Fall 2011

The Relationships Among Rapid Automatized Naming (RAN), Processing Speed and Reading Fluency in Clinic Referred Children

John DeMann

THE RELATIONSHIPS AMONG RAPID AUTOMATIZED NAMING (RAN), PROCESSING SPEED AND READING FLUENCY IN CLINIC REFERRED CHILDREN

A Dissertation

Submitted to the School of Education

Duquesne University

In partial fulfillment of the requirements for

the degree of Doctor of Philosophy

By

John J. DeMann

December 2011

DUQUESNE UNIVERSITY
SCHOOL OF EDUCATION
Department of Counseling, Psychology, and Special Education

Dissertation

Submitted in partial fulfillment of the requirements
for the degree
Doctor of Philosophy (Ph.D.)

School Psychology Doctoral Program

Presented by:

John J. DeMann
B.S. Elementary Education, Duquesne University, 1994
M.S. Ed. Child Psychology, Duquesne University, 1998
Certificate of Advanced Graduate Study, Duquesne University, 2000

July 28, 2011

THE RELATIONSHIPS AMONG RAPID AUTOMATIZED NAMING (RAN), PROCESSING SPEED AND READING FLUENCY IN CLINIC REFERRED CHILDREN

Approved by:

____, Chair
Ara J. Schmitt, Ph.D.
Assistant Professor
Department of Counseling, Psychology, and Special Education
Duquesne University

____, Member
Jeffrey A. Miller Ph.D., ABPP
Professor/Associate Dean
Graduate Studies and Research
Duquesne University

____, Member
Rose Mary Mautino, Ph.D.
Assistant Professor
Department of Instruction and Leadership in Education
Duquesne University

ABSTRACT

THE RELATIONSHIPS AMONG RAPID AUTOMATIZED NAMING (RAN), PROCESSING SPEED AND READING FLUENCY IN CLINIC REFERRED CHILDREN

By

John J. DeMann

December 2011

Dissertation supervised by Ara J. Schmitt, Ph.D.

Converging evidence suggests that phonological awareness is at the core of reading ability. Rapid automatized naming (RAN), defined as how quickly individuals can name continuously presented familiar visual stimuli, is also known to be a strong predictor of reading performance, and reading fluency in particular. The double deficit hypothesis suggests RAN deficits represent an additional core deficit associated with the reading process. Although there are many ways to measure RAN (e.g., using letters, numbers, pictures, objects), not well established is which RAN task is most predictive of the reading fluency skills of clinic referred children. Further research is also needed to understand the relationship between RAN and general processing speed, and the extent to which RAN tasks uniquely predict the reading fluency of clinic-referred children. The purpose of the current study is to determine a) the relationships among phonemic awareness, RAN, general processing speed, and reading fluency; b) the predictive value of phonemic awareness and RAN tasks in determining reading fluency performance; c) which RAN task best predicts reading fluency; and d) if RAN tasks continue to predict reading fluency while controlling for general processing speed. 64 children from a university reading clinic were used as participants in this study. The results suggest that alphanumeric RAN task performance —and letter naming in particular— are unique contributors to reading fluency performance in dysfluent readers. Further, the results indicate that this contribution to reading fluency extends beyond that of other theoretical components of fluency.

DEDICATION

To my children, Johnny, Abbey and Ellie, for giving up precious time with Dad; my wife Jenny, for her love, patience, and unceasing support; my mother, for teaching me self-determination and always believing in me; and the memory of my father — your life inspired me to begin this journey and your influence is what carried me through. I owe this accomplishment to all of you and thank you from the bottom of my heart.

ACKNOWLEDGEMENT

Several people were instrumental in supporting the completion of this dissertation. First, I would like to thank Dr. Ara Schmitt for taking an interest in my research topic and for his willingness to serve as the chair of my dissertation committee. I truly appreciate the time you spent advising this project and providing the guidance and support that enabled its completion. I also want to thank Dr. Rose Mary Mautino and Dr. Jeffrey Miller for serving on my dissertation committee. I appreciate your thoughtfulness and constructive feedback that helped shape the outcome of this project. I would also like to extend special thanks to Dr. Miller for acting as my academic advisor and for his mentorship during all the years of my graduate studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I: Introduction

Reading is an essential academic skill as children with reading difficulties are at risk for broad academic failure, conduct problems in school, school drop-out, and poor peer relations (Bennett, Brown, Boyle, Racine & Offord, 2003; Daniel et al., 2006; Ingesson & Gunnel, 2007). As such, it is critical to identify early those students who are not meeting literacy benchmarks and apply evidence-based interventions. Learning to read is a complex, neurobiological process, and for many children problems learning to read cannot be solely explained by poor intellectual abilities, inadequate instruction, or lack of socio-cultural opportunities (Shaywitz, 2003). The inability to develop age appropriate reading skills despite seemingly typical cognitive development and adequate instruction is commonly referred to as developmental dyslexia.

A variety of theories have been posed to explain the presence of dyslexia (see Ramus et al., 2003 for a review). However, there is now consensus in the field that the primary deficit associated with word decoding problems occurs at the phonological level (Lyon, Fletcher, & Barnes, 2003; Morris, et al., 1998; Shaywitz, 2003). When learning to read, children must be able to detect and manipulate sounds (phonology) and then link those sounds to symbols, or letters (orthography). This process of recognizing and manipulating the sounds in spoken words—or phonemic awareness— is recognized as the core deficit in children with reading difficulties (Morris, et al., 1998; Vellutino, Fletcher, Snowling, & Scanlon, 2004). In fact, the Report of the National Reading Panel (NRP, 2000) concluded children who received instruction that explicitly taught phonemic awareness had more developed reading skills than children who did not receive explicit instruction in phonemic awareness. Even children who receive direct phonological training may be at risk for poor reading fluency, or rapidly decoding words (NRP, 2000; Shaywitz, 2003; Shaywitz & Shaywitz, 2008). Poor reading fluency is recognized as hallmark of dyslexia that persists into adulthood, even for children who have learned to decode words in isolation (NRP, 2000; Shaywitz & Shaywitz, 2008).

Although a great deal of evidence exists to support the core phonological model, it fails to account for the heterogeneity of reading deficits and why reading fluency problems persist in the face of otherwise successful word reading intervention (Wolf & Bowers, 1999). For more than three decades, research has demonstrated that rapid automatized naming (RAN), defined as how quickly children can name continuously presented familiar visual stimuli, is a robust predictor of both current and future reading performance. First proposed by Geschwind (1965), and supported in a series of studies by Denckla (1972) and Denckla and Rudel (1974, 1976a), this early research demonstrated that RAN tasks differentiated individuals with dyslexia from typical readers. Subsequently, numerous studies have documented the deficits of poor readers in rapid naming (Ackerman & Dykman, 1993; Felton & Brown, 1990; McBride-Chang & Manis, 1996; Wolf, Bally, & Morris, 1986). In particular, the study of RAN has lead to word decoding and reading fluency being understood as related, but distinct academic skills (Bowers & Wolf, 1993; Wolf & Bowers, 1999).

Referred to as the "double-deficit hypothesis," Wolf and Bowers (1999) argue that RAN deficits exist both independently from and along with phonological deficits in poor readers. Children exhibiting difficulties in both skills are known to be the most difficult to treat (McBride-Chang & Manis, 1996; Wolf & Bowers, 1999). Despite consistent findings that RAN is a cognitive correlate of reading, not well understood is how RAN deficits directly result in poor reading skills. Some have argued that RAN tasks primarily assess the rapid retrieval of stored phonological information from long-term memory. Therefore, RAN should be understood within the construct of phonology (Torgesen, Wagner, & Rashotte, 1994; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). On the other hand, Bowers and Wolf (1993) first proposed that phonology and RAN are distinct constructs and their impact on reading should be considered separately (Bowers, Golden, Kennedy, & Young, 1994; Wolf, Bowers, & Biddle, 2000). This proposition was supported by research that 1) RAN continues to account for significant variance in reading skills after controlling for the contribution of phonological awareness; 2) the correlation between RAN and phonological awareness is typically low, and 3) studies conducted in different language systems, particularly languages with a one-to-one letter to sound correspondence, indicate that RAN is a stronger predictor of reading difficulty than phonological awareness (Bowers et al., 1994; Bowers & Ishaik, 2003; Wolf et al., 2000; Wolf & Bowers, 1999).

The distinction between RAN and phonology aside, also debated is if RAN is a construct distinct from general processing speed. Kail and colleagues (Kail & Hall, 1994; Kail, Hall, & Caskey, 1999) offer empirical evidence that the association between RAN and reading reflects developmental changes in general processing speed. According to Kail and colleagues, global processing speed increases across childhood and RAN deficits may be an artifact of slow processing speed (Kail & Hall, 1994; Kail et al., 1999). The relationship between processing speed and reading was also investigated by Cutting and Denckla (2001). This study found that processing speed indirectly impacts reading through its influence on both phonological awareness and RAN.

Germane to this proposed study, Neuhaus, Foorman, Francis, and Carlson (2001) found that RAN of letters was the most robust predictor of reading decoding and reading comprehension in a sample of first and second grade students, and the relation between letter naming and reading was associated with the unique demands of letter processing rather than the result of general verbal processing speed. Likewise, Powell, Stainthorp, Stuart, Garwood, and Quinlan (2007) studied the distinct contribution of processing speed and RAN on reading. General processing speed did predict a small but significant proportion of the variance in reading scores; however, regression analyses revealed that even when processing speed was entered first into a regression equation, RAN accounted for additional variance in word reading skills. In a related study, Bowey, Storey, & Ferguson (2004) also demonstrated that general processing speed and RAN make distinct contributions to reading performance. A limitation of the previously mentioned studies is the focus on word reading skills and not reading fluency. In brief, an increasing body of evidence exists to suggest RAN and processing speed can be measured separately and may be independent correlates of reading. This study will seek to confirm this finding in a clinic-referred sample of children.

In addition to explaining the word recognition difficulties experienced by some children with dyslexia, there is also strong evidence supporting RAN's involvement in the development of reading fluency skills (Bowers & Ishaik, 2003; Savage & Frederickson, 2005). Reading fluency, defined by the National Reading Panel (NRP, 2000), involves the reading rate, accuracy, and fluent expression of passage reading. Traditional assessment and definitions of dyslexia focus on single-word reading and decoding deficits, however difficulty with reading fluency is increasingly recognized as an important characteristic of students with dyslexia. For example, the most recent reauthorization of the Individuals with Disability Education Improvement Act (IDEA, 2004) now recognizes reading fluency as one of the eight areas of specific learning disability. More recent conceptualizations of the term dyslexia (Lyon, Shaywitz, & Shaywitz, 2003) also include references to fluency as an area of difficulty experienced by individuals with dyslexia. Reading fluency represents a largely under-studied area of reading research that may be a key area of assessment for children who experience reading problems (Meisinger, Bloom, & Hynd 2009; Sofie and Riccio, 2002).

For many dyslexic readers, becoming a fluent reader remains elusive, in part because children with dyslexia can be taught to decode words, however teaching children to read fluently has proven more difficult (Shaywitz & Shaywitz, 2008). It stands to reason that other cognitive processes are involved in reading, and that disruption of these mechanisms may play a causal role in reading fluency difficulties. Although RAN's involvement in predicting word reading and decoding skills is well documented, a growing accumulation of research suggests that RAN's relationship with reading appears to be stronger with text reading fluency. Several studies investigating the impact of slow RAN on reading fluency (e.g., Bowers et al., 1994; Savage & Frederickson, 2005; Young & Bowers, 1995) demonstrate that RAN may be a powerful, yet simple task that yields insight into the reader's ability to obtain age-appropriate fluency skills. Bowers and Ishaik's (2003) review of recent RAN findings indicates that RAN appears to be highly related to fluent reading. Further, Lervåg and Hulme (2009) provide evidence suggesting RAN is a strong predictor of later growth in reading fluency skills, and that RAN continues to exert an influence on the development of reading fluency over several years after reading instruction has started.

While this growing body of literature suggests that RAN is a distinct factor important to the development of reading fluency skills, there is a need to better understand this relationship by examining different types of RAN tasks. Some research findings suggest that different versions of the RAN task can account for different amounts of variance in reading ability (Compton, Olson, DeFries, & Pennington, 2002; Neuhaus et al., 2001). More specifically, the empirical literature suggests that RAN effects are more robust for alphanumeric (letter and digit) naming over more general (picture and object) naming tasks (e.g., Compton, 2003; van den Bos, Zijlstra, & Spelberg, 2002). However, it is not well established which RAN task is most predictive of reading fluency performance in clinic-referred children. Limitations of existing studies (e.g., Benson, 2008; Vaessen & Blomert, 2010) include not addressing reading fluency, not including all RAN tasks, or not using clinical samples of children with reading difficulties. It is necessary to evaluate a model that includes all aspects of the RAN task and reading fluency with children suspected of reading difficulties.

