old children and a group of adults. He found a common slope for age across tasks with a correlation of .93. In a later study, processing time on a wide variety of tasks was measured for adults and three groups of older children (Hale, 1990). Results indicated surprisingly similar performance for age groups across tasks, with a mean correlation of .99. Kail (1991a) concluded this round of early studies with a meta-analysis of 72 studies that included response times and different ages, and concluded that 90% or greater of the variance in changes of processing speed was accounted for by a general developmental factor.

Once a global processing speed mechanism that operates across tasks was established, it remained to be seen if this mechanism impacts reading achievement. While research is not conclusive, several pieces of evidence support that it does. First, in her studies of rate and accuracy readers, Lovett (1992) consistently found that processing speed was a reliable predictor of reading performance, especially reading rate. In connectionist models discussed earlier, surface dyslexia patterns were created in the models by decreasing general computational power, an equivalent of processing speed in these programs (Harm & Seidenberg, 1999). From the reverse angle, Nicolson & Fawcett (1994) investigated the processing speeds of 25 children with dyslexia and 32 children with normal reading achievement. They found that time to make decisions and pick between stimuli was slower in the group with dyslexia, but overall reaction times were similar. This study adds caution to simple reaction time explanations in reading achievement.

A final question is how processing speed impacts reading, and whether the research question involving rapid naming is a viable hypothesis. Two studies by Kail (1992; 1994) provide both support and detractment from this viewpoint. Using popular measures of processing speed, articulation rate, and memory, Kail (1992) found that age related changes in processing speed affect articulation rate, which may then affect the efficiency of the phonological working memory system. In the second study, also discussed earlier, Kail (1994) gave processing speed measures, RAN tasks, and measures of reading achievement to a group of 72 children. Using multiple regression, he found that processing speed predicted rapid naming, which in turn predicted reading achievement. Thus this study supports rapid naming mediating the effects of processing speed on reading achievement, while the earlier study suggests processing speed has primary influence on phonological working memory (Kail, 1992).

Conclusion

In this chapter the literature on dyslexia was reviewed with a particular focus on variables found to be the most reliable predictors of reading achievement. Early studies and single factor theories were reviewed, with a consensus that no single factor can fully explain the reading difficulties seen in all children. Reading acquisition research showed that reading skills fluctuate with development, and that age must be considered in all studies of reading behavior.

The dual route and connectionist theories of reading heralded the arrival of the modern information processing models. Studies of the dual route model found that two types of dyslexia based on phonological deficits and lexical deficits existed in individuals with dyslexia (Castles & Coltheart, 1993). However, the majority of those with reading problems evidenced both impairments. Connectionist models asserted this was because phonological, lexical and semantic information are combined to retrieve words (Seidenberg & McClelland, 1989). The information processing theories thus provided two important aspects of learning to read; the importance of phonological skills as highlighted by dual-route theorists, and the importance of global processing mechanisms highlighted by the computer models in connectionist theory.

The chapter then proceeded to discuss research on the best predictors of reading achievement, coalescing around phonological awareness and rapid naming as the two best predictors (Torgesen et al., 1997; Wolf & Bowers, 1999). Unfortunately, the independence of these predictive areas is highly debated, with some researchers asserting that phonological awareness is the core variable and others demanding that rapid naming contributes as much variance (Holland et al., 2004; Stanovich, 1988).

This debate is at the center of the first research question of this study. The first hypothesis is that the effects of rapid naming on reading achievement are moderated by the level of phonological awareness. This hypothesis is based on the study by Meyer et al. (1998) that found rapid naming skills to be more predictive in children with low phonological awareness scores.

The final sections of this chapter discussed research on the component processes that underlie the three best predictors of reading achievement. Phoneme analysis was found to be a prominent independent factor in phonological awareness after children enter the alphabetic stage (Gathercole et al., 1991). It was suggested that phoneme synthesis was related to phonological working memory, as both require manipulation of phonological information. In the rapid naming section, the possible component processes of environmental influences and visual processing were discussed and refuted. The possibility that processing speed underlies much of the variance in rapid naming was then discussed.

This discussion leads to the final hypotheses that will be examined in this study. Phoneme analysis, phoneme synthesis, and rapid naming will all be examined as mediating factors for the effect of phonological working memory and processing speed on reading achievement. It is hypothesized that phoneme synthesis will mediate the effects of phonological working memory, while rapid naming will mediate the effects of processing speed.

By examining the underlying processes in phonological awareness and rapid naming tasks, the basic deficits in most cases of dyslexia can be described. Discovering the basic deficits in any reading disability will help guide treatment and improve reading performance. This impact will hopefully lead to decreases in illiteracy and improved reading performance by elementary students. Future hopes such as these provide the continued pressure and impetus for research on dyslexia.

CHAPTER III

METHOD

This chapter outlines the specific manner in which this study investigated the hypotheses discussed in chapter two. First, the participants included in the study are discussed. Next, the measures that operationalize each construct in the hypotheses are described. Next, the procedures used for administering measures and collecting the data are outlined. Finally, the steps of data analysis that were utilized are discussed.

Participants

Power analysis

The number of participants in this study was based on a power analysis using Cohen's (1977) approach to estimating necessary sample size. The study conducted by Torgesen and colleagues (1994) utilized similar measures in regression analyses and found effect sizes on reading achievement of .35 for rapid naming and .75 for phonological processing. Likewise, the Meyer and colleagues (1998) study found rapid naming to have a .34 effect size while phonological processing had a .82 effect size on word identification. Using Cohen's (1977) power tables, a minimal sample of 19 subjects in two groups (N = 38) is necessary for statistical power.

Participant characteristics

Subjects were recruited from a local reading clinic during fall and summer tutoring sessions. All subjects were referred to the reading clinic by local schools or their parents for reading difficulties. A summary of participant characteristics is provided in Table 1. The age range for participants was six to sixteen. Each participant's hearing acuity, visual acuity, and developmental status were screened. Gathering this information allowed for greater inclusion of participants as these variables can impact reading performance but be statistically accounted for in the data analysis. Exclusionary criteria for the study were a previously diagnosed developmental disorder or mental retardation as these two conditions have an extraordinary impact by themselves on reading skills.

Measures

This section describes the tasks used to measure the phonological working memory, processing speed, phoneme analysis, phoneme synthesis, rapid naming, and reading achievement constructs. In addition, general verbal ability estimates were collected. For each construct, one or more measures are described in terms of task description, reliability, and validity. In addition, two standard batteries as well as two other standardized tests were used in this study. As several subtests of the batteries were utilized for different measurements, a general description of these two tests is required before any discussion of specific measures.

Wechsler Intelligence Scale for Children – Fourth Edition

The first test battery is the *Wechsler Intelligence Scale for Children-Fourth Edition* (WISC-IV; Wechsler, 1993). The WISC-IV is the latest edition of the long-standing Wechsler intelligence series that dates back to 1939. The test is standardized for individuals between the ages of 6 and 16 years. It has historically been composed of ten or more subtests that provide a Full Scale Intelligence Quotient (FSIQ), a Verbal Intelligence Quotient (VIQ), and a Performance Intelligence Quotient (PIQ). The WISC-IV maintains these scores, though the VIQ and PIQ are now called the Verbal Comprehension Index (VCI) and the Perceptual Reasoning Index (PRI). Also new to the test are two other indexes that compose the FSIQ, the Working Memory Index (WMI) and Processing Speed Index (PSI). Subtests from these latter indexes composed the phonological working memory and processing speed measures in this study.

The WISC-IV was standardized on 2,200 individuals through a stratified sample. Each age level was matched to census figures from the year 2000 on geographic region, ethnicity, and parent education. Equal numbers of females and males were included in the normalization procedure. The sample and procedures for standardizing the WISC-IV are among the most rigorous for any psychological assessment device.

Reliability and validity data are reported for each subtest, but it is important that these data be applicable to children with reading problems such as those in this study. The WISC-IV manual shows that reliability and validity are unchanged for a sample of 56 children with reading disabilities, again reflecting the appropriateness of this measure with this population.

The last important consideration is whether the factor structure of the WISC-IV exhibits construct validity. Factor analysis of the normative data using principal axis factoring indicates that all subtests load at .62 or higher with their respective indexes, with no extraneous loadings above .19. As such, the convergent and discriminative validity of the WISC-IV is sound.

Comprehensive Test of Phonological Processing

The second test battery in this study is the *Comprehensive Test of Phonological Processing* (CTOPP; Wagner et al.; 1999). The CTOPP was standardized on 1,656 individuals between the ages of 5 and 24. Test development was completed in 1998 and matched to census figures from the prior year, this test offers normative comparisons to a large, representative group. Based on longitudinal research spanning a decade (Torgesen et al., 1994; Torgesen et al.,1997), the test measures the strongest predictors of reading from these studies, namely phonological awareness, phonological memory, and rapid naming. Each test demonstrates reliability in the .77 to .90 range. Construct validity for this model was established for the subtests, with high correlations between the phonological awareness and rapid naming tests and factors, and moderate correlations between phonological memory tests and factors (Wagner et al., 1999). Furthermore, the three main factors show moderate to high correlations with each other, which the authors interpret as showing they measure similar but distinct constructs. One study since the CTOPP was published has replicated this finding at the younger ages of the test (Havey, Story, & Buker, 2002).

Research has also been conducted relating the CTOPP to pre-existing groups and measures. A further study of 60 children with learning disabilities established that the CTOPP does differentiate this group from average readers as the mean for children with learning disabilities was approximately one standard deviation lower than the overall population (Wagner et al., 1999). One later study comparing the popular *Dynamic Indicators of Basic Early Literacy Skills* (DIBELS) kindergarten measures found the tests for phoneme analysis, phoneme segmentation, and naming fluency all correlated the strongest with their counterparts on the CTOPP (Elision, Blending Words, and Rapid Naming) (Hintze, Ryan, & Stoner, 2003). This provides evidence that the CTOPP has excellent concurrent validity and is related to current conceptualizations of these skills.

Phonological working memory

Several different tasks have been used to measure phonological working memory since the introduction of the Baddeley and Hitch model (1974). Studies conducted by

Baddeley and Gathercole (Baddeley, 1986; Baddeley et al., 1982; Gathercole & Baddeley, 1990a; Gathercole et al., 1991; Gathercole, Willis, Emslie, & Baddeley, 1992) have preferred to use nonword repetition as the best measure of working memory. According to this research group, nonword repetition allows for measurement of working memory without the influence of semantic memory. However, two difficulties arise with this measure. First, nonwords vary in phonemic regularity, and ability to analyze these phonemes can depress scores and add variance outside of the working memory system (Castles & Holmes, 1986). Second, repetition of nonwords may only measure the storage component of working memory, as no manipulation is required. According to more recent models, manipulation of phonological information is an important component of the working memory system (Miyake & Shah, 1999).

Span tasks have been utilized by several research groups to represent working memory in their studies (Gathercole, Hitch, Service, & Martin, 1997; Nelson & Warrington, 1980). The most common format is digit span, but letter and word spans have also been utilized (Daneman & Carpenter, 1980; Ellis & Large, 1988; Kail, 1992). These tasks are a measure of purely phonological working memory, as each type of stimuli can be encoded in a phonological format, and studies have found that individuals will use phonological coding to store and manipulate these types of information (Brandimonte et al., 1992). In addition, use of span tasks avoids the complications associated with Baddeley's (1986) use of non-word repetition in measuring working memory. Two versions of span tasks were given in this study.

The WISC-IV Digit Span (WISC-IV DS) subtest was the first measure of phonological working memory. This test is composed of two portions, Digit Span

Forward and Digit Span Backward (Wechsler, 2003). The first portion required subjects to listen to a span of two to nine digits and repeat them back in the same order. The second portion provided two practice items then required participants to listen to a series of two to eight digits but repeat them back in reverse order. Researchers have shown that Digits Forward measures storage components of working memory (Sattler, 2001), while Digits Backward measures both storage and manipulation capabilities (Sattler, 2001; Watkins, Kush, & Glutting, 1997).

Subjects were given two trials for every span length on both forward and backward portions. When each participant did not repeat the span correctly for both trials, the test was discontinued. The number of trials correct on Digits Forward and Digits Backward was summed, and this total score was compared to three-month interval normative data. The resultant scaled score represented their performance compared to age equivalent peers.

Internal consistency of the WISC-IV DS subtest is reported as .87, with a range of .81 to .92 across ages (Wechsler, 2003). The subtest was administered twice to 243 individuals from the standardization sample with an average interval between administrations of one month. Test-retest correlations from this study were between .83 and .88 for all ages (Wechsler, 2003). These two types of reliability indicate that WISC-IV DS scaled scores are consistent.

Content validity of the WISC-IV DS subtest was already discussed for span tasks in general, and all spans but one have been utilized in earlier versions of the WISC. Correlations with other subtests show that WISC-IV DS has the strongest relationship to Letter-Number Sequencing at .49, and correlates with the WMI at .86. This indicates adequate construct validity. Unfortunately, no studies were conducted comparing this subtest to nonword repetition, so criterion validity as related to this study is lacking. Nonetheless, the two types of validity reported convey strong evidence that WISC-IV DS is an appropriate measure of phonological working memory.

The second measurement of phonological working memory is the Letter-Number Sequencing task from the WISC-IV (WISC-IV LNS). Together with WISC-IV DS, the WISC-IV LNS comprises the WMI of the WISC-IV. It requires both storage and processing of information in working memory (Crowe, 2000). On the subtest, participants were asked to listen to a series of letters and numbers, then to repeat the numbers back in numerical ordered followed by the letters in alphabetical order.

For ages six and seven, examiners were required to ensure that subjects know the numbers one through five and the alphabet through letter C. For every item there are six trials of different stimuli. All participants were given two practice items followed by two items with one letter and one number. Following this, subjects were given a practice item with three stimuli, followed by the remaining eight items of three trials each. The subtest was discontinued when a participant did not correctly answer any of the three trials for an item. Total trials answered correctly were summed, and this number was compared to three-month interval normative data to obtain a scaled score.

The average internal consistency estimate for the WISC-IV LNS subtest is .90, with a range of .85 to .92 for all ages (Wechsler, 2003). Test-retest reliabilities were gathered using the same sample as discussed for WISC-IV DS, with resultant correlations between .81 and .84. This finding supports the subtest as a reliable measure.

Content validity is maintained by adapting this test from the adult version of the Wechsler scales (Wechsler, 1997). It is also considered a span task, which have a long-history as valid measurements of working memory (Baddeley, 1986). As stated earlier, the subtest correlates at .49 with WISC-IV DS and also at .86 with the WMI. Letter number sequencing is thus an appropriate measure of phonological working memory for this sample.

The construct of phonological working memory will be measured by the WISC-IV Digit Span and WISC-IV Letter Number Sequencing subtest. Both measures are reliable and valid tests of this construct. Use of the (WISC-IV) WMI also allows comparisons between results of this study and the most popular assessment device for children. Psychologists completing the WISC-IV thus have information that guides the selection of follow up reading assessments and potential interventions.

Processing speed

With the advent of computer technology and processing, information-processing theories of human cognition were developed (Kail & Bisanz, 1982). One research trend from this theory has been the concept of processing speed. Extensively researched by Kail (1991a, 1991b, 1992), he discovered that several timed tasks of mental addition, copying, tapping, and naming all developed at the same rate (Kail, 1991b). He shortened the name for this global speed of information processing to just processing speed, which has now been adopted by popular test batteries (Wechsler, 2003). Later studies began linking processing speed to reading difficulties, and the measure most commonly used in those studies was the Coding task from the WISC series (Kail, 1992: Kail & Hall, 1994).