It is also necessary to determine whether RAN is simply an artifact of processing speed, or whether it taps into a distinct process that is related to reading. Studies that have included measures of general processing speed as an explanation for RAN's influence on reading (e.g., Bowey et al., 2004; Catts, Gillespe, Leonard, Kail, and Miller, 2002; Kail et. al., 1999; Powell et al., 2007) have been limited by not including all RAN measures and not examining fluency in their studies. As mentioned, existing studies suggest (Bowey et al., 2004; Powell et al., 2007) that while processing speed does predict a small but significant portion of the variance in reading, these studies included only one measure of word reading and no measures of fluency. Further, these studies have used hierarchical regression techniques, and have not considered the impact of RAN and processing speed separately in predicting reading fluency.

The limitations of these studies and others (e.g., Savage & Frederickson, 2005; Young & Bowers, 1995) suggest the need to further examine these variables in a selected sample of students with reading difficulties. In order for us to further elucidate the defining characteristics of students who exhibit difficulty obtaining fluency, we must evaluate all potential variables as suggested from the existing literature. Given that we are just beginning to understand fluency and its importance as a marker for successful reading, still not enough is known about the impact of RAN on reading fluency when processing speed is taken into account for school-age children. This study seeks to address the unique role RAN plays in explaining individual differences in reading fluency performance.

Significance of the Problem

The Report of the National Reading Panel (NRP, 2000) established that reading fluency is a critical component of learning to read and that an effective reading program needs to include instruction in fluency. The National Center for Education Statistics indicates that nearly half of American fourth graders had not achieved minimal levels of fluency in their reading, which was associated with significant difficulties in comprehension (NCES, 2004; Pinnell et al., 1995). As a result, it is critical for educators to identify students at-risk for reading fluency problems and provide early and aggressive remediation. In order to develop and implement these evidence-based practices and provide effective early intervention services, we need to better understand the predictors of reading fluency from a theoretical and practical perspective.

Although it is understood that RAN deficits represent an additional core deficit associated with reading fluency performance, not well established is which RAN task (i.e., naming of letters, numbers, pictures, objects) is most predictive of the reading fluency skills of clinic referred children. Also, with the increased emphasis on RAN's connection with fluency, RAN's independence from general processing speed has not been firmly established.

Given the limitations of the existing studies, this study represents an attempt to add to the literature base by further exploring reading fluency in clinic-referred children. Further investigation of RAN's unique connection with reading fluency may add additional insight into the importance of RAN as a future indicator of reading fluency skill development independent from phonemic awareness and general processing speed. Additionally, if RAN uniquely predicts reading fluency, and there are multiple ways to measure RAN, assessment professionals need to know which RAN measure(s) are best to identify those at risk. The finding of efficient, yet valid and reliable, indicators of reading fluency development empowers assessment professionals by offering effective tools to identify fluency-based reading difficulties early in a student's schooling, thus leading to more timely and differentiated intervention.

Problem Statement

While research evidence documents that phonological awareness and phonics form the basis for reading development, the double-deficit hypothesis suggests that RAN is a distinct construct that explains additional variance in reading development (Bowers

& Wolf, 1993; Wolf & Bowers, 1999). In a sample of clinic referred children, it is unknown whether RAN contributes something more than phonemic awareness and phonics to reading fluency performance. It is also unknown what RAN task is most predictive of reading fluency performance. While the previously mentioned studies have explored RAN performance, general processing speed and word reading, research has yet to investigate these variables in a model that includes reading fluency. Further, these studies have not determined whether RAN is distinct from processing speed by considering the influence of both in a model of reading fluency performance. This study seeks to determine which RAN tasks are most predictive of reading fluency and whether RAN predicts variance in reading beyond processing speed. By exploring these questions using a sample of clinic referred children (the very children seen by school psychologists), these questions will inform theories of reading disabilities, as well as inform school psychologist test selection.

Research Questions and Hypotheses

1) What are the relationships among the participants' phonemic awareness, alphanumeric RAN, non-alphanumeric RAN, processing speed, and reading fluency skills?
    a) Hypothesis 1: Phonemic awareness and reading fluency will be highly correlated.
    b) Hypothesis 2: Both RAN tasks, processing speed, and reading fluency will by highly correlated.
    c) Hypothesis 3: The correlation between RAN tasks and phonemic awareness will be moderate.

d) Hypothesis 4: The correlation between processing speed and phonemic awareness will be low.

2) Does RAN account for additional variance in reading fluency beyond phonemic awareness?

   a) Hypothesis 1: RAN will contribute uniquely to reading fluency performance beyond phonemic awareness.

3) If so, and depending on the results above, which of the RAN tasks accounts for the greatest variance in reading fluency?

   a) Hypothesis 1: Alphanumeric RAN tasks will better explain individual differences in reading fluency performance than non-alphanumeric RAN tasks.

   b) Hypothesis 2: Non-alphanumeric RAN tasks will not explain additional variance in reading fluency performance after accounting for variance in alphanumeric RAN tasks.

4) If alphanumeric RAN predicts reading fluency beyond phonemic awareness, does it predict reading fluency while controlling for processing speed?

   a) Hypothesis 1: RAN will explain additional variance in reading fluency performance beyond what is explained by general processing speed.

   b) Hypothesis 2: General processing speed will account for a small but significant portion of the variance in reading fluency performance.

Chapter II: Literature Review

Developmental Dyslexia

Since the 1960s, developmental dyslexia has been characterized as a disorder in individuals, who, despite conventional educational opportunities, fail to attain the skills of reading, writing, and spelling commensurate with their intellectual capacities (Catts, 1989). Early attempts to define dyslexia have typically relied on exclusionary factors focusing more on what it is not than what it is (Rutter, 1978). For example, Critchley (1970) describes developmental dyslexia as a disorder manifested in difficulty in learning to read despite conventional instruction, adequate intelligence and social-culture opportunity. This simple definition is congruent with the many approaches to describing developmental dyslexia, including the current DSM-IV-TR (American Psychiatric Association [*DSM-IV-TR*], 2000) definition. Currently, Lyon et al. (2003) provide the following working definition of developmental dyslexia that is commonly recognized by researchers and practitioners:

> Dyslexia is a specific learning disability that is neurobiological in origin. It is characterized by difficulty with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge. (p. 2)

This definition of developmental dyslexia distinguishes the condition from other learning disabilities, and emphasizes that developmental dyslexia originates from problems in cognitive development irrespective of other developmental disabilities or socioeconomic or educational deficiency. Depending on how dyslexia is defined, prevalence in western school populations is typically between 3-4% (Lyon et al., 2003);

however, much higher estimates have been proposed by Shaywitz (2003) ranging up to 20% in school populations. Although it is generally assumed that dyslexia is more common in males than in females, studies focusing on community populations find comparable numbers of males and females identified as dyslexic (Shaywitz, 2003).

Theories and Background

Theories abound regarding the possible causes for the disorder; however dyslexia has most often been attributed to deficiencies in visual, sensory, and linguistic functions (Vellutino et al., 2004). Visual deficit theories were prominent at the turn of the century (Hinshelwood, 1917; Morgan, 1896) until the 1970s when language deficit theories began to contend with these explanations. Early explorations of dyslexia held that deficiencies in the visual system explained the reversal of words thought to characterize the disorder. Subsequent research has aggressively shown that children with dyslexia are not unusually prone to reversing letters of words, and the cognitive deficits responsible for the disorder involve other processes, namely deficits in the linguistic system (e.g., Fletcher, Foorman, Shaywitz, & Shaywitz, 1999; Snowling, 1990; Vellutino, 1979; Vellutino et al., 2004).

Individuals with dyslexia have been shown to have deficits in auditory processing (Tallal, 1980), rapid visual processing (Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998; Lovegrove, Martin, & Slaghuis, 1986), receptive and expressive language deficits (Snowling, Bishop, & Stothard, 2000), orthographic processing weaknesses (Roberts & Mather, 1997), phonological coding deficits (Lyon, 1995; Shaywitz, 2003), delays in motor skills (Nicolson, Fawcett, & Dean, 1999; Wolff, 1990), and weaknesses in specific executive functions (Brosnan, et al., 2002; Helland & Asbjornsen, 2000;

Reiter, Tucha, & Lange, 2005). Additionally, research has demonstrated that dyslexics also demonstrate deficiencies in the rapid retrieval of acquired knowledge and automaticity (Denckla & Rudel, 1976a; Wolf & Bowers, 1999), which will be further explored in greater detail later in this paper. In light of these preceding theories, there is no question that the phenomenon of dyslexia is a well studied area of research with many broad theoretical explanations.

Reading Fluency

Traditionally, dyslexia has been primarily characterized as deficits in single word decoding; however, difficulty with reading fluency has been increasingly acknowledged as a significant aspect of dyslexia. The Report of the National Reading Panel (NRP, 2000) includes fluency as one of five areas critical to the development of reading skills. Recent definitions of dyslexia (Lyon et al., 2003) also include reading fluency as an area of difficulty for individuals with dyslexia. Reading fluency was added to the federal definition of a specific learning disability in the reauthorization of the Individuals with Disabilities Education Improvement Act (IDEA, 2004). Furthermore, intervention research has shown that it is harder to attain improvements in reading fluency compared to improvements in reading comprehension, decoding, and word identification skills (Meyer & Felton, 1999; Torgesen, Rashotte, & Alexander, 2001). However, more work is needed to explore reading disability characterized primarily by a lack of fluency (Lyon et al., 2003; Meisinger et al., 2009).

Although there is still no consensual definitions of reading fluency, the term is typically used when describing time-related processes such as automaticity, speed of processing, reading rate, and word recognition proficiency (Wolf & Katzir-Cohen, 2001). Reading fluency, defined by the National Reading Panel (NRP, 2000), involves the reading rate, accuracy, and fluent expression of passage reading. Similarly, Meyer and Felton (1999) defined fluency similarly as "the ability to read connected text rapidly, smoothly, effortlessly, and automatically with little conscious attention to the mechanics of reading such as decoding" (p. 284).

Most theoretical discussions of reading fluency trace their foundations to the work of LaBerge and Samuels (1974) and their automaticity model of reading. These researchers described how the execution of complex skills necessitates the coordination of many component processes within a short time frame. If each component of a specific task invokes attention, the performance of the complex task would exceed attentional capacity and therefore be impossible. In contrast, if enough components are executed automatically, then attentional load would be manageable, allowing for successful performance. They proposed that learning to read involves increasing automaticity in processing word units (e.g., letter–sound correspondences), processing these units into recognizable words, and connecting the words while reading a passage. In effect, improvement in the processing of units, words, and connected text cognitively releases the reader to think about the meaning of the text. Their work forwarded several ideas of successful reading including the notion that, with increased speed (automaticity) of lower-level skills, attention can be reallocated elsewhere; and attention can be shifted from lower-level decoding to higher level comprehension skills. This early work established the modern foundation for reading fluency as the bridge between word-reading and comprehension.

Posner and Snyder (1975) offered an additional account furthering the relationship between word recognition and automaticity. They theorized that the semantic context affects word recognition via two independently acting processes - an automatic activation process and a conscious-attention mechanism. The automatic activation process controls the activation of a memory location when information is first presented, which spreads automatically to semantically related memory locations. This process is thought to be automatic and requires no attentional capacity. With the conscious-attention mechanism, this process relies on context to formulate a prediction about the upcoming word and directs the limited capacity processor to the memory location of the expected stimulus. This process is thought to be slow-acting, utilizes attentional capacity, and it inhibits the retrieval of information from unexpected locations. As it relates to reading, for good readers, fluent word recognition by-passes the attention-demanding mechanism and the automatic activation process dominates the cognitive processing of word recognition. By contrast, for poor readers, contextual facilitation results from the combined effect of the conscious-attention and the automatic-activation mechanisms. As a result of utilizing the conscious-attention mechanism, poor readers expend their capacity in the prediction process in the recognition of words, which constrains the integrative reading comprehension process (Fuchs, Fuchs, Hosp, & Jenkins, 2001).