The two measures of processing speed that were used in this study are the PSI subtests from the WISC-IV (Wechsler, 2003). The first of these tasks is the Coding subtest (WISC-IV CD), which measured how quickly subjects can copy symbols tied to either numbers or other simple drawings. Participants between the ages of six and seven were given part A, which contains eight rows of eight shapes, alternating between five types of shapes. Subjects eight years and older were given part B, which consists of six rows of 21 numbers, alternating from numbers one to nine.

Each number or shape has a specific mark associated with it, and participants were instructed to copy these marks across the rows into the numbered boxes or shapes. For part A, the first three items were demonstrated with two subsequent practice items, while for part B the first three items were demonstrated with four practice items. Subjects were given two minutes to copy as many marks as they can, and the total subtest score equals the amount of correctly copied marks. Raw scores were converted to scaled scores by comparison to three-month interval normative data.

Due to the timed nature of WISC-IV CD, only test-retest reliabilities are reported. Using the WISC-IV test-retest sample, correlations between scores with an average one-month intervening time were between .72 and .89 across all ages, with a mean of .85. This result supports WISC-IV CD score consistency across short intervals.

Providing familiar shapes or numbers increases sensitivity to developmental level, and the speeded nature of this task matches popular conceptualizations of processing speed (Kail, 1991b, 1992; Kail & Hall, 1994; Kail & Park, 1994). Coding correlates with the overall PSI at .87, with the next strongest correlation being only .40. This demonstrates the construct validity of this test.

The second WISC-IV subtest used to measure processing speed was Symbol Search (WISC-IV SS). This task required subjects to indicate whether a row of drawings contains the same drawing as a target drawing(s) displayed at the beginning of the row (Wechsler, 2003). Similar to the WISC-IV CD test, this test also has a part A for ages six and seven, and a part B for those older than seven. The younger version consists of 45 rows of three items with one target item shown before each row. The older version contains 45 rows of five items with two target items shown before each row.

Participants were provided a demonstration using two items, where one row is marked “yes” for having (one of) the target items in the row, and another is marked “no” for not containing the target item(s). Subjects completed two rows to practice the task, and then were given two minutes to mark yes or no on as many rows as possible. The total score was calculated by summing the number of correctly marked rows and subtracting the number of incorrectly marked ones. Scores were compared to three-month interval normative data to obtain scaled scores.

Reliability for this test is also appropriately measured by test-retest methods. Using the WISC-IV sample of 243 individuals, the average correlation between tests administered one-month apart was .79, with a range of .78 to .82 across ages. While slightly lower than the Coding subtest, these reliability coefficients still indicate adequate consistency of the measure.

Content validity is again represented by the two versions of the task for different developmental periods, as well as the timed nature of the measure (Kail, 1991b, 1992; Kail & Hall, 1994; Kail & Park, 1994). Construct validity is also represented by correlations with other components of the WISC-IV, and WISC-IV SS correlates with the

PSI at .87 and all other measures at .50 or lower. It appears to be a valid measure of processing speed.

While WISC-IV CD and WISC-IV SS separately are reliable measures of processing speed, they represent an even stronger measure of this construct when combined into the PSI. Reliabilities for this index are between .81 and .90 for all ages, with a mean of .88. In addition, the index was sensitive for a group of students with reading disabilities as indicated by a study of 56 children that found their mean PSI to be half a standard deviation lower than the non-referred population (Wechsler, 2003). These findings indicate that these tests provide a valid estimate of processing speed for the participants in this study.

Phoneme analysis

The ability to recognize separate sounds in both spoken and written language is referred to as phoneme analysis (Torgesen et al., 1997). This construct is a recent development that can be traced to longitudinal studies conducted in the past two decades that identified different phonological processing skills (Barker, Torgesen, & Wagner, 1992; Manis, Custodio, & Szeszulski, 1993). These authors used phoneme deletion tasks, also referred to as elision tasks, to measure this construct. Other research groups have argued that phonological processing skills are one combined factor (Badian, 1996a; Bailey et al., 2003). However, these studies also use phoneme deletion tasks as measuring one aspect of their proposed phonological factor. Examination of both viewpoints indicates that elision tasks are the most appropriate measure of phoneme analysis, whether it is considered a separate phonological factor or a component of phonological processing.

CTOPP Elision (EL) is one of three phonological awareness subtests for ages five to six, and one of only two phonological awareness tests for age seven and older (Wagner et al., 1999). Subjects were read a word, required to repeat it, provided with a sound(s) to remove, and asked to then say the word without the sound(s). Containing 20 items, the test begins with three items that practice dropping whole word-parts. Subjects must correctly answer one item to proceed. Following this, three items that practice removing sounds were administered. Participants must again correctly answer one of these items to proceed with the test. The remainder of the test was then administered, with subjects removing syllables, onset-rime units, individual phonemes within rimes, and finally phonemes located in consonant clusters. The test was discontinued when a participant answered three consecutive items incorrectly or reached the last item.

A raw score was calculated by summing all correctly answered items. Comparing this score to six-month normative-intervals provided a scaled score. Reliabilities for this scaled score are all in the high range. Chronbach's alpha for the EL test is .89, with a range of .81 to .92 for the age group that will be in this study. Test-retest reliability based on a study of 91 individuals is more than acceptable at .88 (Wagner et al., 1999).

Content validity for the EL test is shown by the increasing difficulty of the types of sounds to be removed. In addition, item discrimination for all items is between .34 and .72. Differential item functioning did not find that any gender or ethnic groups responded differently to test items.

Additional validity is provided by criterion measures of word reading, showing that EL does predict this type of reading achievement. One study of 164 students found the correlation between EL and the Woodcock Reading Mastery Tests-Revised-Word

Identification (Woodcock, 1987) to be .65. A replication study with a learning disabled population found this correlation to be .53 (Wagner et al., 1999). A later study correlated EL with the popular DIBELS measure of Initial Sound Fluency, with a resultant correlation of .52 (Hintze et al., 2003). Finally, the correlation between EL and age is .65, demonstrating construct validity in regards to development (Wagner et al., 1999).

There is ample evidence that the CTOPP Elision test is a reliable and valid measure of phoneme analysis. It appears to be the most appropriate test for the age ranges included in this study, and has shown strong relationships to other common measures such as Initial Sound Fluency.

Phoneme synthesis

The process of phoneme synthesis has unfortunately been referenced under various names by different research groups. The most common alternative names are word recoding (Ehri, 1992; Jorm & Share, 1983) and sound blending (Lovett, 1987; Lyon & Watson, 1981). Despite these different labels, all these research groups operationalize phoneme synthesis through tasks that require subjects to listen to two or more phonemes and blend them into an actual word.

The CTOPP measures this ability through the Blending Words subtest (SB), appropriate for individuals 5 to 24 years of age. This phoneme synthesis task was standardized on the same recent, large and representative sample as the EL test. It is one of three tasks comprising the CTOPP phonological awareness construct for five and six year olds, and together with EL comprises the construct for those seven years and older.

This test required subjects to listen to a list of sounds from a cassette tape, then combine these sounds into an actual word. Length and word complexity increase throughout the test. Similar to EL, this test has 20 items and was discontinued when a participant did not provide the correct word on three consecutive items. Six practice items are also given at the start, and again a subject must get at least one of the words correct to be administered the test.

All words blended correctly were summed to obtain the raw score, which was then compared to normative information at six-month intervals to obtain a scaled score. Internal consistency of the scaled score is reported as .84 based on the normative data, with ranges for all ages in this study between .78 and .99 (Wagner et al., 1999). A test retest correlation across a two-week interval was also strong at .88. These correlations indicate this test is highly reliable.

Various empirical measurements have shown the excellent validity of this measure. Evidence of content validity for the SB test exists through the increasing linguistic complexity of the words and the discrimination indexes of all items being between .34 and .78. No bias for gender and ethnic groups was detected using regression equations (Wagner et al., 1999). The relationship between SB and DIBELS Phoneme Segmentation Fluency, another common measure of phoneme synthesis, is .63 (Hintze et al., 2003). The correlations between SB and word reading measures are reported as between .34 and .59, depending on the familiarity of the words (Wagner et al., 1999). The relationship between this test and age is moderate, with a correlation of .57. These studies show that the SB test has excellent criterion and construct validity.

Phoneme synthesis ability has historically been measured through tasks that require blending sounds into words, and no other measure is as reliable and valid as the

CTOPP Blending Words subtest. In addition, this test has already shown a substantial correlation with word reading achievement (Wagner et al., 1999).

Rapid naming

While most research constructs are defined and then operationalized by certain measures, rapid naming arose as a construct from Rapid Automatized Naming (RAN) tasks first introduced by Denckla and Rudel (1976). The full RAN battery is composed of four different types of stimuli; colors, objects, lowercase letters, and numerical digits. The original design consisted of 10 rows of five items arranged in random order. As discussed in the literature review, these RAN tasks have been found to predict subsequent reading ability two years after administration (Wolf et al., 1986). Reliability of the measures over a two-year interval was found to be .62 in the large longitudinal studies conducted by Torgesen et al. (1994).

The CTOPP Rapid Naming (RN) tests provide an improvement in the RAN tasks by standardizing administration and providing a large set of normative data as discussed in the two previous sections. Rapid Color Naming (CTOPP RCN) and Rapid Object Naming (CTOPP RON) were administered to five and six year olds, while Rapid Digit Naming CTOPP RDN) and Rapid Letter Naming (RLN) were given to those seven years and older. This difference is due to the necessity that the items be familiar to each age group. Colors that were named are blue, red, green, black, brown, and yellow while objects were represented by line drawings of pencils, stars, fish, boats, and keys**.** Digits named were two through eight, while letters were s, t, n, a , k, and c.

For each rapid naming test, the subjects were presented with a list of items to name as practice. At least one item must be named correctly for the test to continue.

Participants were then presented with two pages of items arranged in four rows of nine columns. They were asked to name the items as quickly as possible, and given prompts to skip any items after three seconds of delay. Times required to complete the two rapid naming tasks were recorded and compared to normative information at six-month intervals. This provided scaled scores for each subject.

Two forms of RN subtests are available, allowing for alternative form reliabilities to be obtained. The two forms are then combined with the mean performance represented CTOPP Rapid Naming (RN). On color naming tests the forms are correlated at .82, with a range of .74 to .92 across ages. Object naming forms have an average correlation of .79, with a range of .72 to .86. Digit naming reliability is .87, ranging from .75 to .96. Finally, letter naming alternative forms have an average reliability of .82, with a range for this study's ages between .70 and .92. This information supports the equivalency of the forms.

The RN subtests display criterion-related validity in regards to word reading achievement. One sample of children with learning disabilities found correlations between .52 and .57**,** while a study with a normal population reports correlations between .49 and .62 (Wagner et al., 1999)**.** Another study of 81 kindergarten students found RN to be the second best predictor of letter and word reading, explaining 11% of the variance (Havey et al., 2002). Correlations with age are moderate at .60 to .61, relating the tests to development and showing some evidence of construct validity. Furthermore, intercorrelations among the tasks are high enough to substantiate that they are measuring the same factor. Considering this information, the RN tests display adequate validity.

Rapid naming is a construct created by the use of RAN tasks. The CTOPP Rapid Naming subtests take these tasks and compare performance to a large normative sample. These subtests are the most reliable and valid measures of rapid naming skill available.

Reading achievement

The measurement of reading achievement has been plagued with methodological difficulties throughout the history of research. As previously discussed in the literature review, the importance of word identification and comprehension has been debated intensely (Byrne, Freebody, & Gates, 1992), as well as the relative proportion of word decoding, oral fluency, and vocabulary (Gough & Tunmer, 1986; Lovett, 1987; Segal & Wolf, 1993). In the past decade, the National Reading Panel (NRP, 2000) produced a comprehensive report on interventions and reading achievement that has led to a flurry of empirical measures and assessment of reading achievement. The five primary areas of achievement that the NRP focuses on are phonemic awareness, phonics, vocabulary, fluency, and comprehension. As phonemic awareness and phonics are conceptualized as causal variables in this study, they are not included in reading achievement. Each of the remaining areas will be included.

Vocabulary. Measurement of vocabulary requires consideration of the extraneous effects of context and general verbal ability (Torgesen et al., 1997). Tasks such as those found on the WISC-IV tend to measure general verbal skills as subjects are given higher scores for more descriptive definitions (Wechsler, 2003). Tests that include vocabulary words in sentences will also be influenced by any individual's ability to use context as a clue to a word's meaning (Rudel et al., 1981). One solution to avoid measurement of general verbal ability and context is to have individuals read sight words (Wagner et al., 1999).

A sound measure of sight word vocabulary that has been developed is the *Test of Oral Word Reading Efficiency* (TOWRE). Developed by Torgesen et al. (1997), this test was based on ten years of longitudinal studies in word reading. The normative group is composed of 1,500 individuals between the ages of 6 and 24, and was chosen to represent census figures from 1997. This recent, large and representative sample makes the TOWRE one of the most psychometrically rigorous measurements of word reading.

While the TOWRE contains a subtest of phonological decoding, only the test of Sight Word Efficiency is an appropriate measure of vocabulary. This test contains 104 items and requires the subject to read as many items as possible in a 45 second time interval. Hesitations over 3 seconds resulted in prompts to move to the next item. Participants were also given eight practice items first, and must recite one practice word correctly to be administered the test.

The number of words correctly read in 45 seconds was compared to six-month interval normative data, resulting in standard scores for each subject. The TOWRE has two forms that allow for comparison of alternate form reliability. For the Sight Word Efficiency subtest, reliability was found to be .91 across ages, with a range of .82 to .97. The correlation between forms remains steady for both genders and all ethnicities tested. Furthermore, test-retest information was collected on 72 individuals over a two-week period. Resultant correlations were between .82 and .97, depending on the forms administered (Torgesen et al., 1997). These empirical results suggest the TOWRE Sight Word Efficiency test is a reliable and consistent measure.

Words for the test were chosen from the most commonly referenced reading lists in education, and arranged in order of frequency of occurrence. Ability to discriminate between those with low and high total scores was between .46 and .75 for all items. Bias for any gender or ethnic groups was not evident through use of regression equations with differential item functioning (Torgesen et al., 1997).

Further investigations of validity were conducted by comparing the TOWRE to WRMT-R Word Identification scores. As both measure word reading, their relationship should be strong. Results of several studies indicate that the correlation between these measures was .85 or higher (Torgesen et al., 1999; Wagner et al., 1999). The correlation between TOWRE and age was also computed from the normative data and found to be .81, showing that scores follow a developmental trend. Considering results of item analysis as well as criterion and construct validity studies, the TOWRE appears to be a good measure of sight word vocabulary.

Reading fluency and comprehension. Reading fluency and comprehension were both measured by the *Gray Oral Reading Test-Fourth Edition* (GORT-4; Wiederholt & Bryant, 2001). This test has a long history of assessing reading since the original publication in 1963, and the latest revision provides very recent normative data. The GORT-4 was standardized on a stratified sample of 1,677 individuals matched to census figures from 1997. The test is appropriate for ages 6 to 19 years. It contains two alternative forms equated using linear equating procedures. These forms contain 14 reading passages with five comprehension questions per passage. In every instance but one (the easiest passage was added this edition), each composition was part of the previous two editions and has shown excellent sensitivity in measuring oral reading rate and accuracy (Wiederholt & Bryant, 1992).