Both perspectives share the common assumption that the more efficient one becomes with lower-level word recognition, the greater the capacity for higher-level, integrative comprehension of text becomes. This work also frames fluency as an indicator of overall reading competence, or the bridge which connects word identification to extracting meaning from connected text (Fuchs et al., 2001). Similarly, Perfetti's (1985) verbal efficiency model suggested that slow word processing speed interferes with automaticity of reading that leads to difficulty with comprehension. However, Perfetti extended this explanation to suggest that slow word reading is also debilitating because it consumes working memory and, therefore, prevents the individual from thinking about the text while reading. Slow word reading constrains working memory with the processing of word-level reading so as to prevent understanding at the content level. Thus, both rapid reading of high-frequency words and rapid decoding as a means to enhance text understanding appear critical for typical reading development (Fuchs, et al., 2001).

Explanations of dysfluency. Research suggests that the development of fluency depends on the interaction of multiple factors that include, but are not limited to the following cognitive processes: phonological awareness, word recognition, visual perception, orthographic representation, and word recognition, speed of lexical access and retrieval, and higher level language and conceptual knowledge (Wolf & Katzir-Cohen, 2001). Meyer and Felton's (1999) summary of the existing research on explanations of dysfluency divides this research into three major areas. Initially, deficits may arise from phonological, visio-spatial, and/or working memory processes. At this level, the development of fluency is affected by the inefficient timing and coordination of these systems. Secondly, disruption may occur after perceptual identification of words has been completed, leading to a failure to make higher order semantic and phonological connections between words, meaning, and ideas. Additionally, this may involve the slowed retrieval of names, meaning, or both (see Wolf et al., 2000). Lastly, a breakdown occurs at the level of connected text for reading, with deficits exhibited in a lack of prosody and rhythm in oral reading and a lack of sensitivity to prosodic cues (Meyer & Felton, 1999).

Berninger, Abbott, Billingsley, and Nagy (2001) proposed a multi-component model of fluency that describes how various aspects of language and orthography interact with each other to result in fluent reading. Included in the model was morphological awareness or the ability recognize word structures as well as inflectional and derivational suffixes, as another component that impacts the development of fluency. Berninger et al. demonstrated that students' knowledge of morphological relationships influences speed and accuracy of reading, and this relationship increases as students' progress in grade. Further, she and her colleagues note that a variety of factors (i.e., those previously mentioned) converge to facilitate fluency, and also stress the need for executive coordination of all processes for the achievement of fluency.

Although children with dyslexia can be taught to decode words, teaching children to read fluently and automatically represents the next frontier in research on dyslexia (Shaywitz & Shaywitz, 2008). Further, students with reading or learning disabilities are most at risk for presenting difficulties in fluency (Meyer & Felton, 1999). In summarizing Stanovich's (1986) argument on the matter, the importance in developing fluency is critical to maintaining and sustaining a student's interest in reading. Students who practice reading and achieve fluency are more likely to read more extensively than readers who experience difficulty achieving fluency. Thus, the more a student reads, the reader grows in skills that contribute to reading, while non-fluent readers may avoid reading and fall further behind. Reading fluency capability is an important indicator of overall reading development, and contributes greatly to students' ability to achieve comprehension.

Cognitive Components of Dyslexia and Fluency

A substantial body of research has emerged that supports the finding that phonological-core deficits represent the core difficulty in dyslexia (NPR, 2000; Morris et al., 1998; Ramus et al., 2003; Shaywitz, 2003). Phonological awareness represents the ability to perceive and manipulate speech sounds within a word and shows a strong reciprocal connection with reading acquisition (Shaywitz, 2003). Awareness of the sound structure of words is necessary to understand the basic principles of reading in an alphabetic script; conversely, learning to read strongly facilitates awareness of phonemes (Castles & Coltheart, 2004; Ehri, 2005; Torgesen et al., 1994; Wagner & Torgesen, 1987). Although phonological awareness seems to be related to a wide variety of reading tasks, it has been claimed that it is most strongly associated with reading tasks requiring phonological decoding such as pseudoword reading (Bowers, 1995; Bowers, Sunseth, & Golden, 1999; Manis et al., 2000; Savage & Frederickson, 2005; Torgesen et al., 1997).

To understand the contribution of phonological awareness and the language system to reading skill development, Shaywitz (2003) offers a hierarchical model. At the upper levels of the hierarchy are components involved with semantics (vocabulary and word meanings), syntax (grammatical structure) and discourse (connected sentences). Certainly constructs such as these have importance in reading acquisition, however research in this area (for review, see Catts, Fey, Zhang, & Tomblin, 1999) routinely finds co-occurring variables that diminish the hypothesized causal relationship – factors such as language exposure, early literacy exposure, socioeconomic factors and limited English proficiency are often cited as influencing literacy development. Thus, factors such as these might be significant sources of difficulties in some beginning readers, but likely have little to do with the impaired word recognition and decoding difficulties commonly recognized as risk factors in impaired readers (Vellutino et al., 2004). At the lowest level of Shaywitz's (2003) hierarchy is the phonological model, which is responsible for processing the distinctive sound elements of language. This cognitive factor – phonological awareness – is commonly believed to underlie successful reading. Phonological awareness is typically defined as the ability to understand the basic sound structure of language (NRP, 2000). These structures, called "phonemes," represent the individual sounds of language and are commonly believed to lie at the root of difficulties with basic word reading and decoding skills (Shaywitz, 2003). The existence of a phonological core deficit, or the failure to acquire phonological awareness and skill in alphabetic coding, is considered the most strongly supported theoretical account of developmental dyslexia (Morris et al., 1998; Snowling, 2000; Stanovich & Siegel, 1994; Torgesen et al., 1994; Vellutino & Scanlon, 1987). Experimental research (i.e., many of the words cited above) has revealed repeatedly strong correlations between measures of phonological awareness and reading abilities.

Perhaps the strongest support of this argument is derived from the intervention studies documenting improved reading outcomes for individuals when provided with direct training designed to facilitate phonological awareness (Torgesen, Alexander, Wagner, Rashotte, Voeller, Conway, 2001; Wilson & Frederickson, 1995). For example, Torgesen et al. (2001), children with severe reading disabilities were randomly assigned to two instructional programs that incorporated instruction in phonemic awareness and phonemic decoding skills. Both instructional programs produced very large improvements in generalized reading skills that were stable over a two-year follow-up period. The phonological deficit model is held as the dominant view of most dyslexic researchers (Nicolson, 1996), and has greatly contributed to our understanding of the cognitive nature of dyslexia.

The double-deficit hypothesis. Not all researchers studying the cognitive components of reading find that reading difficulties are limited to a core phonological deficit. Another prominent and well studied model of dyslexia is the "double-deficit hypothesis" (Wolf & Bowers, 1999). This hypothesis suggests that some deficits in reading may be related to the speed with which one can name aloud a series of letters, objects, and numbers (rapid automatized naming or RAN), as well as to deficits in phonological awareness. This reading disability model has dominated reading disability research this past decade and represents an evolving, alternative conceptualization of dyslexia. Wolf & Bowers (1999) have found that the naming speed factor makes another significant contribution to reading development that is relatively independent from phonological awareness. Further, and more importantly, the double deficit hypothesis suggests that reading outcomes are most significantly jeopardized when both deficits are combined in the young reader. The major idea being that double deficits can together create the most serious of reading problems, even if each alone does not cause significant problems.

The double deficit hypothesis has been supported by abundant research (Wolf & Bowers, 1999; Wolf et al., 2000). In conjunction with phonological awareness deficits, naming speed tasks (especially letter and digit naming tasks) have consistently been found to contribute unique variance in reading performance (Manis, Doi, & Bhadha, 2000). The combined effects of these processes have been linked to reading sub-skills; whereas phonological awareness has been more strongly correlated with accuracy in word identification and decoding, naming speed has been shown to correlate with word and decoding fluency. More importantly, this line of research (e.g., Wolf et al., 2000) suggests that RAN offers an additional explanation of dysfluent reading, which may provide a more differentiated view of dyslexia and a more comprehensive approach to intervention.

The double deficit hypothesis offers an argument conceptualizing the reading deficits found in dyslexics, however this assumption has been challenged. Some findings appear to contradict the double deficit hypothesis. For example, Ackerman et al. (2001) found children with double-deficit reading profiles were no more impaired in reading and spelling than those with a single deficit in phonological analysis, and those with a single deficit in rapid naming were no more impaired than those with neither deficit. Swanson and his colleagues' (2003) thorough investigation of the double deficits in individuals with dyslexia found weaker relationships between RAN and phonological factors and reading, suggesting further study is warranted. Another ongoing argument is RAN's independence from phonological awareness as a unitary construct. Researchers continue to disagree as to whether RAN and phonological awareness contribute unique variance to reading outcomes. Torgesen, Wagner, and their colleagues (Torgesen et al., 1994; 1997; 1987) have argued that the RAN construct primarily assesses the rate of access to phonological information and should be subsumed by the phonological processing construct. Bowers, Wolf and their colleagues (1999; 2002) have repeatedly provided evidence that supports RAN's distinction as a unique contributor to reading development, hypothesizing that there are two independent sources of reading dysfunction. This conjecture appears consistent with Swanson et al.'s (2003) conclusion in their comprehensive review of the correlational research. Putting aside the issue of interdependence, research has convincingly shown that phonological awareness and RAN are significant cognitive factors underlying developmental dyslexia. The degree to which they contribute to reading is clearly questionable, as is their over all contribution to the understanding of dyslexia (Swanson et al., 2003).

Brief Summary

In summary, much has been learned about the intrinsic and contributory aspects of reading difficulties in typically developing children. It is clear that the linguistic explanations appear to benefit from strong support in the recent literature. Although poor word identification skills constitutes the manifest and most ubiquitous cause of reading difficulties (Vellutino et al., 2004), deficits in reading fluency is increasingly recognized as an important aspect of dyslexia. With regard to the cognitive factors, the phonological deficit theory benefits from abundant and reliable research supporting its role in explaining differences between poor and normal readers. However, much research also supports the claim that weakness in RAN offers an additional explanation of dysfluent reading, which may provide a more differentiated view of dyslexia and a more comprehensive approach to intervention (Wolf et al., 2000). Whereas the phonological deficit theories benefit from a richer understanding of it's cognitive nature (Shaywitz, 2003), the RAN construct is much less well understood. Despite the acknowledged importance of RAN in predicting reading skills, there is still no consensus as to why this is the case, or what cognitive mechanisms underlie this relationship (Kirby, Parrila & Pfeiffer, 2003; Närhi et al., 2005; Scarborough, 1998) raising additional questions regarding our understanding of dyslexia.

To date very few studies have taken up the task of examining the components of RAN in relation to reading. As Torgesen et al. (1997) affirm "our understanding of rapid naming ability's relation to reading development, in general, and orthographic development, in particular, will be enhanced to the extent that we make progress in dissecting the component skills involved in performance on rapid naming tasks…if we can isolate the particular relations with reading, this may take us an important step forward in our understanding of the development of orthographic reading skills" (p. 183). Considering the importance of Swanson et al.'s (2003) comprehensive review, many questions can be raised regarding the isolated importance of RAN and phonological awareness' contribution to fully understanding the deficits underlying dyslexia and the development of fluency. Since RAN as a construct is still not well understood, perhaps the components that comprise the RAN construct offer additional explanations of the deficits found in struggling readers.

Rapid Automatized Naming

Over the past three decades, an increasing body of research has demonstrated convincingly that rapid automatized naming (RAN) speed influences the development of reading skills in alphabetic writing systems (Ackerman & Dykman, 1993; Blachman, 1984; Bowers, 1995; Bowers, Steffy, & Swanson, 1986; Bowers & Wolf, 1993; Cardoso-Martins & Pennington, 2004; Kirby et al., 2003; Scarborough, 1998; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). The terms "RAN," "rapid naming," and "naming speed" are often used interchangeably in the research literature to indicate serial list measures, with performance reported either by the time to name whole lists or by items per second (Bowers & Ishaik, 2003). Many research studies have demonstrated that RAN makes a unique contribution to reading development that is independent of the contribution of other predictors of reading ability such those mention earlier in this paper – namely phonological awareness (Blachman, 1984; Bowers & Newby-Clark, 2002; Bowers, Steffy, & Tate, 1988).

Early Studies

The original reference to RAN can be traced to Norman Geschwind's description of Dejerin's classic case of "pure alexia without agraphia" (Denckla & Cutting, 1999). While studying acquired lesions in the adult brain, Geschwind found a neurological "visual-verbal" disconnection that rendered reading impossible, and began an alternative understanding of children who could not read (Geschwind, 1965). His significant monograph, The Disconnexion Syndrome in Animals and Man (1965), first suggested the possibility that the naming of simple visual stimuli and reading tap similar processes – a neurological connection model based on the adult brain was the beginning of the RAN concept. Building on these early studies, Geschwind and Fusillo (1966) developed the concept behind the color-naming test, an attempt to measure the effects of RAN on reading readiness. In this classic paper, a study of an adult stroke victim suffering from alexia (loss of the ability to read) without agraphia (inability to spell and write words) also experienced the inability to name colors despite normal color matching and no evidence of color blindness (Geschwind & Fusillo, 1966). The finding that color naming was an indicator of an apparent visual-verbal disconnection led Geschwind to hypothesize that a child's color naming ability would be the best predictor of reading readiness (Geschwind & Fusillo, 1966). These early theoretical interpretations laid the groundwork for many cognitive models of reading ability to come, and also established the belief that both color naming and reading require many of the same cognitive, linguistic, and perceptual processes involved in retrieving a verbal match for an abstract stimulus; therefore, color naming should be a good early predictor of later reading (Wolf, 1999). It is important to note here, however, that Geschwind's original hypothesis of "color naming ability" did not differentiate between naming accuracy and naming speed.

Although these early works established early connections between color naming and reading, it wasn't until Geschwind's student, Martha Denckla, applied this relationship to the study of dyslexic children. What made Denckla's (1972) early findings so important was the discovery that color naming speed, rather than color naming accuracy differentiated dyslexic boys from typical readers. Based on this initial finding, Denckla designed the classic color naming task in which she utilized the naming of colors because colors are generally learned early, named often, and because examiners themselves often master color names in foreign languages (Denckla & Cutting, 1999). Furthering the initial research in this area, Denckla and Rudel (1974, 1976a, 1976b) used color naming as a template to construct three additional rapid naming tasks, thus creating the original version of the Rapid Automatized Naming (RAN) task. The RAN task required the subject, children in this case, to name 50 stimuli as rapidly as possible. The stimuli consisted of 5 common letters, 5 digits, 5 colors, or 5 pictured objects, repeated randomly 10 times on board (Denckla & Rudel, 1974, 1976a, 1976b). The findings from these early studies and the development of the original RAN test has become the prototype of many subsequent versions broadly defined as "naming speed" tests in contemporary neuropsychological and cognitive psychology research. This test has also been included in many routine screening assessment procedures for early screening and diagnosis of reading disabilities (e.g., Fawcett & Nicolson, 1994; Mitchell, 2001; Nicolson & Fawcett, 1996).

Measurement and Format Issues

Since different test instruments have been developed over the years that either include a version of the RAN task, or are dedicated RAN assessment instruments, the typical continuous-form RAN task will be described. The RAN task typically includes four sub-tasks that examinees are required to name verbally aloud as quickly and accurately as possible a long sequence of either symbolic (e.g., letters, numbers) or non-symbolic (e.g., colors, pictures of common objects) stimuli presented over five rows containing ten items in each row. The typical RAN task is either presented in isolation on a large card or can be presented to examinees on a computer screen. Typically the performance of the examinee is determined by converting the time required to name the 50 items to a variety of normative scales for peer comparison.

Since the early studies that established the RAN- reading connection, the past three decades' research on RAN has established this construct as a reliable and valid predictor of reading development as demonstrated by cross-sectional, longitudinal, and cross-language studies. However, as Denckla and Cutting (1999) illustrate, early studies raised some methodological debates concerning whether RAN was still a strong contributor of reading development if the task items were presented in a discrete format rather than in a continuous format. This distinction deserves attention in this paper due to the significance of the continuous format argument and its components that will be discussed later in this paper.

In the discrete version of the RAN task, items are presented individually, and the latencies of the 50 items are averaged, as opposed to the continuous format where all 50 items are presented on a board and the examinee's score is the total time to name all the stimuli consecutively. As Wolf (1991) discusses, research surrounding these two formats generally examines the cognitive components or demands of each task. The studies supporting the discrete-trial format have argued that the discrete-trial task eliminates confounding variables such has scanning, sequencing, and motoric components found in the continuous-trial formant. Proponents of the continuous-trial formats argue that it is these extraneous sources of variance (i.e., scanning, sequencing, and processing of serially presented material.) that reflect those processes important for textual reading (Wolf et al., 1986). Despite conflicting research regarding the importance of the discrete-trial method, the continuous-trial method benefits from abundant research supporting its ability to discriminate between good and poor readers (e.g., Ackerman & Dykman, 1993; Blachman, 1984; Bowers et al., 1986) and even among adults (Felton, Naylor, & Wood, 1990). As mentioned previously in this paper, the typical RAN task used in contemporary practice and research is typically a form of the continuous-trial format given the support of this format in the predication of reading skills.

Cross-sectional, Longitudinal and Cross-linguistic Support

The literature that supports the connection between RAN task performance and reading began to flourish as researchers investigated the role naming speed played in its correlation and prediction of dyslexia and other reading disabilities. The importance of these findings have lead to more detailed studies investigating a variety of RAN-reading related topics through cross-sectional, longitudinal, and cross-language research. The cross-sectional studies have focused on how well RAN task performance distinguishes developmental dyslexia from other learning disabilities and the longitudinal studies have demonstrated the relationship between early stages of cognitive development as a predictor of reading performance later on in different age groups. Also, cross-language studies have addressed RAN task performance relationships in non-alphabetic (different language) writing systems. Most research accounts studying the RAN-reading relationships have provided strong evidence in support of the relationship, especially in the context of the double-deficit hypothesis (Bowers & Ishaik, 2003; Denckla & Cutting, 1999; Wolf & Bowers, 1999, for reviews).

The cross-sectional research related to RAN has illustrated that performance on RAN and RAN-like tasks distinguishes between individuals with dyslexia (and overall poor readers) and age-matched average readers. Also, studies have demonstrated the same connections even with individuals with non-reading specific learning disabilities (Ackerman & Dykman, 1993; Bowers et al., 1988; Denckla & Rudel, 1976a, 1976b; Fawcett & Nicolson, 1994; Felton et al., 1990; Wolf et al., 1986).

For example, Blachman (1984) found in a sample of kindergarten students that rapid naming of colors was significantly related to early reading measures, and also found rapid naming of letters and phoneme segmentation were significantly related to measures of 1st-grade reading achievement. Studying a group of 7-12 year-olds, Ackerman and Dykman (1993) found that performance on the RAN task distinguished dyslexic children from both slower learners and those diagnosed with attention deficit disorder (ADD). In another study investigating dyslexic patterns in an adult sample, Felton et al. (1990) found that a large sample of adults with a history of reading disability performed consistently poorer on tests of rapid naming after controlling for intelligence and socioeconomic status. Many more examples exist that extend and duplicate the research that established RAN as a predictor of reading performance, however not all of findings indisputably demonstrate that RAN task performance is distinctively linked to reading skill development.

Perhaps the most significant contribution to the longitudinal research supporting the RAN-reading connections is drawn from the work of Wolf et al. (1986) exploring the developmental course of RAN task performance in children with and without dyslexia. Results from the group's five-year longitudinal study indicated that differences in RAN performance for children with reading disabilities were evident from the first day of kindergarten (Wolf et al., 1986). Generally, the results suggested that children with dyslexia began school with a naming speed deficit that remained through their fourth grade year, especially for letter and number naming deficits. Additional research duplicating and extending these original findings suggest that these differences extend through eighth grade and into adulthood (Meyer, Wood, Hart, & Felton, 1998; Scarborough, 1998). Also, a study by Swanson (1986) found strong stability over time in correlations between naming speed and reading – test/retest reliabilities on measures taken one year apart were .79 for color naming speed and .90 for digit naming speed. More recently Schatschneider et al. (2004) assessed the relative importance of multiple measures obtained in a kindergarten sample for the prediction of reading outcomes at the end of first and second grades. Analyses revealed that measures of naming speed along with phonological awareness and letter sound knowledge consistently accounted for the unique variance across reading outcomes. These results provide further support that naming speed is a strong predictor of reading outcomes through second grade.

Some of the most convincing examples of cross-linguistic studies involving RAN further support the predictive RAN-reading relationship in several documented languages. Studies demonstrate that the more transparent the language grapheme-phoneme structure (i.e., the more word pronunciation directly matches spelling), the more closely RAN task performance predicts reading. In one study, Wolf, Pfeil, Lotz, and Biddle (1994), studied a sample of German-speaking poor readers and found not only that naming speed deficits differentiated reader groups, but that RAN task performance was a better predictor of later reading than phoneme deletion tasks. In another study, van den Bos (1998) used correlational methods to analyze the relationship between word identification skills and the reading-related variables of intelligence, phonological awareness and continuous-naming speed in a Dutch sample of school-age children. Findings from this study suggests that although RAN task performance and intelligence factor scores are both significantly correlated with the poor decoders' word identification scores, RAN task performance correlations are significantly larger than intelligence factor correlations. The support for RAN-reading relationships in other languages goes on and has been observed and documented in several other languages including Finnish (Korhonen, 1995), Spanish (Novoa, 1988), and Russian (Chandarina, 2003). Interestingly, as documented in the studies by Wolf et al. (1994) and Chandarina (2003), the cognitive factor of naming speed, as measured by RAN task performance, appears to surpass phonological awareness as the more powerful predictor of reading outcomes, especially in these more phonetically regular languages.

RAN and Reading Fluency

RAN can be viewed as a simple task that measures the efficiency of lower-level processes that are critical to the development of automaticity of word recognition, or fluency (Denckla & Cutting, 1999). RAN measures the ability to rapidly name single visual stimuli, which appears to mirror the slow retrieval of words or word parts found in children with slow naming speed. This disruption in the complimentary phonological and/or orthographic processing for fluent word recognition may lead to the breakdown in reading fluently. Several researchers have investigated naming speed and text reading speed. The focus of this next section will be to examine the empirical support for RAN's connection to reading fluency.

In their early work, Denckla and Rudel (1976) viewed rapid naming deficits as a diagnostic marker of reading disability but without specifying a causal mechanism (see Wolf et al., 1986). Examining the relationship between RAN and different reading skills, Manis, Seidenberg and Doi (1999) suggested that rapid naming is best at predicting unique variance in reading comprehension, word reading latency and reading speed. Rapid naming performance is a weaker predictor of word identification accuracy and a poorer predictor of non-word reading accuracy. Providing support for this, Manis et al. (2000) found that the unique contribution of naming speed to reading was greatest for orthographic skills, and the contribution to phonological skills was greatest for non-word decoding skills. Savage and Frederickson (2005) also argued that rapid naming and phonological processing are distinct contributors to different aspects of reading in poor readers, suggesting that rapid alphanumeric naming is a highly specific predictor of reading rate.

Lervåg and Hulme's (2009) three-year longitudinal study of RAN-reading outcomes provides strong support for RAN's predictive power of later reading fluency. Their study measured young children's RAN performance prior to reading exposure with non-alphabetic stimuli, and found that RAN was a strong predictor of later growth in reading fluency. Further, their study found that RAN continues to exert an influence on the development of reading fluency over several years after reading instruction has started. Meyer et al. (1998) found that RAN has predictive power only for poor readers but not for average readers, suggesting that impaired readers are qualitatively different from the normal-reading population and are not simply the tail of a normal distribution of reading ability. Their findings also suggested that the automaticity of retrieval, not the knowledge of names itself (as in confrontational naming tasks), gives RAN it's predictive power in relation to word reading.

Regarding reading comprehension, several studies have demonstrated RAN's direct and indirect effects on tasks demanding comprehension. Confrontation object naming and object naming speed are better predictors of reading comprehension than other naming speed tasks (Wolf & Goodglass, 1986; Wolf & Obregón, 1992). The added semantic requirements of these tasks contrast with the heavier emphasis on automatic rates of processing in letter and digit naming, and in word recognition. Also, letter and digit naming speed appear to be related to comprehension largely through the shared variance with word identification (Bowers et al., 1988, Spring & Davis, 1988; Wolf, 1991).