Starting points for each participant were determined according to their current reading level and suggested starting points provided in the manual. A student book accompanies the test and provides the reading passages and multiple choice questions. For each passage, subjects were prompted to begin reading and timing will start. Any deviations from correct pronunciations were recorded. Timing is stopped when they have completed the composition, and this time is recorded as well as the total deviations from print. Participants were then asked the five comprehension questions. Testing continued until each subject answered three or more comprehension questions incorrectly or read the last passage. At this point, if the participant did not answer all five comprehension questions correctly on the first passage given, the examiner administered the passage one level below this. Reverse sequence administration continued until each subject got all five questions correct on a composition, or reached the first passage in the student book.

After the comprehension questions for each passage are administered, the examiner compared the reading time to quartile scores provided on the protocols. Quartiles three through five represent 25% of performances of the normative sample from highest to lowest. Quartiles two and one represent 9% of performances each, while a score of zero is equivalent to the bottom 6% of performances in the standardization sample. The resultant score for each passage is the oral reading rate achieved on the composition. Amount of deviations from print are also compared to these quartile scores, providing an accuracy measure for each passage.

For each composition rate and accuracy scores are summed, while the total number of correct answers to comprehension questions was recorded. The rate and accuracy scores were then added across all passages administered on the GORT-4 to obtain a raw fluency score. This raw score was then compared to six-month interval normative data and a scaled score obtained for each subject (labeled as FL in this study). This score was used as the measure of fluency for every participant. The number of correct comprehension questions was summed for the entire GORT-4 test, and this score was also compared to six-month interval normative data. The resultant scaled score represented reading comprehension for each subject (labeled as COMP in this study).

Several estimates of the reliability of the GORT-4 are provided in the manual (Wiederholt & Bryant, 2001). First, internal consistency estimates for the fluency scores on both Form A and B are .93, with a range of .90 to .96 across the ages in this study. Reliability for comprehension scores on both forms is .95, with a range of .94 to .97 for the appropriate ages. Alternate form reliabilities for fluency and comprehension scores are .95 and .85, respectively, with fluency being more consistent across forms. This finding is not surprising as error variance increases for multiple choice responding. Finally, test-retest data were also collected on 49 individuals administered the GORT-4. Across a two-week interval, and depending on the form administered, scores were correlated at .91 to .94 for fluency, and .78 to .86 for comprehension. Taken together, these results provide evidence that the GORT-4 is a consistent measure of fluency and comprehension.

Passages were created about general themes that persist across groups and birth cohorts (Wiederholt & Bryant, 2001). Words were chosen from three vocabulary lists that reflect increasing grade levels. Wording of comprehension questions was also chosen from this list, though different nouns and verbs than those in the passage are used. Stories are then ordered according to scores for rate, accuracy, comprehension, and readability. Item discrimination comparing each passage score to total scores shows discrimination indexes between .57 and .89 for fluency, and .47 to .71 for comprehension. Differential item functioning did not detect any significant item bias for either gender or any group. These findings indicate excellent content validity for the GORT-4.

Criterion validity comparisons use the GORT-3, and although they find substantial relationships with other reading achievement measures, this appears to be an area in which the GORT-4 requires more research. Construct validity for the test is much more thorough. The concept of measuring rate and accuracy to obtain reading fluency extends to the studies of Lovett (1984, 1987), and is reflected on other common reading achievement measures such as the DIBELS (Good & Kaminski, 2002). The correlation between GORT-4 fluency and age is .66, while that with comprehension is .74. This indicates that the developmental aspect of reading is captured by the test scores. Furthermore, one study with a pre-identified group of children with learning disabilities found their mean score to be over one standard deviation lower on fluency, and about .75 standard deviations lower on comprehension (Wiederholt & Bryant, 2001). These results provide support for the GORT-4 as distinguishing those with reading problems as well as being an accurate measure of reading fluency and comprehension.

Reading achievement is conceptualized in the current study as the measurement of phonological processing, vocabulary, fluency, and comprehension. Considering phonological processing as a causal variable, the three remaining areas defined reading achievement in this study. Vocabulary was measured by the TOWRE, while fluency and comprehension were measured by the GORT-4. As reliable and accurate measures of these constructs, these tests provided an excellent portrait of reading achievement.

General verbal ability

A reliable measure of general cognitive ability was administered to control for variance in reading achievement that is related to global cognitive deficits. As discussed by Stanovich (1988), any study predicting reading achievement must differentiate and control for reading problems caused by specific deficits compared to global cognitive deficits. The Vocabulary subtest from previous versions of the WISC has been a popular estimate of general verbal ability (Torgesen et al., 1997), but as vocabulary in this study is conceptualized as a component of reading achievement, another measurement was required.

General verbal ability was measured by the WISC-IV Similarities subtest. This test required each subject to listen to two words and explain how they are similar to each other. Answers using classification or pronounced properties of each item were given more credit than general statements or superficial similarities. Each response was scored as incorrect (zero points) or with one or two points according to scoring guidelines in the manual (Wechsler, 2003).

Starting points are set for ages 6 to 8, 9 to 11, and 12 and older. If a subject nine and older missed one of the first two items, they were administered earlier items until two consecutive items were correct. The Similarities subtest contains 23 word pairs, and each participant was read each item until they reached the last pair or incorrectly answered five consecutive items. The number of one and two-point responses were summed for the total subtest score, and this was compared to three-month interval normative data to obtain scaled scores.

The Similarities subtest is a very consistent and valid measure of general verbal ability. Reliability estimates of internal consistency are .84 to .88 across ages, with a mean of .86. Another estimate was obtained from the WISC-IV test-retest sample discussed earlier, with a correlation of .83 to .91 between administrations for all ages. Construct validity is established by a .89 correlation with the VCI, second only to the Vocabulary subtest. Most importantly for this study, the manual reports Similarities shares the highest correlation with total achievement as measured by the Wechsler Individual Achievement Test-Second Edition (WIAT-II; Wechsler, 2003). This criterion comparison shows that Similarities is a good predictor of academic achievement, which is highly related to general cognitive ability.

Procedure

Parents of children in the reading clinic who met the sample inclusion criteria were approached about participation in the study. Informed consent was obtained and the tests given explained to both parent and child.

After informed consent was obtained, data were collected from each participant's file at the reading clinic. Demographic information such as hearing testing and vision testing was collected. Any administration of the CTOPP, TOWRE, or GORT-4 from the past twelve months was used as the scores for these measures. If multiple administrations exist, the most recent was utilized. If any specific measure is not already available in the file, this measure was then given to the child by a reading clinic specialist supervised by a Ph.D. level assistant professor.

Every participant was scheduled for a session to be administered the WISC-IV subtests. These subtests were given by a certified school psychologist. Subtests were administered in the order presented in the manual (Wechsler, 2003): Similarities, Digit Span, Coding, Letter Number Sequencing, and Symbol Search.

Data Analysis

Scores for all participants were placed on a cover sheet (Appendix A) and designated by a subject number. Any participant with a scaled score on Similarities that was two standard deviations below the mean was excluded from analysis. The Working Memory Index (WMI) and Processing Speed Index (PSI) from the WISC-IV were included on the cover sheet as well as a mean reading achievement performance (RD ACH) calculated by averaging scores on the FL, COMP, and TOWRE tests. This mean performance represented reading achievement in the product variable and regression series analyses.

Once all data were examined for low general ability, scores were standardized for comparison using a z-transformation. This process is recommended for testing moderator variables (Baron & Kenny, 1986). As every score in this study is either a scaled or standard score, this transformation did not cause any changes in the data. Descriptive statistics were presented for each variable, allowing for examination of each distribution. A correlation matrix was created for all measurements, the WMI and PSI, and the RD ACH score. This table allowed for a cursory examination of the relationships between these variables.

Inferential analysis consisted of two main components. The first two analyses focus on the predictive relationship of phoneme analysis, phoneme synthesis, and rapid naming for reading achievement. The existence of moderating influences was examined. The next two questions analyzed the relationship of phonological working memory and processing speed, respectively, to the three reading predictors. Specifically, data analyses looked at whether phoneme analysis, phoneme synthesis, or rapid naming is a mediating influence between phonological working memory or processing speed and reading achievement.

Assumptions of research question one

The first research question analyzed was whether phoneme analysis or synthesis moderates the effects of rapid naming on reading achievement. Baron and Kenny (1986) define a moderator as a "…variable that affects the direction and/or strength of the relationship between an independent or predictor variable and a dependent or criterion variable" (p. 1174) It is predicted that poor phoneme analysis and synthesis scores will greatly increase the strength of rapid naming's influence on reading. As all variables adhere to normality, they are considered continuous variables. In addition, the predictor, moderators, and dependent variables are modestly correlated. The product variable approach to moderation is appropriate for these assumptions about the data and is thus used for this analysis (Baron & Kenny, 1986).

Data analysis for research question one

This analysis utilized the product variable approach discussed in Aiken and West (1991). First, reading achievement was regressed on rapid naming and phoneme analysis. Then reading achievement was regressed on rapid naming and phoneme analysis as well as their interaction. Next, separate regression equations were created for low (standard deviation ≤ 1.5), average (standard deviation zero), and high (standard deviation ≥ 1.5) scores of phoneme analysis. Following this, scores were entered for rapid naming and results plotted. Any interactions or significant changes in slope indicate the presence of moderation. This process was then repeated with phoneme synthesis replacing phoneme analysis. Based on the literature review, it is hypothesized that low scores on phoneme analysis or synthesis will increase the predictive influence of rapid naming.

The first analysis provided a model for the best predictors of reading achievement. The direct, indirect and total effects for each variable were calculated and the implications for predicting reading achievement addressed. However, each predictor may have common sources of variance that underlie their relationship to reading achievement. Two of these sources of variance are phonological working memory and processing speed. The effect of these variables will drive the remaining data analyses.

Assumptions for research questions two and three

For mediation to occur two assumptions must be met. First, the mediator must contain minimal measurement error. Considering the .84 to .89 reliabilities of EL and SB as well as the .82 to .87 reliability of RN, this condition is considered met (Wagner et al., 1999). Second, the dependent variable cannot cause the mediator. Reading fluency and vocabulary have been shown as criterion of phoneme analysis and synthesis, not as causal variables (Torgesen et al., 1994). Similar relationships have also been found for rapid naming and reading achievement (Wolf & Bowers, 1999). As such, the second condition for conducting mediation analysis is met.

Data analysis for research question two

The literature on phonological working memory has indicated it has a significant relationship to reading achievement, but the process of this relationship has been infrequently studied. One question discussed earlier is whether phoneme analysis, phoneme synthesis, or rapid naming mediate the effects of phonological working memory on reading achievement. Baron and Kenny (1986) stated a mediator “accounts for the relationship between the predictor and the criterion” (p. 1176). It has been suggested that either rapid naming or phoneme synthesis may mediate this effect. Both these suggestions and the alternate phoneme analysis path were examined in the current study.

This analysis used the regression model series discussed by Baron and Kenny (1986) that required three equations for each model. First, the three proposed mediators (EL, SB, and RN) were regressed on the WMI through separate equations for each model. Second, reading achievement was regressed on the WMI for each model. Finally, regression equations utilizing both the WMI and the mediator to predict reading achievement were created. If any of these latter equations significantly improved prediction, as tested by the Sobel (1988) significance method, the presence of a mediator was indicated. Research studies discussed in the literature review lead to the hypothesis that phoneme synthesis mediates the effects of phonological working memory on reading achievement.

Data analysis for research question three

The literature on processing speed also indicates that this construct has an effect on reading achievement, but again research on this relationship is lacking. The regression model series described for research question two was conducted again using processing speed as the independent variable. For these equations the hypothesis is that rapid naming will mediate the effects of processing speed on reading achievement.

Data analysis can be summarized as having three main components. The first concerns description of the data, as well as standardization of all variables. The next analyses examined whether the three predictors of reading achievement have direct effects, or whether one or more predictors moderates the effects of another. This is accomplished through the product variable regression approach. The next two analyses established if phonological working memory and processing speed, respectively, have influence on reading achievement indirectly through one or more of the predictors.

CHAPTER IV

RESULTS

This chapter describes the results of data analysis outlined in chapter three. First, descriptive statistics are presented for all variables with consistency of composite scores analyzed. Next, the product variable approach to moderation (Aiken & West, 1991) is applied to examine if phoneme analysis or synthesis moderates the effects of rapid naming on reading achievement. The following analysis utilizes the regression model series (Baron & Kenny, 1986) to examine if phoneme analysis, phoneme synthesis, or rapid naming are mediators of working memory's influence on reading achievement. The final section uses the same approach to analyze if phoneme analysis, phoneme synthesis, or rapid naming mediate the effects of processing speed on reading achievement.

Descriptive analysis

Data collection resulted in a sample of 45 subjects (Table 1). Due to incomplete data, seven subjects were subsequently removed from data analysis. Complete data were thus obtained from 38 subjects comprised of 22 males and 16 females. The higher number of male participants was expected as it reflects the prevalence of reading problems in the general population (Hooper & Willis, 1989). The mean age for subjects was 11.08 years with a range of 7.11 to 16.9 years. No subjects performed below two standard deviations on the WISC-IV Similarities subtest, an exclusionary criteria. In addition, all subjects whose guardians indicated that participants had visual difficulties were properly corrected via prescription lenses at the time of testing.

Table 1

Participant characteristics.

Total Participants	Female	Male	Age Range	Mean Age
N = 38	16	22	7.11 to 16.9	11.08

All scores were transformed to a standard z-score scale for comparison and are reported in Table 2. For all independent variables participant means were within one standard deviation below the overall population mean with standard deviations ranging from .745 to 1.178. The data thus show normal variations for all independent variables with slightly lower performances than each test's norm group, a finding that is expected for a referred, reading clinic population.

Table 2

Means and standard deviations for reading variables

Variable	Mean	Stand. Dev.	Variable	Mean	Stand. Dev.
EL	-.772	.930	PSI	-.372	1.178
SB	-.657	.745	CD	-.175	1.154
RN	-.559	.771	SS	-.412	1.084
RDN	-.539	.792	RD ACH	-.932	.847
RLN	-.579	.804	TOWRE	-1.005	.979
WMI	-.742	.929	FL	-1.288	1.187
DS	-.535	.922	COMP	-.396	.902
LNS	-.570	.923			

Note. EL = CTOPP Elision, SB = CTOPP Sound Blending, RN = CTOPP Rapid Naming Composite, RDN = CTOPP Rapid Digit Naming, RLN = CTOPP Rapid Letter Naming, WMI = WISC-IV Working Memory Index, DS = WISC-IV Digit Span, LNS = WISC-IV Letter Number Sequencing, PSI = WISC-IV Processing Speed Index, CD = WISC-IV Coding, SS = WISC-IV Symbol Search, RD ACH = Mean Reading Achievement, TOWRE = TOWRE Sight Word Efficiency, FL = GORT-4 Fluency Score, COMP = GORT-4 Comprehension Score

Pre-analysis

Tests underlying independent variable composites were examined for their consistency. CTOPP RDN and CTOPP RLN had very similar mean and standard deviations as well as a correlation of .869 ($p < .01$) across subjects. Considering this high correlation, rapid naming was represented by the RN (CTOPP Rapid Naming Composite) in all further analysis. Analysis of the WISC-IV WMI shows similar means and standard deviations for WISC-IV DS and WISC-IV LNS with a correlation of .549 ($p < .01$) across participants. This significant correlation and similar population set support using only WMI in further analysis. Subtests underlying the WISC-IV PSI also show similar means and standard deviations, though WISC-IV CD shows the highest mean score for any variable in this study. The correlation between these tests was .666 ($p < .01$) for subjects in this study, supporting the use of PSI in all further calculations.