In their comprehensive review of RAN's specific relationship to fluency (characterized as orthographic processing), Bowers and Newby-Clark (2002) argued that sufficient empirical data exists to support the RAN - orthographic processing relationship. Further, they provided a review of the data supporting RAN's influence on the development of fluent word reading by stating that gains in reading development with practice (intervention) have been documented to be affected by RAN. Their research suggests that gains in fluency due to practice with individual words or repeated reading interventions can be predicted by RAN even after controlling for baseline fluency levels in students (Bowers, 1993; Bowers & Kennedy, 1993). Similar studies have also reported results consistent with the argument that poor RAN constrains the development of fluency. For example, Levy, Bourassa, & Horn (1999) studied the affects of a fluency intervention on poor readers. In their study, 128 poor readers in second grade were assigned to one of two groups - slower RAN and faster RAN - based on pre-existing testing results. After being exposed to a 20-day training session that involved learning a series of words, the faster RAN children learned the training words more quickly than the slow RAN children. These findings reportedly remained significant even after controlling for pretest reading differences.

In a more recent study, Meisinger and colleagues (2009) explored the diagnostic utility of reading fluency in the identification of children with reading disabilities and examined which cognitive features differentiate children with specific reading fluency deficits from struggling and normal readers. In their sample of 50 students with dyslexia or suspected of reading problems, a group of children emerged with specific deficits in fluency opposed to normal word reading skills. Utilizing established criteria to identify reading problems, 24% of their sample was identified as having specific deficits in reading fluency (20.5 standard score point deficit in fluency on an established measure of reading fluency when compared to a measure of their word reading skills. The results of their study not only suggested that reading fluency measures are more sensitive in detecting reading problems than word reading measures, but also that RAN is an underlying process that plays an important role in determining the rate at which children read connected text. Compared to children with normal reading skills, Meisinger et al. argued that children with deficits in reading fluency were characterized by deficits in rapid naming speed but not in phonological processing, as measured by a phoneme blending task. Their results also supported the identification of a subgroup of children who exhibit specific deficits in reading fluency without concordant deficits in single word reading in isolation or in decoding unknown words ("double-deficit" reading disability subtypes).

Bowers, Wolf, and colleagues (Bowers & Wolf, 1993; Bowers et al., 1994; Wolf et al., 2000) believe that RAN may be a marker of difficulties in orthographic, rather than phonological, processing. If naming letters proceeds too slowly, letter representation in words will not be activated in sufficiently close temporal proximity to induce sensitivity to commonly occurring orthographic patterns, resulting in poor word reading fluency. For example, if a child is slow in identifying individual letters, representations of single letters in a word will not be activated quickly enough to allow sensitivity to letter patterns that occur frequently in print. These children could have difficulty forming memory representations of letter patterns in words and, therefore, may develop poor sight vocabulary processing skills. Similarly, Manis et al. (1999) agreed with the role of orthographic processing but suggested that instead of timing, the critical property of RAN tasks is that the relationship between the symbol and name is arbitrary. They believed that the RAN-reading relationship should be stronger when reading involves more arbitrary orthography-to-phonology mappings, as in reading "exception" words (words with irregular phonological patterns) versus reading phonetically regular words. (i.e., RAN predicts reading better when reading irregular -exception- words, rather than reading regular -phonologically consistent- words). This argument suggests that RAN task performance may be consistent with the "lexical route" to developing fluent reading; reading more holistically, which may help explain RAN’s specific relationship with reading fluency.

In a study investigating the contributing links of general and specific cognitive ability to reading achievement, Benson (2008) utilized the data set from the Woodcock-Johnson III Tests of Cognitive Abilities and Tests of Achievement (Woodcock, McGrew, & Mather, 2001, 2007) to determine the relationship between reading achievement and cognitive abilities. Benson’s study included a reading fluency measure in developing a causal model of reading. His study also included a subtest measuring the RAN construct, notably Naming Facility, a narrow ability in the CHC taxonomy that measures speeded recall of previously learning information. Benson's results suggested that processing speed had a direct effect on reading fluency that increased as the grade level increased. A noted limitation of this study was that only a single measure of reading fluency was included in his model, and only one measure of RAN (picture naming) was included in the analysis. Moreover, reading fluency is often measured by recording the number of words correctly read (e.g., rate and accuracy of timed oral reading). The reading fluency indicator used in this study measures silent reading fluency and requires children to quickly read a series of statements for three minutes and indicate if they are true or false (i.e., involves comprehension).

Studies also suggest that the relationship between RAN and reading appears to vary as a function of the type of RAN task used (i.e., alphanumeric vs. non-alphanumeric) and the type of reading outcomes measured (e.g., accuracy, fluency, comprehension) (Georgiou, Parrila, Kirby, & Stephenson, 2008). Although studies have documented a relationship between non-alphanumeric naming (color and picture naming) and reading (Wimmer & Mayringer, 2002; Wolf et al., 1986), findings suggest that the RAN- reading relationship is stronger when letter and digit naming, as opposed to color or object naming, is used as a measure and reading and when reading speed as opposed to accuracy is used to measure reading ability. (e.g., Compton, 2003; Compton et al., 2002; van den Bos et al., 2002). However, it is not well established which of the RAN tasks are most associated with reading fluency performance in students who experience reading difficulties. Existing studies (e.g., Benson, 2008; Vaessen & Blomert, 2010) addressing the RAN/reading fluency connection have not included all RAN tasks, or not specifically used samples of children with reading difficulties. This leads one to speculate on the relationship between various RAN tasks (i.e., letters, digits, pictures, and colors) and reading fluency performance. Based on the existing literature, it appears necessary to evaluate a model that includes all aspects of the RAN task and reading fluency with children suspected of reading difficulties.

In summary, much evidence has been offered that provides support for RAN's specific relationship to reading fluency. In particular it appears that RAN's influence begins early in child development and influences the development of fluent reading even before formal reading instruction begins (Lervåg & Hulme, 2009). RAN's influence on reading development becomes more important as students grow in reading skills when the demands of fluency and comprehension increase with increases in grade level (Kirby et al., 2003; Manis et al., 1999). Recent studies summarized in this review also reveal that the relationship between RAN and reading may vary as a function of the type of RAN task used and the type of reading outcome measured. Although more research is needed, alphanumeric RAN performance appears to be more strongly related to reading fluency skills and development and less so with word identification accuracy. Further, Bowers and Ishaik's (2003) review of recent RAN findings indicates that RAN appears to be highly related to fluent reading and also demonstrates relationships to reading accuracy different from phonological awareness. Weaknesses associated with the cognitive components of the RAN construct may reflect disruption of the low-level automatic processes that support the induction of these orthographic patterns. It has been suggested that RAN may be more related to reading fluency through these similar mechanisms which help establish these orthographic representations or the bridge to developing fluency.

Summary of RAN Research

There appears to be much support regarding the correlational and predictive nature of the RAN task to reading and its ability to differentiate between good and poor readers. Notwithstanding this evidence, significant debate remains around the conceptualization of RAN as an independent deficit. Further, there remain many important questions about the cognitive nature of performance on the RAN task that underlies its strong association to reading performance. Several researchers have argued, as mentioned previously in this paper, that psychometrically speaking, RAN and phonological processes are best seen as reflecting aspects of an underlying phonological processing variable, and that additional RAN effects are, at best, modest (Pennington, Cardoso-Martins, Green, & Lefly, 2001; Torgesen et al., 1994; Torgesen et al., 1997). A second broad challenge to the RAN construct comes from research suggesting that RAN can be subsumed under a general processing speed factor that determines all processing efficiency in children (Catts et al., 2002; Kail & Hall, 1994; Kail et al., 1999). These researchers argue that once general processing speed is considered in a model predicting word reading skills, RAN no longer predicted unique variance in reading skills. With these questions in mind, this paper will now turn to an examination of the components of the RAN construct to further elucidate their specific relationship with readings skills, and their relationships with other cognitive processing factors.

Cognitive Components of RAN

The complexity of the task demands in RAN – the need to perform a series of efficient cognitive tasks – is comparable to the complexity of reading itself. Therefore, it is unlikely that some single universal mechanism will be responsible for making RAN work the way it does. Despite the overwhelming success of the findings that show that RAN is a simple, yet powerful task that helps identify dyslexia and other reading difficulties, our understanding of why dyslexic individuals display these deficits is still limited. As researchers in this area have argued (Denckla & Cutting, 1999; Wolf, 1991, 1999; Torgesen et al., 1997), the more we are able to unfold the components of RAN, the greater our chances of determining the shared relationship with reading. In spite of

RAN's simplicity, RAN is a cognitively highly complex task requiring the coordinated interplay of a number of different cognitive processes (Willburger, Fussenegger, Moll, Guilherme Wood, & Landerl, 2008). Given the robust relationship between continuous-trial RAN tasks and reading outcomes, as mentioned earlier in this paper, research has attempted to unravel the multi-component nature of RAN; those combined processes that, when taken together, formulate the most powerful relationship to reading skill development and reading outcomes.

Previously, research focusing on the multiple components of RAN has examined the orientation of the task – discrete vs. serial task performance. As discussed, reading skill development is more strongly related with RAN task performance when the task is presented in the serial fashion format. Wolf (1999) argues that performance on RAN tasks include a range of attentional, perceptual, cognitive, phonological, semantic, and articulatory processes, and further states that only when a true multi-dimensional model of these processes is understood will we be able to appropriately match remedial efforts to individuals. The reason why RAN is not well understood is due to its complexity (Bowers & Newby-Clark, 2002; Cutting & Denckla, 2001); according to Wolf and Bowers (1999), RAN (especially for letters and numbers) requires a variety of linguistic and cognitive processes, which include:

> (a) attention to the letter stimulus; (b) bihemispheric, visual processes that are responsible for initial feature detection, visual discrimination, and letter and letter-pattern identification; (c) integration of visual feature and pattern information with stored orthographic representations; (d) integration of visual information with stored phonological representations; (e) access and retrieval of phonological labels; (f) activation and integration of semantic and conceptual information; and (g) motoric activation leading to articulation. Precise rapid timing is critical both for the efficiency of operations within individual subprocesses and for integrating across them (p. 418)

Because of the complexity of RAN, exactly how, or by which processes, it has an influence on reading is not well understood. Different hypotheses about RAN and its relationship to reading, as well as other predictors of word reading have been offered. For example, phonological factors have been proffered to explain RAN (e.g., Torgesen et al., 1997), attentional/executive processes have been offered (e.g., Clarke, Hulme, & Snowling, 2005; Denckla & Cutting, 1999), processing speed (e.g., Kail et al., 1999), and behavioral components have been investigated (e.g., Georgiou et al., 2008). However, the two most studied areas include both RAN's relationship with and independence from phonological factors and processing speed factors.

Phonological Processing

There has been ongoing debate as to whether RAN deficits add a unique contribution to the prediction of reading outcomes after controlling for phonological awareness. Does RAN simply measure the speed to which one accesses phonological information stored in memory, or phonological processing? Or does RAN measure unique cognitive processes that make it such a simple, yet effective tool to identify reading problems? The extant literature does not offer a simple answer to these questions - the debate clearly continues, and more work needs to be done in order to extricate these two cognitive constructs.

Consistent with the phonological theories of dyslexia, Wagner, Torgesen and their colleagues (Wagner & Torgesen, 1987; Torgesen et al., 1997) proposed that RAN tasks are an index of the speed with which phonological information can be accessed from memory, or speed of lexical access, and are best described as an aspect of phonological processing, in other words a linguistic skill. This conjecture is shared by other researchers

(Savage & Frederickson, 2005; Wagner et al., 1993) as well and continues to place RAN performance as a component of phonological processing. Certain researchers (Wagner & Torgesen, 1987; Torgesen et al., 1997), as mentioned, did not find such a strong relationship between reading sub-skills and independence of RAN. Their findings support the RAN - reading relationship during the early stages of reading development. In later grades, however, only phonological awareness made a unique contribution to reading performance. Torgesen et al. (1997) provided additional support to this argument. In their longitudinal study with older children, when “autoregressive” (entering reading first into a regression equation) effects were included in the analysis, RAN performance did not predict any unique variance in any reading measures they used, whereas phonological awareness did predict unique variance. Further, some studies have reported modest but substantial degrees of overlap between RAN and phonological awareness claiming RAN to be essentially a phonological variable (Hammill, Mather, Allen, & Roberts, 2002). For example, Kirby et al. (2003) found a correlation of .47 between RAN and phonological awareness, Schatschneider, Carlson, Francis, Foorman, & Fletcher (2002) found a correlation of .44, and a correlation of .38 was found by Hammill et al. (2002). Given that the degree of overlap is moderate, it does suggest that RAN is a construct that may be measured separately from phonology. Also, some researchers (e.g., Wolf et al., 2002) have argued that unselected sampling techniques and limited developmental ranges were used in studies that report weaker RAN - reading relationships. Further possible is that due to the limited number of students with significant reading disabilities included in these studies, the impact of RAN on the performance of children with reading disabilities was not fully appreciated.