In regards to dependent variables, participant means ranged from -.396 to -1.288 (Table 2) with standard deviations between .847 and 1.187. These results again support normal variations for these variables with lower mean performances in the study's reading disabled population. The RD ACH composite was next analyzed for consistency. The TOWRE and FL measures showed similar means and standard deviations while COMP scores were noticeably higher. Correlations between the dependent variables indicate a significant relationship between TOWRE and FL ($r = .649$, $p < .01$) as well as

TOWRE and COMP (r = .389, $p < .05$). The relationship between FL and COMP, however, is non-significant (r = .213), undermining the consistency of the RD ACH composite. Further analysis shows that TOWRE and FL are significantly related to four and five independent variables, respectively, while COMP is related to none. Considering these results, the RD ACH composite was discarded and COMP was not utilized in further analysis. The TOWRE and FL measures were examined as separate types of reading achievement in all further calculations.

Table 3 displays the correlation matrix for all study variables (with subtests underlying composite scores eliminated as noted above). In preliminary data analysis it is imperative to identify those variables with significant relationships, as those lacking such cannot be related as mediators or predictor-criterion variables in the second and third data analyses (Baron & Kenny, 1986).

Table 3

Correlation matrix for all reading variables

	EL	SB	RN	WMI	PSI	TOWRE	FL
EL	1.000						
SB	.456**	1.000					
RN	.354*	.111	1.000				
WMI	.302	.384*	.405*	1.000			
PSI	.346*	.354*	.584**	.615**	1.000		
TOWRE	.574**	.365*	.468**	.529**	.597**	1.000	
FL	.519**	.284	.479**	.398*	.462**	.649**	1.000
COMP	.214	.241	.319	.163	.030	.389*	.213

**p < .01, *p <.05

Note. EL = CTOPP Elision, SB = CTOPP Sound Blending, RN = CTOPP Rapid Naming Composite, WMI = WISC-IV Working Memory Index, PSI = WISC-IV Processing Speed Index, TOWRE = TOWRE Sight Word Efficiency, FL = GORT-4 Fluency, COMP = GORT-4 Comprehension

Several correlations impact the hypothesis that phoneme analysis, phoneme synthesis, or rapid naming mediate the effects of working memory on reading achievement. The SB and FL measures are not significantly correlated, eliminating SB as a predictor of fluency. In addition, WMI and EL have a non-significant correlation which eliminates phoneme analysis as a mediator for working memory. The third hypothesis examining mediation between processing speed and reading achievement is also affected by one correlation. The limited relationship between SB and FL again necessitates the elimination of sound blending as a predictor of fluency and thus as a mediating influence between processing speed and fluency measures.

Moderators of rapid naming on reading achievement

The first research question examined is whether phoneme analysis (EL) moderates the influence of rapid naming (RN) on reading achievement, specifically vocabulary (TOWRE) or fluency (FL). Results are presented in Table 4. The regression of TOWRE on EL and RN results in 41% of the variance in vocabulary explained (r = .64, $\hat{y}_{TOWRE} = -.41 + .49x_{EL} + .39x_{RN}$) while the regression of TOWRE on EL and RN as well as their product accounts for 42% of the variance (r = .65, $\hat{y}_{TOWRE} = -.46 + .38x_{EL} + .31x_{RN} - .13x_{ELXRN}$). Power analysis for interactions as described by Aiken and West (1991) results in an effect size of $f^2 = .03$ for the interaction. Although the effect is small it does not discount the possible moderating relationship.

Table 4

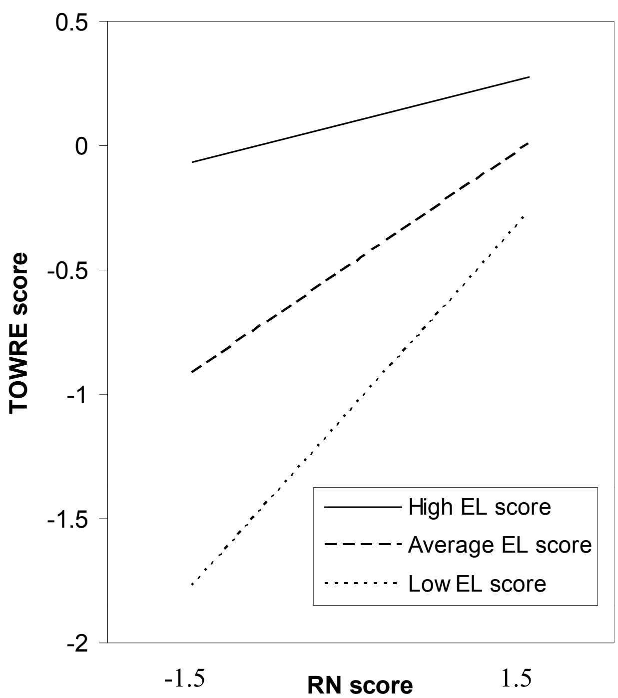
Regression analysis for rapid naming moderating the influence of phoneme analysis on vocabulary.

Variable	B	SE B	ß
Linear Model			
EL	.49	.15	.47
RN	.39	.18	.30
Moderation Model			
EL	.38	.19	.36
RN	.31	.21	.24
EL x RN	-.13	.18	-.17

Note. EL = CTOPP Elision; RN = CTOPP Rapid Naming; EL x RN = Interaction of CTOPP Elision and CTOPP Rapid Naming

Utilizing the procedures of Aiken and West (1991) for interaction effects, separate regression equations were calculated for high (standard deviation 1.5), average (standard deviation zero), and low scores (standard deviation -1.5) of phoneme analysis. Rapid naming scores were then entered into these equations to predict vocabulary scores. Figure 1 shows the resultant regression equations which form an ordinal interaction. Subjects with high EL scores, regardless of their RN performance, would be predicted to achieve TOWRE scores between -.06 and .28. However, subjects with poor EL scores would be strongly influenced by their RN score. A subject with low EL and RN scores would be predicted to achieve a TOWRE score of -1.77 while a high RN and low EL score predicts a TOWRE score of -.27. Significance testing shows that RN does not influence TOWRE scores when high or average EL scores are present (F [34] = .27, 1.47), but does influence TOWRE when EL scores are low (F [34] = 2.08, $p < .05$). Considering the results for this sample, phoneme analysis does moderate the influence of rapid naming on vocabulary scores.

Figure 1. Vocabulary scores predicted from rapid naming with phoneme analysis as a moderating influence.



TOWRE = TOWRE Sight Word Efficiency

EL = CTOPP Elision

RN = CTOPP Rapid Naming

The next part of the moderating research question is whether phoneme analysis moderates the influence of rapid naming on reading fluency. The regression of FL on EL and RN results in 39% of the variance in reading fluency explained ($r = .62$, $\hat{y}_{FL} = -.58 + .57x_{RN} + .57x_{EL}$) while the addition of the interaction between EL and RN accounts for 41% of the variance ($r = .64$, $\hat{y}_{FL} = -.65 + .39x_{EL} + .44x_{RN} - .24x_{ELXRN}$). Results of regression analysis are presented in Table 5. Power analysis again indicates an f^2 of .03 for the interaction, small but again non-reflective of possible moderating influences.

Table 5

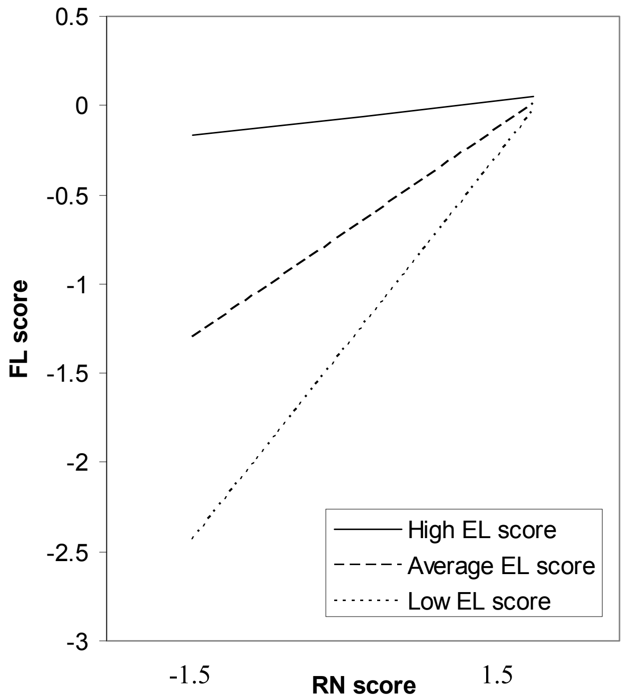
Regression analysis for rapid naming moderating the influence of phoneme analysis on reading fluency.

Variable	B	SE B	ß
Linear Model			
EL	.57	.19	.42
RN	.57	.22	.36
Moderation Model			
EL	.39	.27	.29
RN	.44	.26	.28
EL x RN	-.24	.26	-.22

Note. EL = CTOPP Elision; RN = CTOPP Rapid Naming; EL x RN = Interaction of CTOPP Elision and CTOPP Rapid Naming

The same Aiken and West (1991) procedures as utilized for predicted TOWRE scores were applied to the FL analysis. Resultant regression equations are presented in Figure 2 and display a disordinal interaction. Similar to TOWRE, high scores on EL predict similar scores on FL regardless of RN score (-.17 to .05). However, a subject with a low EL and RN score would have a predicted FL of -2.43 while a high EL and low RN score predicts a FL of -.17. This two-standard deviation difference shows significant moderation. For high or average EL scores, RN does not impact FL (F [34] = .13, 1.68) while subjects with low EL scores have RN performances that significantly influence FL (F [34] = 2.43, $p < .05$).

Figure 2. Reading fluency scores predicted from rapid naming with phoneme analysis as a moderating influence.



FL = GORT-4 Fluency

EL = CTOPP Elision

RN = CTOPP Rapid Naming

Data analysis next turned to phoneme synthesis (SB) as a possible moderator for the influence of rapid naming on either vocabulary or reading fluency. Data from these analysis are presented in Table 6. First, TOWRE was regressed on SB and RN with a resultant 32% of variance explained ($r = .56$, $\hat{y}_{TOWRE} = -.42 + .42x_{SB} + .55x_{RN}$). Next, TOWRE was regressed on these variables and their interaction with results showing 33% of variance accounted for ($r = .57$, $\hat{y}_{TOWRE} = -.48 + .31x_{SB} + .46x_{RN} - .14x_{SBRN}$).

Table 6

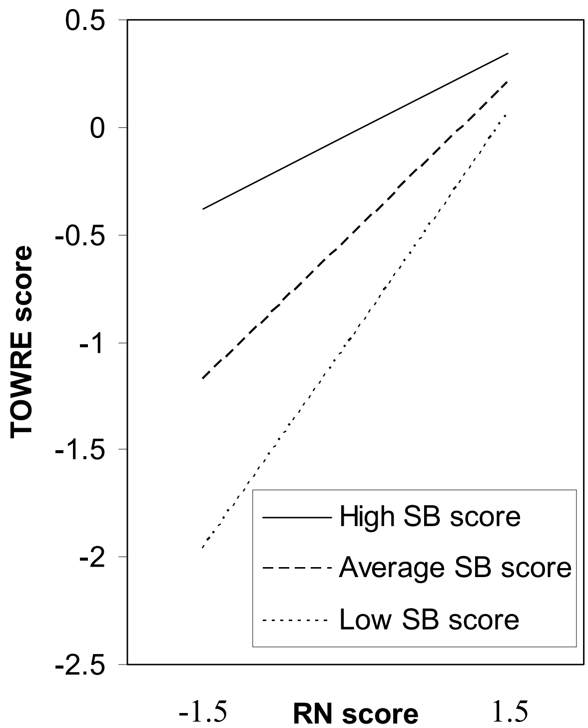
Regression analysis for rapid naming moderating the influence of phoneme synthesis on vocabulary.

Variable	B	SE B	ß
Linear Model			
SB	.42	.18	.32
RN	.55	.18	.43
Moderation Model			
SB	.31	.25	.24
RN	.46	.23	.36
SB x RN	-.14	.23	-.14

Note. SB = CTOPP Sound Blending; RN = CTOPP Rapid Naming; EL x RN = Interaction of CTOPP Sound Blending and CTOPP Rapid Naming

With a small interaction effect size found, the procedures of Aiken and West (1991) were once again utilized. The resultant regression equations for high, average, and low sound blending scores are presented in Figure 3 and indicate an ordinal interaction. Similar to the results for EL as a moderator, RN does not contribute significant variance to TOWRE when SB scores are average or high (F [34] = 1.99, .47) but does when SB scores are low (F [34] = 2.52, $p < .05$). A subject with a high SB but low RN had a predicted TOWRE of -.38 while a participant with a low SB and RN had a predicted score of -1.96. These results indicate that phoneme synthesis is also a moderating variable for the effects of rapid naming on vocabulary scores.

Figure 3. Vocabulary scores predicted from rapid naming with phoneme synthesis as a moderating influence.



TOWRE = TOWRE Sight Word Efficiency

SB = CTOPP Sound Blending

RN = CTOPP Rapid Naming

The second examination of phoneme synthesis as a moderator is identical to the previous analysis but with fluency as the criteria. FL regressed on SB and RN results in 30% of the variance explained (r = .54, $\hat{y}_{FL} = -.64 + .42x_{SB} + .73x_{RN}$) while FL regressed on these variables and their interaction results in 31% (r = .56, $\hat{y}_{FL} = -.73 + .26x_{SB} + .60x_{RN} - .23x_{SBRN}$). Results are displayed in Table 7.

Table 7

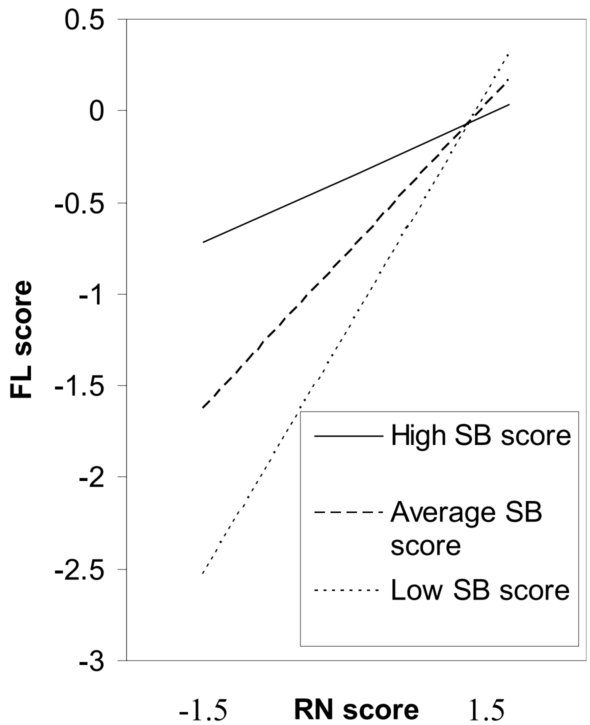
Regression analysis for rapid naming moderating the influence of phoneme synthesis on reading fluency.