In contrast, Wolf and Bowers (1993; 1999) argue that RAN task processes are independent of phonological processing, and that the simultaneous presence of both deficits leads to the most severe cases of dyslexia. Wolf and Bowers (Wolf & Bowers, 1999) propose that the cognitive deficits leading to poor RAN performance affects reading by disrupting the quality of orthographic representations and the forming of links between orthographic-phonological representations critical to successful reading performance. The term "orthographic processing" as defined by Burt (2005), refers to the ability to form, store and access orthographic representations, and is typically measured by assessing a child's success in learning unfamiliar word-like letter strings. Many studies examining RAN's relationship with reading have compared RAN task performance to different aspects of reading. Although the phonological route, which involves phonetic decoding and word reading accuracy, are well understood, additional attention in the RAN research has focused on the tasks affect on orthographic processing. The dual-route theory of reading acquisition (Coltheart & Rastle, 1994) suggests that the learning-to-read process may involve two pathways. The first is the sub-lexical route, which relies on the serial mapping of letter sounds (i.e., reading pseudowords). The second is the lexical route, which relies on orthographic processing -printed words or representations are stored and retrieved during the reading process. Therefore, it stands to reason that if poor RAN performance disrupts both the quality and the formation of the links between orthographic-phonological representations, as Wolf & Bowers claim, then RAN performance may be instrumental in the acquisition of reading skills through this lexical route. This argument also provides support for RAN's unique contribution to the acquisition of reading skills.

Much of the evidence supporting the claim that RAN makes a unique contribution to reading stems from the hierarchical regression analyses providing support for this argument (Bowers, 1995; Compton et al., 2001; Manis et al., 2000). In studies conducted by Bowers and colleagues (Bowers & Swanson, 1991; Bowers, 1995), they were concerned with whether phonological awareness and RAN were related to different aspects of reading skill. In a study (Bowers, 1995) of average and poor readers, grades second through fourth controlling for oral vocabulary skills, phonological awareness and RAN contributed shared and unique variance to word recognition. RAN's strongest, unique contribution to latency of correct word identification (reading speed), as well as comprehension, contrasted with the less significant unique contribution of phonological awareness to these measures. RAN's contribution to comprehension, an interesting finding, was explained through the association with reading speed.

In another related study Manis et al. (2000) studied 85 children assessed at the end of their second grade year on various measures of reading skills, phonological awareness, and RAN. Hierarchical regression analyses provided additional evidence for RAN's independent contribution to reading. Their results provide additional support that RAN is more related to knowledge of orthographic patterns than to phonological decoding skills. Although RAN is found to be related to both learning to read unfamiliar words and factors associated with reading speed, findings from these studies suggest RAN is more strongly related to speed of correct word recognition (Bowers & Ishaik, 2003). Bowers and Kennedy (1993) found that RAN associated not only with initial fluency but also with gains in reading fluency after practice.

There is further research supporting RAN's dissociation with phonological processing (Cutting & Denckla, 2001; Catts et al., 2002; Neuhaus et al., 2001; Powell et al., 2007). Swanson and his colleague's (Swanson et al., 2003) meta-analysis of the correlation research, perhaps, provides the strongest support of the dissociation, although their findings did find a modest correlation between phonological awareness and RAN. Regardless, strong evidence continues to support the dissociation between RAN and phonological processing as demonstrated by a number of correlational studies supporting RAN's unique contribution to the prediction of reading skills in poor readers (Ackerman & Dykman, 1993; Blachman, 1984; Felton et al., 1990; Manis et al., 1999) and in normal readers (Cutting & Denckla, 2001). In poor readers the relationship appears to be stronger and to endure longer through development (McBride-Chang & Manis, 1996; Meyer et al., 1998; Kirby et al., 2003). However, as mention previously, the independence of RAN has also been found in studies of normally developing readers (Cutting & Denckla, 2001). Unlike phonological awareness, RAN appears to be more strongly related to these aforementioned orthographic skills, while phonological awareness appears to be more related to phonetic decoding. Bowers and Ishaik (2003) also provide evidence that find RAN is more highly related to poor performance on reading (beginning readers, dyslexics) than average to skilled readers. Most notable, RAN plays a larger role in distinguishing dyslexics from normally achieving readers in languages other that English, where high regularity in sound-symbol correspondence, orthographic consistency, and easier decoding are present and are less reliant on phonological awareness (Wimmer & Goswami, 1994).

Overall, primary researchers (Bowers & Wolf, 1993; Wolf & Bowers, 1999; Wolf et al., 2002) claim that RAN measures processes that are not fully understood, and that are important for reading other than those that involve phonological processing. Support for their argument comes primarily from three areas of support: 1) Hierarchical regression analyses demonstrate that when phonological awareness is partitioned out, RAN continues to make a significant contribution to reading development; 2) low correlations between RAN and phonological awareness; and 3) language systems involving regular orthography support RAN as a more important factor predicting successful reading (Bowers et al., 1994; Bowers & Ishaik, 2004; Wolf et al., 2000; Wolf & Bowers, 1999).

In summary, the equivocal nature of these rival theories explaining RAN's relationship to reading emphasizes the fact that many questions remain regarding RAN's impact on reading. The mixed findings concerning RAN's relationship to reading sub-skills and the apparent time-limited inter-relations described between RAN, phonological awareness, and reading have confounded causal explanations of these relationships (Cutting & Denckla, 2001). Although the debate ensues, researchers such as Wolf et al. (2002) continue to argue that subsuming other possible explanatory processes under a phonological rubric minimizes the importance of other factors in explaining the heterogeneity of poor readers.

General Processing Speed

Not all researchers' support the claim that performance on RAN tasks is restricted to the phonological system. Kail and his colleagues (Kail & Hall, 1994; Kail et al., 1999) argue that RAN performance deficits reflect weakness in generalized processing speed.

According to Kail and colleagues, the relationship between RAN and reading reflects the gradual increase in processing speed children develop as a result of their development. In Kail's view, the relationship between RAN and reading is explained by the same underlying factor - general processing speed. Support for this claim comes from evidence Kail and colleagues (Kail et al., 1999) proffered examining age-related changes in reading. In their study, naming times were predicted by age-related change in processing time but not by reading experience, resulting in their claim that the RAN - reading relationship is explained by these developmental changes in generalized processing speed. Catts et al. (2002) provided additional support for this argument. Their results suggested that RAN explained minimal variance in reading after general processing speed measures were entered into a regression analysis. However, other studies have found dissimilar results; Scarborough and Domgaard (1998) found no relationship between RAN and processing speed tasks as operationalized by the visual scanning speed tasks, motor speed tasks, and visual search speed tasks. However, their study has been criticized citing problems with the measures utilized and some suggestion that the sample used in their study may have had language and/or reading impairments (Cutting & Denckla, 2001). Further, the studies by Kail (1994) and Catts et al. (2002) have been criticized in the literature as a result of using samples of older readers and an over-representation of language-delayed readers. Many older children will have made rapid naming automatic, which would reduce the available naming speed variance. Also, color naming (as opposed to alphanumeric naming) tasks were used in these studies, which evidences a weaker relationship with reading performance than the more robust alphanumeric variable (e.g., Van Den Bos et al., 2002).

In an attempt to corroborate the seemingly conflicting results surrounding processing speed role as a component of RAN, Cutting and Denckla (2001) studied these two variables within an exploratory model of word reading. RAN, phonological awareness, and orthographic knowledge were all found to have direct effects on word reading, whereas memory span did not. RAN had no direct effects on phonological awareness, further supporting that RAN and phonological awareness should be considered separately with respect to reading. Processing speed factors were found to contribute directly to RAN (also memory span, phonological awareness, and orthographic knowledge). Processing speed was also strongly related to RAN, and its relationship to reading was strengthened through its strong association with RAN. Interestingly, processing speed did not account for the variance associated with RAN and word reading in their model. Cutting and Denckla acknowledged several limitations of the study including a narrow age range sample of average readers. Argued was that further studies should include larger sample sizes with poor readers. Also, the model developed was not longitudinal in format, only providing preliminary causal relationships in word reading.

In a similar study, Catts et al. (2002) investigated whether processing speed's contribution to understanding RAN's relationship to reading was due to more specific cognitive processing factors, or whether the relationship reflected more general processing speed slowness, as suggested by Kail and colleagues (1994; 1999). In their study of 279 good and poor third grade readers, measures of response time in motor, visual, lexical, grammatical, and phonological tasks were administered and measures of rapid object naming, phonological awareness, and reading achievement were given to the same group in second and fourth grades. Findings further suggest that many children experience a deficit in speed of processing, however the nature of the deficit remains unclear. Important to note is that this study used RAN - object naming, rather than the RAN - letter/digit naming task used in the Cutting & Denckla (2001) study. Their study did, however, suggest that poor readers may have a domain general deficit in speed of processing - RAN of objects tasks failed to contribute unique variance in reading after IQ and response time tasks were considered. Although the study supported the theory that RAN tasks explain variance in reading, they surmised that this relationship is explained through RAN's association with general processing speed. Processing speed (as measured by response time tasks), subsumed by IQ, and processing speed alone (controlling for IQ) contributed significantly to reading skills in their study. As mentioned, their study was limited by the use of only RAN-object naming; perhaps varying results could have been discovered if a measure of letter/digit (alphanumeric) naming was included in their study.

Given the mixed results demonstrated by these studies, if the non-phonological factors associated with RAN object naming in individuals with dyslexia is explained by general processing speed, as the above mentioned studies suggest (e.g., Catts et al., 2002; Kail et al; 1994; 1999), then perhaps the underlying factors associated with RAN letter/digits is explained, in part, but something unique. Perhaps RAN's relationship with reading varies as a function of the type of RAN task used (alphanumeric vs. non-alphanumeric) as these and many other studies suggest (Manis & Doi, 1995; Savage & Frederickson, 2005; Stringer et al., 2004). Does the alphanumeric naming (as opposed to object naming)- reading relationship extend beyond the generalized slowing found in object naming studies to include more specific timing factors?

Considerable evidence exists that suggests that the processing specific to letter-naming adds significantly to word recognition over phonological skills (Neuhaus et al., 2001; Neuhaus & Swank, 2002; Wolf et al., 2000). Neuhaus and colleagues (2001) found strong relationships between measures of naming speed —letter processing speed— and fluency. These researchers speculated that the pause time for letters measured processing speed specifically associated with letters and that pause time for objects measured a more general processing speed factor. Their findings suggested that letter pause time was the most robust predictor of reading as measured by decoding and comprehension tasks. Their findings supported the argument that this relationship (pause time for letters and reading) was found to be associated with the unique demands of letter processing rather than the result of general processing speed. This argument has been replicated by many other studies further supporting this important finding (e.g., Denckla & Cutting, 1999; Georgiou, Parrila, & Kirby, 2006; Georgiou et al., 2008).

Bowey and colleagues (2004) examined the merits of Kail and colleagues (1994; 1999) general processing speed account and the orthographic processing speed account (Bowers & Wolf, 1993; Wolf & Bowers, 1999) of the association between RAN and word reading skill. They questioned whether naming speed would predict independent variance in word reading after controlling for the effects of age and general processing speed. Bowey et al. theorized that in contrast to the general processing speed count, which does not differentiate between different aspects of processing speed, the orthographic processing speed account may produce different predictions for measures of general processing speed and naming speed depending on whether or not processing involves alphanumeric symbols. They hypothesized that, with the effects of age and general processing speed controlled, processing speed associated with alphanumeric symbols (i.e., orthographic processing speed) would still explain significant variation in word reading skills. In order to test their hypothesis, they examined general processing speed ability, both alphanumeric and non-symbol (colors and animals) RAN and word reading skills in a sample of 125 fourth through sixth graders with age-appropriate reading levels. According to their results, general processing speed explained only 5.3% of the variation in word reading skills, and was not able to explain individual differences in reading ability once the effects of age were controlled. In contrast, RAN explained a further 11% of variation in word reading when both age and general processing speed effects were controlled. Their findings suggest that, within this limited age range, the association between RAN and word reading is unlikely to reflect the contribution of general processing speed.

In addition to providing evidence challenging Kail's argument, Bowey et al. (2004) also examined the orthographic processing speed account - whether alphanumeric RAN is a stronger predictor than general speeded naming tasks. After controlling the effects of age and RAN tasks involving non-symbol items, alphanumeric RAN performance explained a further 13% of the variance in word reading. Their findings provide additional support for the suggestion that alphanumeric RAN performance contributes substantially to word reading. Further, the results of their principal components analysis examining the independent variables revealed a clear separation of the general processing speed measures (factor I) and all RAN measures (factor II). The results of this study provides additional support for the argument that the RAN construct taps cognitive processing beyond what is explained by general processing speed, and that these two constructs can be measured separately. Further, alphanumeric RAN appears to contribute substantially to word reading skills, although non-alphanumeric RAN was still found to be a significant predictor of word reading skills in their model. Although Bowey et al.'s study included a broad range of general processing speed and RAN measures, only single word reading and decoding skills were used as outcome measures in their study. Additionally, their study was limited by the use of a sample with a narrow age range of normal readers, where RAN effects have be demonstrated to be stronger in poor readers (Meyer, et al., 1998).

Powell and colleagues (2007) also investigated Kail et al.'s (1999) proposal by studying which aspects of processing speed underlie its relationship to reading. A total of 160 children were selected from a larger sample of third and fourth graders to form two experimental groups: a low RAN group and a group of matched controls. Half of these children (37 in Year 3 and 43 in Year 4) comprised a low RAN group, and were those who were identified through a screening procedure as having a single RAN deficit (RAN performance at least 1 SD below the mean and phonological awareness not less than 1 SD below the mean). The remaining 80 children (37 in Year 3 and 43 in Year 4) formed a control group and were selected from a no-deficit group (both RAN and phonological awareness scores not less than 1 SD below the mean). In their study, children with single alphanumeric RAN (letters and digits) deficits (as opposed to single phonological deficits and/or double deficits) showed slower speed of processing and slower speeds on simple reaction time tasks than did closely matched controls performing normally on RAN measures, providing support for existing studies. However, hierarchical regression analyses revealed that even when processing speed and simple reaction time were entered first into a regression equation, RAN was still a significant predictor of reading, accounting for a unique 17% of the variance in reading scores (Powell et al., 2007). Given these results, processing speed, although a component of the RAN construct, did not completely account for the relationship between RAN and word reading. An acknowledged limitation of their study was the use of single word reading as the outcome measure - larger effects, they conclude, might have been found on measures of reading fluency, given that performance on RAN is strongly related to fluency (Bowers, 1995; Morris et al., 1998; Pennington et al., 2001). This study will investigate RAN's relationship with reading fluency while controlling for the influence of general processing speed.

An interesting finding supported by this study is the differentiation between simple and choice reaction time tasks utilized in their study. Simple reaction time (as measured by the time to make a computer key press following the appearance of a target stimulus) as opposed to choice reaction time (as measured by the time to make a computer key press after making a decision regarding two target stimuli) related to RAN, but not reading. However, choice reaction time (and processing speed) measures related to both RAN and reading. It appears the introduction of decision making (and other additional cognitive processes involved in choice reaction time tasks) may offer additional insight into the underlying components (or shared components, for that matter) of RAN and processing speed.

Limitations of these existing studies (e.g., Bowey et al., 2004; Powell et al., 2007) suggest that while processing speed does predict a small but significant portion of the variance in reading, their studies included only one measure of word reading and no measures of fluency. Although these studies provide some support for the argument that while general processing speed is related to RAN performance, these results suggest it does not fully account for the relationship between RAN and reading. This suggests that the rate-limiting factors associated with poor RAN performance may share both general cognitive recognition efficiency and identification and retrieval performance aspects, and, more specifically, may reflect the efficient retrieval of alphanumeric information. Another question that will be investigated by the current study will be to further explore the relationships among processing speed and reading fluency and different RAN tasks involved in predicting reading fluency. By addressing this question in the current study, it can be determined whether RAN deficits represent a more general slow speed of processing, or whether RAN deficits are related to slowness specific to letters/numbers that hampers the development of fluent reading.

Summary and Conclusions

To summarize, the question about what cognitive components are responsible for the strong relationship between RAN task performance and reading development is still debatable and requires more research. Despite the acknowledged importance of RAN in predicting reading, there is still no consensus as to what cognitive process or processes are driving the relationship between RAN and reading. There remain many important questions about the cognitive nature of performance on the RAN task that underlies its strong association to various aspects of reading performance. The research presented in this chapter indicates that, much like the reading process itself, many different factors play a role for successful naming ability. Although phonological and processing speed factors are important to RAN performance, it remains unclear whether their impact underlies the association between RAN and other aspects of reading, namely reading fluency.

While this growing body of literature suggests that RAN is a distinct factor important to the development of reading fluency skills, there is a need to further examine this relationship to determine its specific relationship with reading fluency. The empirical literature suggests that RAN effects are more robust for alphanumeric (letter and digit) naming over more general (picture and object) naming tasks (e.g., Compton, 2003; Van Den Bos et al., 2002). However, it is not well established which RAN task is most predictive of reading fluency performance in children with reading difficulties.

Additionally, the relationships among RAN, general processing speed, and reading have not been thoroughly investigated. Although a burgeoning body of evidence suggests that RAN and general processing offer unique connections with reading, this relationship has not been investigated in a sample of children with reading difficulties. Additionally, the limitations of existing studies inhibit our ability to further understanding this relationship with reading fluency due to the focus on word reading skills. Considering the acknowledged importance of reading fluency development, a better understanding of the cognitive components of fluency provides clinicians with useful information for assessment selection and designing evidence-based interventions.

Chapter III: Method

The current study investigates the relationships among distinct aspects of rapid automatized naming ability (RAN), phonemic awareness, general processing speed, and reading fluency in a purposeful sample of clinic referred children. Specifically, this study investigates whether RAN explains reading fluency performance beyond phonemic awareness and phonics in this sample of clinic referred children. Additionally, this study seeks to determine which RAN tasks (alphanumeric or non-alphanumeric) are most predictive of reading fluency and whether RAN performance explains further variance in reading fluency beyond general processing speed. The purpose of the chosen design is to determine the correlation between performance on RAN tasks on the chosen sample, as well as measure the distinct contribution of RAN performance, phonemic awareness, and processing speed to reading fluency performance in students who demonstrate reading difficulties.

Participants

A clinic-referred sample from a university-based reading clinic was selected as the participants for the current study. The 79 participants for the study were referred to the reading clinic by local schools or their parents for reading difficulties. The participants in this study included both male and female students aged 7.25 years to 15.5 years with an average age of 10 years. No exclusionary criteria for the study were applied; all participants seeking evaluation through the reading clinic were included in the study. However, for the purposes of this study, only individuals whose fluency performance was average or below were included in the final analyses. As a result, the final sample contained 64 participants that met this criterion.

An a priori power analysis was completed using G*Power (Faul, Erdfelder, Lang & Buchner, 2007) in order to determine the required sample size for detecting significance in an F-test of multiple regression analysis and to develop a prediction equation that is generalizable. Utilizing Cohen's (1988) guidelines to detect a moderate effect size in a multiple correlation or multiple regression analysis, the power analysis effect size was set at .25. The significance level was set at .05, using a moderate power level of .70 with three predictor variables. It was determined that a total sample size of 62 ($n = 62$) would be necessary. Such a required sample size indicates that the sample size chosen for the subsequent analyses is adequate.

Measures

Rapid Automatized Naming

The Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) was used to assess the participant's continuous naming ability of the various stimuli on the testing, namely letters, digits, colors, and objects. The CTOPP was designed as an assessment of phonological awareness, phonological memory, and rapid naming for identifying individuals who perform below their peers in phonological processing ability. It was developed to identify individuals who are performing poorly on phonological processing, to determine individuals' strengths and weaknesses with regard to phonological processes, to document the progress of interventions in phonological processing, and to be used as a research instrument for studies examining phonological processing abilities (Wagner, et al., 1999). The non-alphanumeric tasks included the Rapid Color Naming (RC) task and the Rapid Object Naming (RO) task, while the alphanumeric tasks were measured by the Rapid Digit

Naming (RD) task and the Rapid Letter Naming (RL) subtest. 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.

Each of the four naming tasks (letters, digits, colors, and objects) use a picture book format that contains 72-items displayed on two different pages. Each of the pages contains four rows and nine columns of stimuli (i.e., colors, objects, digits, and letters) that are administered in a continuous format. The examinee is instructed to name the stimuli starting on the top row, from left to right, moving to the next row without stopping until all stimuli are named on the page. After the examinee completes the first page, he or she is instructed to follow the same format on the second page. The score is derived from the total number of seconds taken to name all the stimuli on both pages. The CTOPP provides scaled scores for each of the RAN tasks, which have a mean of 10 and a standard deviation of 3, whereas other measures used in this study produce standard scores with a mean of 100 and a standard deviation of 15. Therefore, a linear transformation was used to convert the CTOPP RAN scaled scores to standard scores having a mean of 100 (SD = 15) to facilitate comparisons across measures.

Reliability and Validity of the CTOPP (RAN). According to the test manual, three sources of test error were calculated to determine the reliability of the CTOPP: content sampling, time sampling, and interscorer reliabilities. Content sampling refers to test error associated with the degree of homogeneity among items within a test of subtest. Testing error due to time sampling refers to the extent to which an examinees test performance is constant over time, typically estimate by the test-retest method; and interscorer reliability estimates the error due to examiner variability in scoring the test (Wagner et al., 1999). The reliability of the items on the CTOPP subtests, except for the rapid naming subtests, was estimated using Cronbach's (1951) coefficient alpha, whereas an alternate-form reliability procedure was used to estimate error due to content sampling for the timed tests (rapid naming subtests). Measures of reliability for speeded tests have special circumstances and are not typically investigated using Cronbach's coefficient alpha. Instead, alternate-form reliability is the recommended approach to assess the consistency of the instrument (Anastasi & Urbina, 1997). Across these sources of test error, each of the CTOPP subtests demonstrates adequate reliability in the .77 to .90 range. The rapid naming subtest alternative-form reliability average .87 for digit naming and .82 for letter naming across 14 different age ranges. The reliability of the rapid naming subtests is based on the entire sample and not a partial sample of the CTOPP norming sample.

The Rapid Naming composite consists of four speeded core subtests: (a) Rapid Digit Naming (72 items) measures the speed at which the respondent names strings of six digits randomly arranged in a 4x9 table; (b) Rapid Letter Naming (72 items) presents strings of six letters to be reported, randomly arranged in a 4x9 table; (c) Rapid Color Naming (72 items) measures the speed at which the respondent identifies a series of blocks with different colors; and (d) Rapid Object Naming (72 items) presents a series of six objects, randomly arranged in a 4x9 table, to be named as quickly as possible. Specific to the four RAN tasks, the test manual reports adequate reliabilities between .79 and .99 for the chosen age range for this study. Alternate-form reliability for the Rapid Color Naming subtest was in the .76-.86 range for the chosen sample and the Rapid

Object Naming subtest was in the .79-.84 range. For the alphanumeric subtests, the Rapid Digit Naming subtest was in the .84-.90 range and the Rapid Letter Naming subtest was in the .70-.85 range for the chosen age range. Additionally, test-rest reliabilities of the RAN tasks indicate correlation coefficients ranging between .72-.97 on a selected sample as reported in the test manual for the age range of the chosen sample. This data suggests that the CTOPP rapid naming subtests either met or exceeded the recommended reliability coefficient of .80, with some subtests approaching the most desirable level of .90 (Anastasi & Urbina, 1997).

Based on evidence provided in the test manual reporting a variety of validity studies, the CTOPP is considered a valid measure of phonological processing including rapid naming. The RAN tasks of the CTOPP are considered faithful interpretations of the continuous trial format of Denckla and Rudel's (1974) classic RAN task. Validity evidence for the CTOPP comes from the assessment of traditional indicators including content, criterion-related, and construct validities. With regard to content validity, each of the subtests that comprise the CTOPP has been used in research paradigms examining phonological processing over the past two to three decades. The RAN paradigm utilized by the authors of the CTOPP have been replicated by various researchers demonstrating it's ability to predict reading including Bowers et al., (1988); Bowers and Swanson (1991); McBride-Chang and Manis (1996); and Wolf et al., (1986) among many others.