Variable	B	SE B	ß
Linear Model			
SB	.42	.23	.26
RN	.73	.23	.26
Moderation Model			
SB	.26	.31	.16
RN	.60	.28	.38
SB x RN	-.23	.29	-.18

Note. SB = CTOPP Sound Blending; RN = CTOPP Rapid Naming; EL x RN = Interaction of CTOPP Sound Blending and CTOPP Rapid Naming

Applying the moderation analysis used in previous calculations results in the regression equations shown in Figure 4. This figure shows that SB forms a disordinal interaction with RN on FL. Subjects with high scores on SB will again have no significant variance in FL explained by RN (F [34] = .16). However, both subjects with average and low SB scores have significant variance in FL explained by RN (F [34] = 2.10, 2.66, $p < .05$). A participant with an average SB and low RN score had a predicted FL of .71 while a subject with a low SB and RN score had a predicted FL of -2.53. The interaction of SB and RN indicate that sound blending is a significant moderator for the influence of rapid naming on reading fluency. As noted in Figure 4, the moderator is also not significantly correlated with the predictor or criterion, a situation resulting in a "clean" moderator as described by Barron and Kenny (1986).

Figure 4. Reading fluency scores predicted from rapid naming with phoneme synthesis as a moderating influence.



FL = GORT-4 Fluency

SB = CTOPP Sound Blending

RN = CTOPP Rapid Naming

Mediators of working memory on reading achievement

The next hypothesis examines whether sound blending or rapid naming mediate the influence of working memory on reading achievement. These hypothesized relationships use the Baron and Kenny (1986) regression model series of testing for mediation. Regression results are presented in Table 8. First, sound blending was examined as a mediator for working memory on vocabulary. Regression of TOWRE on SB explains 13% of the variance (r = .37, $\hat{y}_{TOWRE} = -.69 + .48x_{SB}$) while regressing TOWRE on WMI explains 28% (r = .53, $\hat{y}_{TOWRE} = -.59 + .56x_{WMI}$). The equation representing SB mediating WMI on TOWRE explains 31% of the variance (r = .56, $\hat{y}_{TOWRE} = -.49 + .48x_{WMI} + .25x_{SB}$). Significance testing utilizing the Sobel (1988) method results in p = .09, not supportive of a significant mediating influence for sound blending. Path diagrams for this model are displayed in Figure 5a.

Table 8

Regression analysis for mediators of working memory on reading achievement.

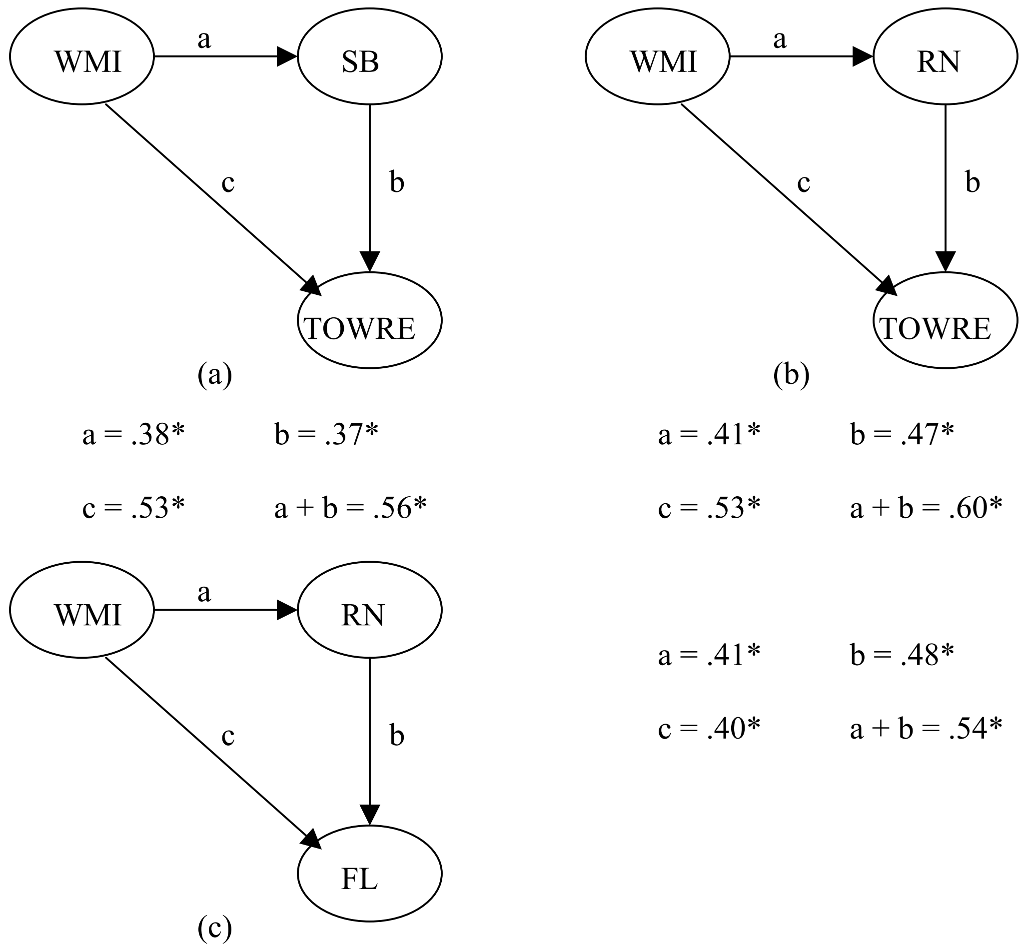
Variable	B	SE B	ß
TOWRE regressed on SB and WMI independently			
SB	.48	.20	.37
WMI	.56	.15	.53
TOWRE regressed with SB as a mediator of WMI			
SB	.25	.20	.19
WMI	.48	.16	.46
TOWRE regressed on RN and WMI independently			
RN	.59	.19	.47
WMI	.56	.15	.53
TOWRE regressed with RN as a mediator of WMI			
RN	.39	.19	.30
WMI	.43	.16	.41
FL regressed on RN and WMI independently			
RN	.75	.23	.48
WMI	.57	.22	.40
FL regressed with RN as a mediator of WMI			
RN	.61	.24	.39
WMI	.38	.22	.27

Note. TOWRE = TOWRE Sight Word Efficiency; SB = CTOPP Sound Blending; WMI = WISC-IV Working Memory Index; RN = CTOPP Rapid Naming; FL = GORT-4 Fluency

The next analysis examines rapid naming as a mediator for working memory on vocabulary. Regression of TOWRE on RN indicates 22% of the variance explained (r = .47, $\hat{y}_{TOWRE} = -.67 + .59x_{RN}$) while TOWRE regressed on WMI accounts for 28% of the variance (r = .53, $\hat{y}_{TOWRE} = -.59 + .56x_{WMI}$). The equation representing RN as a mediating influence of WMI on TOWRE explains 36% of the variance (r = .60, $\hat{y}_{TOWRE} = -.47 + .43x_{WMI} + .39x_{RN}$). The effect size of the mediation is.08, thus small and not significant (p = .10) as well as indicating that rapid naming does not significantly mediate the influence of working memory on vocabulary. Path diagrams for this series are shown in Figure 5b.

The final analysis for working memory examines whether rapid naming mediates the influence of working memory on fluency. FL regressed on RN encompasses 23% of the variance (r = .48, $\hat{y}_{FL} = -.89 + .75x_{RN}$) while FL regressed on WMI explains 16% (r = .40, $\hat{y}_{FL} = -.91 + .57x_{WMI}$). The equation representing RN mediating the effects of WMI on FL accounts for 29% of the variance (r = .54, $\hat{y}_{FL} = -.71 + .38x_{WMI} + .61x_{RN}$). Utilizing the Sobel (1988) method, significance is not obtained (p = .12) and rapid naming is not considered a significant mediating influence for working memory on reading fluency (see Figure 5c.

Figure 5. Path diagrams of phoneme synthesis and rapid naming mediating the effects of working memory on reading achievement.



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* = Standardized Coefficient

Note. WMI = WISC-IV Working Memory Index; RN = CTOPP Rapid Naming, SB = CTOPP Sound Blending; TOWRE = TOWRE Sight Word Efficiency; FL = GORT-4 Fluency

Mediators of processing speed on reading achievement

The final hypothesis in this study questions if phoneme analysis, phoneme synthesis, or rapid naming mediate the effects of processing speed on reading achievement. Results of the regression analysis for phoneme analysis and synthesis are presented in Table 9. The first set of analyses focused on whether phoneme analysis mediates the effects of processing speed on vocabulary. First, TOWRE was regressed on EL ($\hat{y}_{TOWRE} = -.54 + .60x_{EL}$), an equation that results in 33% of the variance explained (r = .57). Next, TOWRE was regressed on PSI with a resultant 36% of variance accounted for (r = .60, $\hat{y}_{TOWRE} = -.53 + .38x_{PSI} + .44x_{EL}$). Finally, TOWRE was regressed on both EL and PSI and resulted in 51% of the variance explained (r = .71, $\hat{y}_{TOWRE} = -.53 + .38x_{PSI} + .44x_{EL}$). Testing for significant mediation effects resulted in $p = .08$, thus indicating that phoneme analysis and processing speed have a strong effect on TOWRE but no significant mediational relationship. These analyses are represented in Figure 6a.

Table 9

Regression analysis for phoneme analysis and synthesis as mediators of processing speed on reading achievement.

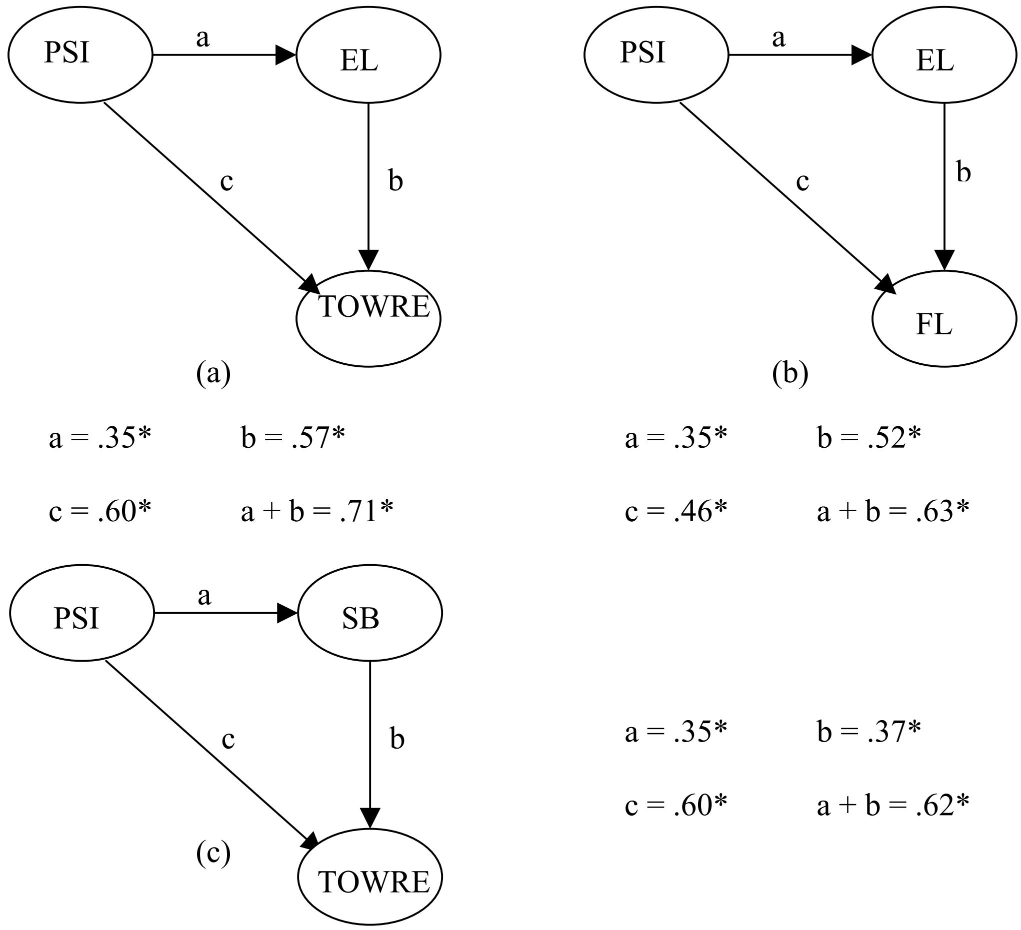
Variable	B	SE B	ß
TOWRE regressed on EL and PSI independently			
EL	.60	.14	.57
PSI	.50	.11	.60
TOWRE regressed with EL as a mediator of PSI			
EL	.44	.13	.42
PSI	.38	.11	.45
FL regressed on EL and PSI independently			
EL	.71	.20	.52
PSI	.50	.16	.46
FL regressed with EL as a mediator of PSI			
EL	.60	.19	.44
PSI	.39	.15	.36
TOWRE regressed on SB and PSI independently			
SB	.48	.20	.37
PSI	.50	.11	.60
TOWRE regressed with SB as a mediator of PSI			
SB	.23	.19	.18
PSI	.45	.12	.54

Note. TOWRE = TOWRE Sight Word Efficiency; EL = CTOPP Elision; PSI = WISC-IV Processing Speed Index; FL = GORT-4 Fluency; SB = CTOPP Sound Blending

The next set of equations examines whether phoneme analysis mediates the effects of processing speed on reading fluency. FL regressed on EL explains 27% of the variance ($r = .52$, $\hat{y}_{FL} = -.78 + .71x_{EL}$) while FL regressed on PSI accounts for 21% ($r = .46$, $\hat{y}_{FL} = -1.14 + .50x_{PSI}$). Variance explained by FL regressed on both EL and PSI was noticeably higher at 39% ($r = .63$, $\hat{y}_{FL} = -.75 + .39x_{PSI} + .60x_{EL}$). Testing for significant mediation effects results in $p = .10$, not supporting phoneme analysis as a significant mediator for processing speed on fluency. These analyses are represented in Figure 6b.

The next analysis examines whether sound blending mediates the influence of processing speed on vocabulary. The TOWRE measure regressed on SB, as previously noted, explains 13% of the variance. The TOWRE measure regressed on PSI, also previously discussed, explains 36% of the variance while the combined prediction of TOWRE from SB and PSI accounts for 38% ($r = .62$, $\hat{y}_{TOWRE} = -.69 + .45x_{PSI} + .23x_{SB}$). Sobel's (1988) method for testing significant mediation effects results in $p = .07$, not supporting a significant mediation relationship between processing speed and sound blending on vocabulary. This set of equations is represented in Figure 6c.

Figure 6. Path diagrams of phoneme analysis and phoneme synthesis mediating the effects of processing speed on reading achievement.



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* = Standardized Coefficient

Note. PSI = WISC-IV Processing Speed Index; EL = CTOPP Elision; SB = CTOPP Sound Blending; TOWRE = TOWRE Sight Word Efficiency; FL = GORT-4 Fluency

The last two analyses examine whether rapid naming mediates the influence of processing speed on vocabulary or fluency. Both sets of results are displayed in Table 10 with path diagrams shown in Figure 7. First, TOWRE was regressed on RN and then on PSI, noted previously as explaining 22% and 36% of the variance, respectively. The combined predictive effect of RN and PSI on TOWRE explains 38% of the variance (*r* = .62, $\hat{y}_{TOWRE} = -.73 + .41x_{PSI} + .23x_{RN}$) A significant mediation effect for RN on TOWRE was not detected (*p* = .09). In regards to fluency, FL was previously regressed on RN with 23% of the variance shared while regression on PSI results in 21% of the variance explained. The combined regression of FL on RN and PSI explains 29% of the variance (*r* = .54, $\hat{y}_{FL} = -.93 + .31x_{PSI} + .51x_{RN}$). In this analysis no significant mediation effect was detected (*p* = .11). From these analyses it can be concluded that rapid naming does not mediate the influence of processing speed on vocabulary or reading fluency for this population.

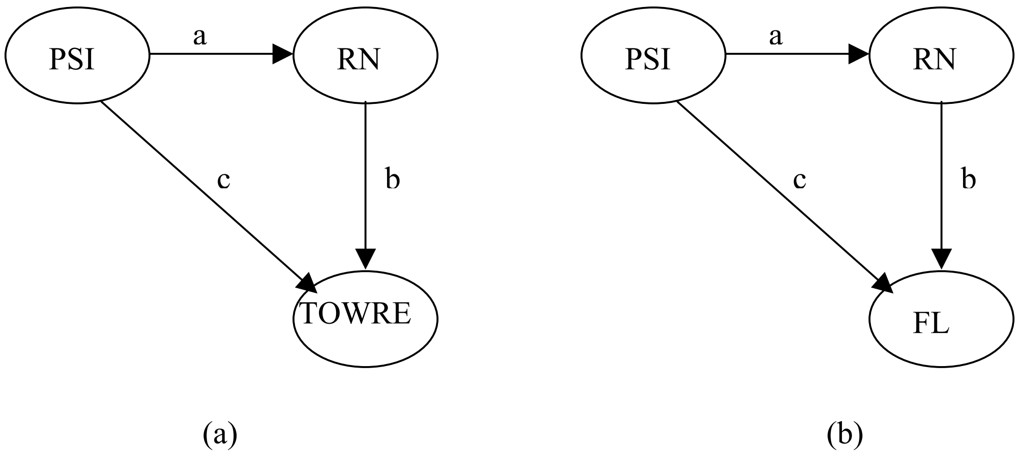
Table 10

Regression analysis for rapid naming as a mediator of processing speed on reading achievement.

Variable	B	SE B	ß
TOWRE regressed on RN and PSI independently			
RN	.59	.19	.47
PSI	.50	.11	.60
TOWRE regressed with RN as a mediator of PSI			
RN	.23	.21	.18
PSI	.41	.14	.49
FL regressed on RN and PSI independently			
RN	.75	.23	.48
PSI	.50	.16	.46
FL regressed with RN as a mediator of PSI			
RN	.51	.27	.32
PSI	.31	.19	.29

Note. TOWRE = TOWRE Sight Word Efficiency; RN = CTOPP Rapid Naming; PSI = WISC-IV Processing Speed Index; FL = GORT-4 Fluency

Figure 7. Path diagrams of rapid naming mediating the effects of processing speed on reading achievement.



a = .58* b = .47*

c = .60* a + b = .62*

a = .58* b = .48*

c = .46* a + b = .54*

Note. PSI = WISC-IV Processing Speed Index; RN = CTOPP Rapid Naming; TOWRE = TOWRE Sight Word Efficiency; FL = GORT-4 Fluency

Summary of data analyses

The data analyses examined all variables included in this study and supported the consistency of composite scores for rapid naming, working memory, and processing speed. Of note during descriptive analysis was that comprehension scores (from the GORT-4) correlated weakly with vocabulary but did not correlate with any other variable in this study. Comprehension was thus discarded as a variable and is discussed further in chapter five.

Through application of the product variable approach to moderation, it was determined that both phoneme analysis and synthesis moderate the influence of rapid naming on reading achievement. These variables accounted for 31% to 41% of the variance in vocabulary and reading fluency. While phoneme analysis and synthesis were significant moderators of rapid naming on vocabulary scores, the relationship was very pronounced for reading fluency. In addition, phoneme synthesis does not directly predict reading fluency and thus exerts only a moderating influence on this variable.

The next data analysis utilized regression model series to examine if sound blending or rapid naming mediate the influence of working memory on reading achievement. No significant mediation effects were detected. The correlation between working memory and rapid naming was minimal, an anticipated result. However, the correlation between working memory and sound blending was also smaller than predicted (r = .384), undermining the hypothesized relationship between these variables. In addition, working memory was found to be a weak predictor of reading fluency but accounted for 28% of the variance in vocabulary. The strongest predictive relationship was the combination of working memory and rapid naming explaining 36% of the variance in vocabulary.

The final analysis examined phoneme analysis, phoneme synthesis, and rapid naming as mediators of processing speed on reading achievement. As predicted, no mediation effects were found for phoneme analysis and synthesis. These variables produced only small correlations with processing speed. Phoneme analysis was strongly predictive of reading achievement, accounting for 27% of the variance in reading fluency and 33% in vocabulary. Rapid naming was also not found as a mediator for processing speed on reading achievement. While the prediction that processing speed and rapid naming are strongly related was supported (*r* = .584), rapid naming did not account for addition variance in vocabulary and reading fluency, Instead, processing speed accounts for 21% of the variance in reading fluency and 36% of vocabulary. The strongest predictive relationship in this series was the combination of processing speed and phoneme analysis explaining 51% of the variance in vocabulary.

In conclusion, the moderating hypotheses for these studies were supported by the data analysis while results did not show significant mediators for reading achievement. The results of the data analysis are further discussed and applied in Chapter five.

CHAPTER V

DISCUSSION

This chapter reviews the results from chapter four and applies them to previous research discussed in chapter two. The discussion begins with the findings concerning working memory and it's effect on reading achievement. Following this, the results concerning the relationship between processing speed and reading are reviewed. The next section discusses the causal agents of reading (phoneme analysis, phoneme synthesis, and rapid naming) in regards to their direct and indirect influences on reading. Proceeding this section are applications of these results to information processing theories as well as results concerning reading comprehension. This chapter then concludes with a review of the limitations of this study as well as suggestions for future research.

Working Memory

In chapter one it was hypothesized that working memory underlies a substantial amount of the variance in phoneme synthesis, half of the phonological awareness construct. As such, phoneme synthesis should appear as a mediating variable for the influence of working memory on reading. This relationship was not supported by the regression analysis as only 2% of the variance in vocabulary and no variance in fluency was explained by mediation. This was largely due to the lower than predicted correlation between working memory and phoneme synthesis, sharing 15% variance.

These results do not support the hypothesis that working memory underlies much of the influence that phonological awareness has on reading achievement (Daneman & Carpenter, 1980; Jorm, 1979). One explanation for this was actually given by Jorm (1983) himself and reiterated by Brady (1991), who postulated that the relationship between these constructs could be explained by influences of phonological awareness on working memory instead of the opposite model.

The Daneman and Carpenter (1980) study found that working memory did influence phonological awareness and subsequent reading achievement, contradictory to the current results. However, their operationalization of reading involved comprehension as a major component, differing substantially from the reading measures used here. While the current study found comprehension unrelated to working memory in students with reading problems, it is quite possible that the mediation hypothesis would appear significant when comprehension is measured in a typical student population.

This interpretation is supported by Shankweiler & Crain (1986) who found that working memory resources are very taxed by underdeveloped phonological awareness. As such, students with poor phonics have impacted working memory systems and subsequent poor reading. As phonological skills develop and mature their influence on comprehension decreases, while any deficits in working memory will begin to impact reading achievement. This theory is further supported by studies with normal readers (Helland & Asbjornsen, 2004; Pennington, Orden, Kirson, & Haith, 1991) and adults (Dixon, LeFevre, & Twilley, 1988; Stanovich, 1982).

Another finding from the current study is that working memory directly predicts sight vocabulary in this poor reader sample, accounting for 28% of the variance. This amount of variance coincides with the 11% to 22% found in a clinic population by Bowers and colleagues (1988). The slight differences in variance may be attributed to measurement as their study used digit span and sentence memory to represent the working memory construct. Digit span explained 18% of word identification (similar to the vocabulary measure in the current study) while sentence memory did not explain additional variance.

Meta-analysis of early studies indicates 2% to 9% of word reading is attributable to working memory (Pennington et al., 1991). In the Gathercole and colleagues (1991) study, working memory explained 15% of performance in vocabulary. Their study also found that working memory shared 5% of the predictive variance with rhyme measures, slightly lower than the 9% to 14% relation with phonological awareness variables in the current study. These authors hypothesized that working memory thus supports the formation of long term word associations. This hypothesis (Gathercole & Baddeley, 1993; Gathercole, 1994) is supported by the 28% shared variance between working memory and vocabulary in the current study.

Torgesen and colleagues (1994) study found that 18% of their subjects' performance in vocabulary was attributable to digit span. They also found working memory shared significant variance with phonological awareness, while the current study found that these constructs influence reading independently. Two reasons may explain these contradictory findings. First, Torgesen and colleagues (1994) were studying a typical population which has greater variability in their phonological skills than the clinic population studied here (Meyer et al., 1998). Second, the authors utilized non-word reading as another measure of working memory. As discussed by Castles and Holmes (1986), non-word reading may tap more phonological skills than span tasks such as digit span and letter-number sequencing. As a result the two types of measures are only modestly correlated ([$r = .31$] Johnston, Johnson, & Gray, 1987). In direct support of this, earlier studies by Wagner and Torgesen (1987) found that working memory span tasks contributed independently to reading.

Several conclusions can be drawn from these results in regards to the relationship of working memory to causal agents and subsequent reading achievement. First, phonological awareness does not appear to mediate the influence of working memory on reading achievement in students with reading problems. However, this relationship may still exist in typical students and appears stronger when non-word reading is utilized as a memory measure. Additionally, working memory explains significant variance in sight vocabulary, with this relationship appearing even stronger in a sample of poor readers.

Processing Speed

The second hypothesis discussed in chapter one predicted that global processing speed underlies substantial variance in rapid naming. As rapid naming predicts reading achievement, a mediational relationship was proposed in which rapid naming mediates the influence of processing speed on reading. This relationship was not supported by regression analysis as mediation explained only an additional 2% of vocabulary and 7% of reading fluency variance. Despite the lack of mediation, processing speed was found to predict both rapid naming and reading achievement. The WISC-IV Processing Speed Index (PSI) explained 34% of the variance in rapid naming, 36% of vocabulary, and 21% of reading fluency. Rapid naming was a worse predictor of vocabulary and provided only 2% more variance in reading fluency, thus not supporting the mediation model.

Results from the current study support processing speed underlying significant variance in rapid naming, replicating results from previous studies (Ackerman & Dykman, 1993; Kail, 1994). In the largest previous study of these variables, Kail and Hall

(1994) reported 36% to 40% of the variance in rapid naming was explained by WISC-IV Coding (half of the PSI composite), just slightly higher than the results for this sample.

Current results, however, do not support the mediation conclusions by Kail (1994). In his study of 24 students it was found that the influence of processing speed on reading was mediated by rapid naming. However, Kail (1994) utilized rapid color naming as part of the measurement of rapid naming and only used half of the PSI (WISC-IV Coding) for processing speed. With these methodological differences he found coding explained 46% of the variance in reading as opposed to the 36% the PSI explained in this study. When the mediation model was added no significant increase in variance occurred, supporting the current study results. Kail (1994) then utilized structural equation modeling to evidence mediation.

A reinterpretation of the Kail (1994) data that is in line with findings from the current study is that processing speed predicts significant variance in both rapid naming and reading achievement concurrently. Processing speed's contribution to reading has been minimally investigated, but experimental studies show consistent links (Bowers & Swanson, 1991; Scarborough, 1990; Wolff et al., 1990).

One study that included both visual processing speed and reading measures found that processing speed predicted 17% of reading performance (Bowers, Steffy, & Swanson, 1986). Of concern though is that the relationship may have been influenced by the auditory-response format of the processing speed measure. In the studies of Nicolson & Fawcett (1994; see also Fawcett & Nicolson, 1994), children with dyslexia demonstrated slower speeds at tasks with both word and tone presentations as well as discrete naming tests. The children did not differ from reading age controls who, according to Wolf and Bowers (1999), will have similar processing speeds. In addition to these studies is the support of historical findings that dyslexia and executive functions have a consistent relationship not explained by intelligence (Ackerman et al., 1971; Birch & Bridger, 1965; Cohen & Netley, 1981).

Unfortunately, no studies outside of the current one and the Kail and Hall (1994) study have examined the predictive power of processing speed. As such any hypothesis must be considered tentative. Nonetheless, the major conclusion from the findings about processing speed is that it has a direct effect on reading achievement while concurrently influencing rapid naming scores. This conclusion will be addressed further in discussions about the moderation model.

Causal Agents

In previous sections the concepts of phonological awareness and rapid naming were discussed as the best predictors of reading achievement. These constructs were utilized in two separate hypotheses examining their effects and interactions on reading achievement. This section discusses results on phonological awareness first, then turns to findings regarding rapid naming.

Phonological awareness

In chapters two and three phonological awareness was defined as a construct with two components, phoneme analysis and phoneme synthesis. These components were then examined separately in this study. Phoneme analysis was not predicted to mediate working memory or processing speed's influence on reading but rather to have a significant direct effect on reading. This prediction was upheld by the regression series. Although phoneme analysis shared less than 12% of the variance with working memory and processing speed, it predicted 27% of the variance in fluency and 33% in vocabulary. Phoneme analysis was found to be the largest predictor of fluency and the second largest of vocabulary

Current results support previous findings that phoneme analysis is the largest predictor of reading (Ackerman & Dykman, 1993; Bradley & Bryant, 1983; Cornwall, 1992; Vellutino & Scanlon, 1987). Results were very similar to the 28% variance in word reading found by Manis and colleagues (2000) in a typical population, but substantially less than the 45% variance found by Torgesen and colleagues (1994). One possible explanation for these differences is that the Torgesen and colleagues (1994) study included only second grade and younger students as opposed to the current study and the Manis and colleagues (2000) sample which included older children.

The replication of phoneme analysis as the strongest predictor of reading achievement adds support to the phonological core-variable difference model (Stanovich, 1992). As discussed in chapter two, this model states that analysis of individual phonemes is the core factor in dyslexia while global cognitive skills cause general learning difficulties including further detrimental effects on reading skill. The current finding that phoneme analysis is a better predictor than cognitive skills thus adds credence to this theory.

The discovery that phoneme synthesis does not mediate working memory was discussed in a previous section, but phoneme synthesis also does not contribute to reading fluency in the current poor reader sample. These results indicating that phoneme synthesis does not affect fluency thus replicating Lovett's (1984; 1987) conclusions that slow readers quite often have good sound blending skills.

Although phoneme synthesis did not predict fluency, it did explain 13% of sight vocabulary performance. This coincides with the 12% to 16% unique variance that Meyer et al. (1998) found in their study of poor readers but substantially less than the 36% found by Manis et al. (2000) in a normal population. It is possible that phoneme synthesis, just like phoneme analysis, explains less variance in a poor reader sample

The strong predictive relationship of phoneme analysis to reading coupled with the lack of a strong relationship between phoneme synthesis and working memory supports another hypothesis. Introduced by Cohen and Netley (1981) and discussed previously, they state that phoneme analysis impedes the encoding of phonological information in working memory, which then impedes reading achievement. In their study of 42 students they found that those who had reading difficulties performed far worse than normal readers on working memory tasks when they did not have opportunity to rehearse. The two groups performed the same when opportunity to rehearse was given. As working memory use decreases with increasing rehearsal time, Cohen and Netley (1981) found support for phoneme analysis ability impeding working memory. Another study found similar results with rhyming (which requires greater phoneme analysis) and non-rhyming words (Siegel & Ryan, 1988). Considering these previous studies, the results discussed here add support to this hypothesis instead of the working memory mediation model (Jorm, 1979).

In conclusion, current results involving the phonological awareness variables provide support for three hypotheses. First, phoneme analysis continues to appear as the best predictor of reading achievement while phoneme synthesis only predicts vocabulary performance. Second, phonological awareness continues to explain variance in a poor reader group, but contributes less explanatory power to their scores. Finally, phoneme analysis appears to influence the encoding of material in working memory and thus affects the performance of this system.

Rapid naming

The rapid naming construct was examined though both the regression series and product variable approaches, but review of the regression series is necessary before further discussion of the moderation model. The lack of a mediating relationship with processing speed was previously discussed and adds support to the hypothesis that rapid naming does not contribute unique variance to word reading (Stanovich, 1992). Instead, rapid naming is a measure of global processing deficits that impede various aspects of learning. Current results showed that processing speed accounts for 36% of variance in vocabulary and 21% in reading fluency while rapid naming provided only 2% and 7% additional variance to these measures certainly supporting rapid naming as a reflection of processing speed in this sample.

Rapid naming's direct explanation of 22% and 23% of vocabulary and fluency variance (when other factors are not included) is similar to previous research findings. Bowers et al. (1986) found rapid naming to predict 38% of a reading composite summarizing all reading components while Wolf et al. (1986) found rapid naming in kindergarten predicts 26% to 30% of reading fluency and 26% to 40% of sight vocabulary in second grade. These findings have been replicated, but it has been shown that the strength of rapid naming predictions declines after second grade (Torgesen et al., 1997; Walsh, Price, & Gillingham, 1988).

Many of these previous studies, however, questioned the independent variance of rapid naming and led to the hypothesis discussed in chapter two that rapid naming only affects reading achievement when students have difficulty with phonological awareness (Meyer et al., 1998; Stanovich, 1992; Torgesen et al., 1997). Results from the current clinic-referred sample are generally supportive of this conclusion.

In participants with well developed phoneme analysis skills (>90th percentile), rapid naming explains 2% of vocabulary performance and no portion of reading fluency scores. Students with average phoneme analysis skills have rapid naming explaining 9% of their vocabulary performance and 20% of their reading fluency while those with poor phoneme analysis skills (<10th percentile) have 25% of their vocabulary and 64% of their fluency performance explained by rapid naming. In only the poor phoneme analysis group was the relationship significant

Equations with phoneme synthesis follow a similar pattern. In participants with high phoneme analysis scores rapid naming accounts for 6% of variance in both vocabulary and fluency performance. For those with average phoneme synthesis skills, rapid naming explains 21% and 36% of the variance in their vocabulary and fluency. In the low phoneme synthesis group, rapid naming accounts for 46% of their vocabulary scores and a surprising 64% of their fluency.

These results indicate that phonological awareness skills are indeed a moderating influence for rapid naming’s effect on reading. The relationship is significant for phoneme analysis but even stronger for phoneme synthesis. Those subjects with poor phonological awareness and rapid naming scores had the lowest vocabulary and fluency scores in this reading clinic population.

A moderating relationship indicates that phonological awareness and rapid naming interact to influence reading achievement and are not located on a continuum, as suggested by Morris and colleagues (1986) and Satz and Morris (1981). Nonetheless, they do account for ample variance in the overall clinic population of the current study. Phoneme analysis and rapid naming accounted for 41% and 32% of the variance in vocabulary and fluency while Manis and colleagues (2000) found that 56% of the variance in reading achievement was explained by these variables. Phoneme synthesis and rapid naming explained 32% and 30% of the vocabulary and fluency measures in this study compared to 59% of reading achievement in the normal population of Manis and colleagues. The greater variability of phonological awareness skills in a normal population likely contributes to the stronger predictive values in typical students.

Findings from the current study support the presence of a double deficit theorized by Wolf and Bowers (1999). They reported, via meta-analysis, that correlations between phonological awareness and rapid naming are between .1 and .4, similar to the .11 to .35 correlations found here. Wolf and Bowers stated "naming speed's particular emphasis on both processing speed and the integration of an ensemble of lower level perceptual processes" (p. 419) make it a separate variable and greatly influence those students with poor phonological skills. This hypothesis is clearly supported by the current study.

Perhaps the greatest agreement between the results discussed here and previous research is with the study conducted by Meyer and colleagues (1998). These authors utilized the same measures of phoneme analysis, phoneme synthesis, and rapid naming but examined 154 normal readers and 64 poor readers. In the normal group (with average or above phoneme analysis and synthesis scores), rapid naming contributed 4% to reading compared to the 15% for the clinic referred sample of this study. In the poor reader sample rapid naming accounted for 16% to 25% of reading achievement compared to 25% of vocabulary and 64% of fluency in this study. Though differences exist, the current findings replicate the same pattern of non-significant influences for rapid naming in an average or above phonological awareness sample but increasingly significant influences in children with poor phonics skills.

The moderating relationship of phonological awareness on rapid naming also supports conclusions drawn by Torgesen and colleagues (1994). In their longitudinal studies of primary grade students, the authors found rapid naming to predict significant variance in reading achievement only for those students with poor phoneme analysis scores. The lack of significant variance for the normal population in Torgesen and colleagues (1994) and the clinic referred population here do not support an independent naming speed deficit as purported by Wolf and Bowers (1999). However, Torgesen and colleagues (1997) and current results do support the contention that students with phonological awareness and rapid naming deficits have the poorest reading performance.

The interaction of poor phonological awareness and rapid naming not only leads to the poorest reading outcomes, but appears to affect reading across development. Wolf and Bowers (1999) found a two and half year delay for this double deficit group that remained throughout schooling. Multiple studies have found that participants with a double deficit performed significantly worse than any other groups at word identification (Lovett, Steinbach, & Frijters, 2000; Manis et al., 2000). Meyer and colleagues (1998) likewise found that subjects with a double deficit had the worst reading outcomes two and five years after testing.

The reasons for the profound affect on reading in those with poor phonological awareness skills is unknown, though hypotheses have been outlined. Meyer and colleagues (1998) suggested that oral fluency or visual-perceptual processing speed deficits are the most common hypotheses. Although many studies on articulation rate do not support an effect on rapid naming (Fawcett & Nicolson, 1994; Kail & Park, 1994; Stanovich, 1988), preliminary studies of processing speed show this connection. According to Wolf (1991), tasks that measure processing speed and rapid naming are both influenced by *temporal processing* skills. Defined as the ability to organize and arrange serially presented information, two studies on temporal processing speed have found a direct explanation of 24% to 59% of reading achievement (May et al., 1988; Wolf & Goodglass, 1986). Subsequent studies of brain structure and evoked potentials have provided preliminary evidence that differences in the visual processing center of the occipital lobe may underlie temporal processing deficits (Livingstone, Rosen, Drislane, & Galaburda, 1991). As concluded by Farmer and Klein (1995), any task that measures speed of manipulating serial information, whether these tasks measure processing speed or rapid naming, will locate differences between dyslexics and normal readers.

The finding in the current study that processing speed explains significant variance in rapid naming supports the temporal processing speed explanation. Several studies of intense reading instruction (Kail, 1991b; Wolf et al., 1986; Wolf et al., 2000) showed drastic increases in rapid naming that are outside the gradient predicted by age-based increases in processing speed. However, their findings support the moderation hypothesis that phonics and processing speed interact to influence reading achievement. The result from this study that 51% of variance in sight vocabulary is explained by processing speed and phoneme analysis suggests that rapid naming represents the effects of processing speed on those students with poor phonological skills. A combination of poor phonics and impaired processing speed would thus lead to the worst reading outcomes.

Summarizing the discussion about rapid naming shows that the double deficit subgroup of students with poor phonological awareness, poor rapid naming, and very poor reading achievement is apparent. The effects of processing speed may well underlie this influence of rapid naming, though further study is required. Finally, the influence of rapid naming on the reading of a clinic referred sample was non-significant and does not support the existence of a naming-speed deficit only group.

Information Processing Theories

Results from the current study also apply to information processing theories discussed in chapter two which are briefly reviewed here. The dual-route theory supposes two routes to reading through phonological or lexical access (Castles & Coltheart, 1993). Difficulties in the phonological route lead to phonological dyslexia while difficulties in the lexical, whole word route lead to surface dyslexia. In contrast to the dual-route theory, Stanovich (1988) proposed that phonological deficits are the main difficulty in dyslexia while surface dyslexia represents individuals with developmental delays and global cognitive deficits. Several proceeding studies supported the phonological core variable difference model (Manis et al., 1996; Stanovich et al., 1997) while others found support for the dual route hypothesis (Coltheart, Curtis, Atkins, & Haller, 1993; Hanley, Hastie, & Kay, 1992).

Findings from the current study generally support components of the phonological core variable difference model. First, the conclusion that phonological awareness moderates the influence of rapid naming, and thus processing speed, is congruent with arguments from Stanovich et al. (1997). He compared phonological and surface dyslexics to reading-level controls to determine if qualitative differences exist in these dyslexics. Twelve of the 17 phonological dyslexics were qualitatively different while only one of the 15 surface dyslexics differed from normal readers. Stanovich et al. (1997) concludes that surface dyslexia is the expression in reading of a general developmental delay, and notes that general processing speed has been considered a culprit of surface dyslexia by previous studies (Beech & Harding, 1984; Rack, Snowling, & Olson, 1992). Stanovich and colleagues (1997) also concluded that readers with the worst difficulties have both phonological and surface dyslexia patterns, thus they resemble the readers in this study who had both phonological awareness and rapid naming deficits.

Although the current study did not identify a naming speed deficit only group, it does support that processing speed has a direct effect on vocabulary skills and rapid naming, two areas that surface dyslexics have historically performed poorly in (Lovett, 1984; Wolf & Bowers, 1999). That surface dyslexia may be a reflection of delayed processing speed was also supported by cluster analyses of the Florida Reading Project (Morris et al., 1998). For the five clusters of individuals with reading problems, four had significant phonological deficits. Only one cluster lacked significant problems in phonics and this group evidenced delayed processing speed.

The causal influence of slow processing speed on surface dyslexia is also supported by connectionist models (Harm & Siedenburgh, 1999). These models used computers to simulate normal word reading and were then modified to demonstrate types of dyslexia. In the computer model by Plaut and colleagues (1996), surface dyslexia patterns were obtained by decreasing the computer's processing speed. When phonological units were damaged in unison with decreased speed, the computer's reading was severely impaired and similar to subjects in this study with poor phonological awareness and rapid naming.

The hypothesized relation of processing speed to surface dyslexia and rapid naming does add caution to the use of reading level controls in studies of dyslexia (Carver, 1991, 1997). Comparing poor readers with slow processing speeds to younger readers will match them with students who have the same processing speed. Thus the detrimental effects of processing speed will be eliminated and the surface dyslexics will appear the same as normal (but younger) readers. Carver (1997) thus cautions against any conclusions that such students do not have dyslexia, a statement supported by the power of processing speed in the current study.

This section results in three conclusions that can be drawn from the application of this study's findings to information processing theories. First, the moderation findings add support to phonological awareness as the core deficit in reading with processing speed affecting reading more strongly in those students with poor phonics. Second, this finding combined with the predictive power of processing speed and phoneme analysis adds support to the hypothesis that surface dyslexia is an expression of delayed processing speed. Finally, the age-based influence of processing speed must be considered and measured in studies utilizing reading level control groups.

Comprehension

Because comprehension is an accepted component of reading achievement (Byrne et al., 1992), if not the end product of primary concern (Gough & Tunmer, 1986; National Reading Panel, 2000), it was included as a measure of reading achievement in the current study. However, results showed that comprehension, as measured by the GORT-4, was not related to any variable but sight vocabulary. While this precluded analysis of comprehension in the current study, it does support findings from previous research.

Kail (1994) included comprehension measures in his study of processing speed and found that rapid naming predicts vocabulary, which then predicts comprehension. Meyer et al. (1998) also found rapid naming to predict word reading but not comprehension, though an indirect route through word reading was suggested. Likewise, the analyses of Wolf and Bowers (1999) and Torgesen and colleagues (1997) showed that phoneme analysis, phoneme synthesis, and rapid naming did not predict comprehension but nonsense word reading did.

The best predictor of reading comprehension to consistently emerge is vocabulary (Stanovich, 1988), though age moderates this relationship. According to Shankweiler and Crain (1986), phonological awareness impacts all aspects of reading, including comprehension, at earlier grades but then its influence dissipates across development. In first grade the influence of phonological awareness on comprehension is estimated at 13% and decreases from there (Cornwall, 1992; Stanovich, Cunningham, & Freeman, 1984). As individuals develop, vocabulary skills influence comprehension in an exponential fashion while phonological abilities continue to exert influence for those who struggle in reading (Byrne et al., 1992; Stanovich et al., 1988). Nonetheless, the influence of phonological awareness on comprehension did not appear significant in the clinic referred, multi-age sample of the current study.

In summary, although the current study does not contribute to research on variation in comprehension, it does support the predominant view that causal agents in word reading may impact early reading comprehension, but do not directly influence comprehension within development. Findings support that vocabulary is the major contributor to text comprehension.

Limitations

While findings about causal agents and reading influences were discovered, several limitations of the current study were detected. First, the sample size of $N = 38$ was less than desired and a larger set of participants may improve detection of specific groups with reading problems as well as the factors underlying the influence of rapid naming on reading achievement. Second, the lack of a normal reader group obviously restricts the findings to individuals with reading concerns.

Other limitations of the current study involve measures not included in the analysis. First, rapid naming has been purported by some researchers to be influenced by prior exposure to print (Stanovich et al., 1988, 1997; Wolff et al., 1990). Inclusion of these measures may have added addition variance and further information about factors underlying the influence of rapid naming. Secondly, an individual's history of reading instruction and success with skill development has a reciprocal relationship with phonological awareness (Perfetti, Beck, Bell, & Hughes, 1987). As such, older readers may have reading variance that is attributable to prior instruction but instead is included in phonological awareness constructs. In addition, executive function measures have been found to have causal influences on reading (Ackerman et al., 1975; Birch & Bridger, 1965; Cohen & Netley, 1981) but were not included in this analysis. Finally, the lack of a general nonverbal ability measure limits conclusions about the influence of general ability (Gathercole et al., 1991). One caveat to this limitation, however, is that this study used the WISC-IV measures to provide relationships to reading, and these relationships could be masked by covariant analysis with a general ability estimate (Wolf et al., 1988).

The second set of limitations to this study revolves around measurement devices. Working memory was represented by storage and retrieval tasks, a method supported by researchers (Castles & Holmes, 1986; Miyake & Shah, 1999) that unfortunately dismisses non-word reading and those who support its' relation to working memory (Baddeley et al., 1982, Baddeley, Logie, & Ellis, 1988; Temple & Marshall, 1983). These differences in operationalization constrict the generalizability of this study in regards to those research teams representing working memory in a different fashion. A second measurement difficulty is the visual nature of the WISC-IV PSI. As the PSI measures visual processing speed only (Wechsler, 2003), it could be confounded by visual deficits. However, several widely accepted publications (Blank et al., 1975; Manis et al., 2000; Vellutino, 1979) have refuted these influences and the effects of this limitation are considered minimal.

Further Study

Results of this study indicate several interesting avenues for future research involving causal agents and reading achievement. One route of further study involves including measures of different types of learning. Stanovich (1992) suggested that processing speed deficits identical to those in this study cause general learning difficulties instead of reading specific deficits. This hypothesis could be studied by including measures from this study with reliable general achievement devices. Such examinations would also add further support to the phonological core variable difference model (Stanovich, 1988), as well as possible factors underlying surface dyslexia (Manis et al., 2000).

Another avenue for future exploration involves further replication with larger samples. Wolf and Bowers (1999) estimate that 24% to 29% of individuals with reading problems have naming-speed only deficits. Applying these findings to the current sample, 9 to 11 subjects would be predicted to have a naming speed only deficit. Nonetheless, this group was not detected. A larger sample size would thus help substantiate or refute the existence of this deficit pattern and further elucidate the reading problems this hypothesized group demonstrates.

Future research that includes measures of specific cognitive functions would also add to our understanding of dyslexic patterns. Studies have suggested that low level visual processing deficits (Livingstone et al., 1991) or temporal order difficulties (Farmer & Klein, 1995) may underlie problems in rapid naming. As these tasks would also affect processing speed, their measurement in conjunction with those in this study would assist in the continued effort to pinpoint causal factors in reading disabilities.

The final avenue for future research involves the measures used in this study. Frequent use of the WISC-IV by school professionals points to a need for research further tying this instrument to learning difficulties will directly impact educational practice. The finding that the WISC-IV WMI explains 28% of the variance in vocabulary could be examined closer. Likewise, results showing that the WISC-IV PSI contribution to vocabulary and fluency variance is 36% and 21% require replication. Findings that rapid naming and processing speed cause increasing difficulties in students with poor phonics could be further studied and allow practitioners to better predict future reading as well as plan more efficient intervention strategies.

Conclusion

Although limitations and the need for further study exist, several conclusions can be drawn from this study and its application to the wealth of information on reading problems. Four major findings can be summarized from the sections previously discussed in this chapter.

The first major finding is that phoneme analysis remains the best predictor of reading achievement in a clinic-referred population. While the influence of this skill decreases in a population that historically struggles with phonics, it remains the core variable in prediction of reading and supports phonological awareness as the defining factor in reading disabilities.

The second finding is that as the influence of phonological awareness decreases in a clinic population, the influence of working memory increases. A majority of these students struggle with the encoding of phonemes in working memory, thus those students with developed working memory skills will build better vocabularies than those whose skills are weaker. As such, professionals working with students with reading disabilities may consider working memory as a factor for instructional planning.

The third finding is that rapid naming has increasingly detrimental effects on reading when phonological skills are impaired. While average students are not impacted by their rapid naming abilities, those students with poor phonological awareness will be drastically influenced by rapid naming. Considering these results, individuals planning instruction should consider those children with deficits in both these areas as those in need of the most intensive instruction.

The fourth and final finding from this discussion is that processing speed directly impacts both reading and rapid naming concurrently. Specific types of dyslexia may thus be related to the effects of delayed processing speed. If this is the case, specific remediation strategies may be warranted for students with poor processing speed (see Wolf & Segal, 1999).

As the factors and component processes of reading continue to be identified, it is essential that professionals measure and consider the effects of these constructs on achievement. Proper measurement and consideration of working memory, processing speed, phonological awareness, and rapid naming will assist practitioners in understanding specific reading problems and support the understanding of reading patterns for future researchers.

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Appendix: Data Cover sheet, Informed Consent, Informed Assent, Questionnaire, and Institutional Review Board Documents

TEST	TEST SCORE	Z SCORE
WISC DS		
WISC LNS		
WISC WMI		
WISC CD		
WISC SS		
WISC PSI		
WISC SI		
WISC MR		
CTOPP EL		
CTOPP SB		
CTOPP NR		
CTOPP RON		

CTOPP RCN		
CTOPP RLN		
CTOPP RDN		
TOWRE		
GORT FL		
GORT CO		

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PARENT CONSENT TO PARTICIPATE IN A RESEARCH STUDY

TITLE: Component processes in the predictors of reading achievement: Direct and indirect influences.

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PURPOSE: You and your child are being asked to participate in a research study that investigates the skills that underlie tasks that predict reading ability. Results of this study will be used by the investigators as part of a dissertation and research project. The goal of the research is to further our understanding of the cognitive skills that are responsible for reading problems.

<u>Parents/Guardians</u>
You will be asked to fill out a one-page document about whether your child has taken part in hearing and vision assessment. You will also be asked your child's grade and whether they have ever been retained in school.

<u>Children</u>

Your child will be asked to complete six subtests of the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV). These tests require children to rapidly copy symbols, mark whether symbols are contained in a line, repeat digits and letters, indicate the complete pattern for different matrices, and provide the similarities between words.

Age, grade, and socioeconomic information will be obtained from your child's file at the clinic. In addition, your child's performance on the Comprehensive Test of Phonological Processing (CTOPP), the Test of Oral Word Reading Efficiency (TOWRE), and the Gray Oral Reading Test-Fourth Edition (GORT-4) will be collected. If administrations of these measures are more than six months old, they will be given to your child again. These tests are normal components of the reading assessment given to all children at the Duquesne Reading Clinic.

These are the only requests that will be made of you and your child.

RISKS AND BENEFITS: This study presents minimal risk to those who participate. Measures of reading skills, achievement, and general cognitive ability can sometimes cause discomfort when the tasks are frustrating.

All examiners will be instructed to inform the child to let them know if a break is required. Participants will be told these tests are common school instruments and to try the best they can without getting worried about their performance. Any observed or reported fatigue or frustration will result in a discussion of conducting multiple sessions. Parents will be notified if any difficulty arises during testing.

COMPENSATION: There is no compensation for participation in this study. Also, there will be no monetary costs to you.

CONFIDENTIALITY: The plan for protecting you and your child's privacy is as follows: Students will have normal Reading Clinic data collected and maintained within the Clinic office. The collection of this data will assist the Clinic in the proper identification and treatment of any reading problems your child may be experiencing. Student data used for research purposes will be identified by a coded sequential number, and kept separate from the normal Clinic records.

Any data that contains identifiers will be kept in a locked file in the researcher's office. Your responses as well as your child's will only appear in statistical summaries. All research data will be maintained for five years following the completion of the study.

RIGHT TO WITHDRAW: Your child's participation in this research project is voluntary. Your decision whether or not to participate will have no effect on the quality of services your child will receive from the Duquesne Reading Clinic. You are free to withdraw your consent to participate at any time.

RESULTS SUMMARY: A summary of the results of this research will be supplied to you, at no cost, upon request.

VOLUNTARY CONSENT: I have read the above statements and understand what is being requested of me. I also understand that my participation is voluntary and that I am free to withdraw my consent at any time, for any reason. On these terms, I certify that I am willing to participate in this research project.

I understand that should I have any further questions about my participation in this study I may call the primary investigator, Bryson Bresnahan (412-400-8824) or lead faculty advisor, Dr. Jeffrey Miller (412-396-4035). Further concerns or comments about how this research study is conducted may also be directed to Dr. Paul Richer, Chair of the Duquesne University Institutional Review Board (412-396-6326).

__________________________________ ______________________

Participant’s Signature Date

__________________________________ ______________________

Researcher’s Signature Date

DUQUESNE UNIVERSITY
600 FORBES AVENUE ♦ PITTSBURGH, PA 15282

ASSENT TO PARTICIPATE IN A RESEARCH STUDY

TITLE: Component processes in the predictors of reading achievement: Direct and indirect influences.

INVESTIGATORS:

Bryson Bresnahan, M.S.Ed.
School Psychology Doctoral Student
Duquesne University
102C Cannevin Hall, 600 Forbes Ave.
Pittsburgh, PA 15282

Jeffrey A. Miller, Ph.D.
Associate Professor of School Psychology
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Assistant Professor, Graduate Reading Program
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Tammy Hughes, Ph.D.
Assistant Professor of School Psychology
Duquesne University
102C Cannevin Hall, 600 Forbes Ave.
Pittsburgh, PA 15282

PURPOSE: You are being asked to participate in a research study that looks at the skills involved in reading. We want to look at why some children have problems learning to read and if other tests will help us understand what causes these problems.

You will be asked to take six short tests. These tests will have you copy marks, look at drawings in a line, repeat digits and letters, complete some patterns, and talk about how words are alike. This should take 20-30 minutes.

We will also look at your file in the reading clinic. Your parents will be asked about your age, hearing, vision, and grade in school.

Nothing else will be asked of you or your parent.

RISKS AND BENEFITS: These tests are very common for children and teens. Because they measure different skills, they can sometimes be hard for kids. In addition, although all tests are short, they can sometimes take over a half hour when given at once. If you need a break please ask the person giving the test, and if you get tired and want to complete the remaining tests at a later time just ask. If any other problems happen, you can ask to speak to your parent or another adult at any time. When you are done with the tests, you will be asked how you are feeling and we will make sure you are comfortable when you leave.

COMPENSATION: You don't get any money for participating, but it won't cost you anything either.

CONFIDENTIALITY: Neither your name or other information will be used on any forms. Only those persons involved in your instruction at the clinic will know of your participation. All written materials and forms will be stored in a locked file in the researcher's office.

RIGHT TO WITHDRAW: You do not have to participate in this study. You are free to stop at any time. If you stop it will not affect your grades or participation in the reading clinic.

RESULTS SUMMARY: A summary of the results of this research will be supplied to you, at no cost, upon request.

VOLUNTARY CONSENT: When you sign this paper it means that you understand what is being asked of you. For example, you know that you have agreed to take six different tests and let us collect information from your file at the reading clinic, You also understand that you are free to stop at any time, for any reason. Also, you understand that your parent/guardian agrees that you can participate in the study.

I agree that I am willing to participate in this research project.

______________________________ ____________________

Participant's Signature Date

______________________________ ____________________

Researcher's Signature Date

DUQUESNE UNIVERSITY
600 FORBES AVENUE ♦ PITTSBURGH, PA 15282

As part of this study on reading skills and cognitive abilities, we request you answer certain questions about your child's education and factors that may influence their learning. Please answer each question as best as possible.

1	What is your child's birthdate?	__/__/____	
2	What grade is your child currently enrolled in?	_________	
3	Has your child ever been retained for any grade level in school?	**Yes**	**No**
4	Has your child missed one consecutive month of school or more during any grade level?	**Yes**	**No**
5	Has your child been diagnosed with Mental Retardation or a developmental disability?	**Yes**	**No**
6	Has your child ever been tested for hearing problems (if Yes, answer question 7. If No, proceed to question 8)?	**Yes**	**No**
7	Did the hearing tests find problems you are aware of?	**Yes**	**No**
8	Has your child ever been tested for vision problems (if Yes, answer question 9)?	**Yes**	**No**
9	Did the vision tests find any problems you are aware of?	**Yes**	**No**

DUQUESNE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
424 RANGOS BUILDING ♦ PITTSBURGH, PA 15282-0202

Dr. Paul Richer
Chair, Institutional Review Board
Phone (412) 396-6326 Fax (412) 396-5176
e-mail: richer@duq.edu

March 30, 2005

Mr. Bryson Bresnahan
36 Hickory Street
Apt. 2
Pittsburgh PA 15223

Re: "Component processes in the predictors of reading achievement: direct and indirect influences" Protocol #05-20

Dear Mr. Bresnahan:

Thank you for submitting the revisions requested by the IRB.

After review by IRB members, Dr. Joseph Kush and Dr. Sarah Peterson, along with the entire board, the study is approved under the federal Common Rule, specifically 45-Federal Code of Regulations #46.101 and 46.111. In addition, the study meets requirements set forth in subpart D, 46.404 (research with minors not involving greater than minimal risk).

Please remember that in accordance with those federal regulations, you must produce two original signed copies of the consent and assent forms, one set for you, one copy for the students, one for parents/guardians, and one for the teachers. The first page of these forms will be stamped with approval and one year expiration dates. If after one year you are still using the forms, you will need to renew them.

This approval will be renewed in one year as part of the IRB's continuing review. You will need to submit a progress report to the board at the address shown above. It should detail the number of subjects whose involvement has been completed and the number yet to be completed.

If, prior to the annual review, you propose any changes in your procedure or consent process, you must inform the board of those changes and wait for approval before implementing them. In addition, if any procedural complications or adverse effects on subjects are discovered before the annual review, they immediately must be reported to the IRB Chair before proceeding with the study.

When the study is complete, please provide the IRB with a summary, approximately one page. Often the completed study's Abstract suffices. Please keep a copy of your research records, other than those you have agreed to destroy for confidentiality, over a period of three years after the study's completion. It is my understanding that you and the co-investigators do not intend to use data you collect for this study in future research, since you did not mention other uses in consent/assent forms. As I explained in my message after our meeting (spelling out revisions), if any researchers on the project intend to use the data in future studies, that use would need to be spelled out to the IRB, to parents/guardians, and to students.

If you have any questions, feel free to contact me at any time.

Sincerely yours,

Paul Richer
Chair, IRB
Duquesne University

C: Dr. Joseph Kush
Dr. Sarah Peterson
IRB Records

DUQUESNE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
424 RANGOS BUILDING ♦ PITTSBURGH, PA 15282-0202

Dr. Paul Richer
Chair, Institutional Review Board
Phone (412) 396-6326 Fax (412) 396-5176
e-mail: richer@duq.edu
web site: http://www.research.duq.edu/humansub.html

June 13, 2006

Mr. Bryson Bresnahan
Department of Psychology
Duquesne University
102C Canevin Hall

RE: **"Component processes in the predictors of reading achievement: Direct and indirect influences"**
Protocol #: 05-20

Dear Mr. Bresnahan:

Thank you for submitting your annual review of the above referenced study. Your study is granted a one-year renewal, **full** board review.

Current approval date: March 2006
Next renewal date: March 2007

This approval is effective for only one year. Before the next renewal date, you must submit an annual progress report to the review board. This approval is for the protocol and consent document in their current form. You must obtain approval from the board for any proposed changes in or variations to your protocol/consent prior to their implementation. Any serious or life-threatening complications must be reported immediately to me. Any adverse consequences must be reported in writing within 14 days of their occurrence. Upon consent administration, you must furnish a copy of the consent form to each participant, and place a copy in your files and in medical records, if appropriate. You must maintain copies of your research records for a minimum of three years after your study is completed.

If you have any questions, please contact our office at 412-396-6326.

Sincerely,

Paul Richer/mv

Paul Richer, Ph.D.
Chair, IRB – Human Subjects
Duquesne University