A series of comparison studies was conducted using the Woodcock Reading Mastery Test - Revised (WRMT-R; Woodcock, 1997) and the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) to examine the criterion-prediction and concurrent validity of the CTOPP RAN subtests in a school-age sample. In a sample consisting of 164 students from kindergarten, second, fifth, and seventh grade, rapid naming tasks were found to be correlated with the letter-word identification subtest from the WRMT. The correlation of .62 between word identification and rapid digit naming was moderate, providing support for the criterion-prediction validity of the test. Similarly, modest to strong correlations were reported between RAN measures of the CTOPP and the sight word efficiency subtest of the TOWRE, with correlations ranging from .33-.54.

Construct validity was supported using confirmatory factor analyses. A three-factor solution for the normative sample yielded (a) Phonological Awareness made up of the Elision, Sound Matching, and Blending Words subtests; (b) Phonological Memory, which includes Memory for Digits and Nonword Repetition; and (c) Rapid Naming, Rapid Color Naming, and Rapid Object Naming. Evidence to support RAN's independence from phonological processing is provided by these analyses. Confirmatory factor analysis revealed smaller correlations between rapid naming and phonological memory (.38) and phonological awareness (.38). In stark contrast, a correlation of .85 was obtained between phonological awareness and phonological memory. These results suggested that rapid naming speed was partially correlated with phonological processing (i.e., phonological memory and phonological awareness), however other factors appear to underlie it relationship with reading.

An analysis of group differentiation or group membership provided by the test manual also offers support for the CTOPP's construct validity relevance. Relevant to this current study was how rapid naming measures differentiated between an identified learning disabled group and the normative group. In a separate analysis of 67 children with reading disabilities, a mean derived score on the rapid naming subtest was 84.2 in comparison with the normative sample's mean rapid naming score of 102.1. Additional studies were offered that demonstrate the differentiation between children with reading disabilities and children with average reading skills. In a sample of students from first through ninth grade who met criteria for reading disability and a control group matched on age and grade without reading deficits, significant group differences on rapid naming performance was established. Students with reading disabilities in this study have a mean score of 92 when compared to matched control's mean score of 103. The results of these studies, and others, further the original argument (Denckla & Rudel, 1976a) that RAN's influence on reading is stronger in students with demonstrated reading difficulties when compared to students without reading difficulties.

Phonemic Awareness

Phonemic awareness was measured using the Phonological Awareness cluster of the CTOPP. The Phonological Awareness cluster was standardized on the same representative sample as the RAN subtests of the CTOPP. For the age range used in this study, the Phonological Awareness cluster consists of the scaled scores from two core subtests that are considered relevant to reading instruction. The first is the Elision subtest, a 20-item subtest that requires the examinee to repeat aloud a target word, then provided with a sound(s) to remove, and asked to then say the word without the sound(s). For the first two items, the examiner says compound words and asks the examinee to say that word, then say the word that remains after removing one of the compound words. For the remaining items, the subjects listen to words and remove smaller word segments including syllables and individual phonemes. The test is discontinued when a participant answers three consecutive items incorrectly or reached the last item. A raw score is calculated by summing all correctly answered items; this score is then converted to a scaled score for normative comparisons.

The second task that comprises the Phonological Awareness cluster is the Blending Words subtest. The Blending Words subtest was standardized on the same sample as the Elision and RAN subtests. It is one of two tasks comprising the CTOPP phonological awareness construct and, together with Elision, comprises the construct for those seven years and older – the age range that will be used in this study. Elision is also a 20-item subtest that measures an individual's ability to combine sounds to form words. This test requires subjects to listen to a list of sounds from an audiocassette recording, and then combine these sounds into an actual word. Length and word difficulty increase throughout the test. This test is discontinued when a subject incorrectly recalls a word on three consecutive items. All words blended correctly are summed to obtain a raw score, which is then converted to scaled score based on normative information in the manual.

Reliability and Validity of the CTOPP (Phonological Awareness). Psychometric properties for the CTOPP come from the technical manual (Wagner et al., 1999) and indicate reliabilities for the Phonological Awareness cluster to be in the high range. For example, Cronbach's coefficient alpha for the Elision test is .89, with a range of .91 to .81 for the age group that will be used in this study. Test-retest reliability based on a study of ninety-one individuals is more than acceptable at .88 (Wagner et al., 1999). For the Blending Words subtest, internal consistency reliability is reported as .84 based on the normative data, with ranges for all ages in this study between .86 and .78 (Wagner et al., 1999). A test-retest correlation study from the test manual was also adequate at .88. These correlations indicate this test evidences acceptable levels of reliability.

Various sources of evidence reported in the test manual demonstrate the excellent validity characteristics of this measure. With regard to content validity, each of the subtests that comprise the Phonological Awareness cluster has been used in research paradigms examining phonemic awareness over the past two to three decades (Wagner et al., 1999). The manual provides descriptions of the subtests with citations to authors who have used the various subtests in their research examining phonological processing.

Construct validity was supported using the same confirmatory factor analyses as the RAN subtests. A three-factor solution for the normative sample of 7- through 24-year-olds confirms that the Phonological Awareness cluster is made up of the Elision and Blending Words subtests.

A concurrent validity study of 164 students, reported in the manual, found the correlation between the Elision subtest and the Woodcock Reading Mastery Tests-Revised-Word Identification (Woodcock, 1987) to be .65. This same study found a correlation of .59 for the Blending Words subtest when compared using the same measure. Additionally, a replication study reported with a learning disabled population found correlations of .74, for the Elision subtest, and .32, for the Blending Words subtest, when compared to the Word Attack subtest of the same measure (Wagner et al., 1999).

Reading Fluency

In order to measure the criterion variable in this study, the Reading Fluency score from the Gray Oral Reading Tests, Fourth Edition (GORT-4; Wiederholt & Bryant, 2001) was used as a latent variable measure. The GORT–4 is a norm-referenced test, designed to be used by practitioners with children from 6.0 to 18.11 years to assess oral reading rate, accuracy, fluency, comprehension, and overall reading ability. The normative sample included 1,677 persons in 28 states, representative of the four major geographical regions of the United States. The GORT-4 measures four components of reading: Rate (the time taken by an individual to read each passage), Accuracy (the correct pronunciation of each word in the story), Fluency (the rate and accuracy scores combined), and Comprehension (the ability to answer the questions about each passage's content). The GORT-4 has two parallel forms (Form A and Form B) - Form A of the test was used for the current study. The examiner provides the individual with a test book containing the passages, follows along on an examiner's copy of the passages, times the reader as he/she reads the passages aloud, and marks any mistakes the reader makes. Upon completion of reading each passage, the examiner removes the passage, provides the individual with five multiple-choice reading comprehension questions, reads each question and answer option aloud, and records the individual's response choice.

Specific to this current study, the Reading Fluency scale was used. On this subtest, examinees are required to read aloud a series of progressively difficult reading passages and respond to five multiple choice comprehension questions per story with reading level and vocabulary corresponding to grades 1 through 12. In order to obtain a Ready Fluency score, a score is assigned for each passage based on the number of reading errors (Accuracy) and the time it took the individual to read the passage (Rate). The Rate and Accuracy scores are summed to form a cumulative Reading Fluency Composite score. Thus, the reading fluency construct is measured as a combination of the

Rate and Accuracy subtests. When combined, a student's reading fluency performance can be calculated from their scaled score performance. The GORT-4 yields scaled score for the Reading Fluency subtests, which have a mean of 10 and a standard deviation of 3. A linear transformation will be used to convert the GORT-4 Reading Fluency scaled scores to standard scores having a mean of 100 (SD = 15) to facilitate comparisons across measures.

Reliability and Validity of the GORT. In estimating reliability, three sources of error variance were measured: content sampling, time sampling, and interscorer differences. Coefficient alphas (Cronbach, 1951) were calculated at 13 age intervals using data from the entire norm sample. The average coefficients for all subtests and composite averaged from .91-.97. Internal consistency reliability for the Fluency subtest for the age range of the sample used in this study ranged from .91- .94. The large alpha coefficients demonstrate that the GORT-4 is reliable for sample chosen for this study. According to the test manual, test-retest data were obtained on 30 elementary students, 10 middle school students, and 9 high school students. Test-retest reliability for the Fluency subtest ranged from .91 to .93. In order to assess interscorer error, a random sample of 30 test protocols was independently scored by the test publishers. Interscorer differences were minimal, evidencing a high degree reliability of .99 for the both forms of the Fluency subtest.

Validity evidence reported in the test manual indicates that the GORT-4 benefits from a rich empirical history that validates its use as a measure of reading fluency. For example, subscores for the Fluency subtest on the GORT-R had modest correlations of .60 with the Wide Range Achievement Test-Revised (WRAT-R; Jastak & Wilkinson,

1984) Reading scores, and .39 with the Woodcock Reading Mastery Tests-Revised (WRMT-R) Word Attack score. The GORT-4 demonstrates strong technical characteristics and is considered a reliable assessment that can be used with confidence to measure a student's reading and reading-related skills.

General Processing Speed

The Visual Matching subtest from The Woodcock Diagnostic Reading Battery (WDRB; Woodcock, 1997) was used as the measure of general processing speed for this study. The WDRB is a comprehensive set of individually administered tests that measures important dimensions of reading achievement and closely related abilities. The WDRB is a selection of several tests from parts of the Woodcock-Johnson Psycho-Educational Battery-Revised (WJ-R; Tests of Achievement and Tests of Cognitive Ability; Standard and Supplemental Batteries). Four (Reading) tests were selected from the Tests of Achievement (Letter-Word Identification, Word Attack, Passage Comprehension, and Reading Vocabulary) and six (Related Abilities Tests) from the Tests of Cognitive Ability (Incomplete Words, Sound Blending, Memory for Sentences, Oral Vocabulary, Visual Matching, and Listening Comprehension). The WDRB is designed to assess reading-related areas including Total Reading (Broad Reading, Basic Reading Skills, and Reading Comprehension), Phonological Awareness, Oral Comprehension, and Reading Aptitude in individuals from preschool through geriatric populations. Normative data are based on a single sample derived from 6,026 individuals ranging from ages 4 to 95 who were administered all tests.

The Visual Matching subtests measures the ability to locate and circle the two identical numbers in a row of six numbers. The task proceeds in difficulty from single-digit numbers to triple-digit numbers and has a three-minute time limit. This subtest is considered a visual processing speed measure and is part of the Reading Aptitude cluster (Woodcock, 1997). This test itself is a measure of general processing speed, or the ability to process visual tasks rapidly and automatically (Woodcock, 1997). The Visual Matching subtest provides standard scores for comparisons, which have a mean of 100 and a standard deviation of 15.

Reliability and Validity of the WDRB. Reliability of the subtests in the WDRB has been estimated through internal consistency procedures as well as by test-retest techniques. Psychometric support is more than adequate with internal consistency reliability coefficients ranging from .78 to .94 for all tests in the battery. The average median internal consistency reliability coefficient for the achievement tests was .92, and the average median coefficient for the cognitive tests was .84. Reliabilities were consistently in the mid-.90s for the clusters (ranging from .90 for phonological awareness to .98 for total reading). Specific reliability information for the Visual Matching subtest reveals that this test has a median reliability of .78 in the age range 5 to 18 and .84 in the adult range. Specific to the sample used in this study, test-retest reliabilities for the Visual Matching subtest were calculated for age 7 (r^{11} = .809); age 9 (r^{11} = .784); and age 13 (r^{11} = .732). Internal consistency reliability for the Visual Matching subtest for all ages was .799. These test characteristics indicate that the Visual Matching subtest evidences acceptable levels of reliability, and produces results that can be generalized in the sample used in the study.

The test manual reports validity evidence for the WDRB using concurrent validity and construct validity techniques for the reading and reading-related broad ability areas.

Although specific validity evidence is not provided for the Visual Matching subtest, several studies are reported that examine the validity of the Reading Aptitude cluster that includes the Visual Matching subtest. Concurrent validity was established citing two studies that evaluated the correlation between the Reading Aptitude cluster and several other instruments measuring similar constructs. For example, in a grade three study reported in the manual of 94 school-age students, high correlations (.75) were found between the WDRB Reading Aptitude cluster and the Wechsler Intelligence Scale for Children-Revised (WISC-R; Wechsler, 1974). In another study of 70 third and fourth grade students, the Reading Aptitude cluster demonstrated strong correlations (.62) with the WISC-R and measures of broad reading achievement (.70) on the Kaufman Test of Educational Achievement (K-TEA; Kaufman & Kaufman, 1985). To demonstrate the construct validity of the WDRB, a study was cited in the technical manual that compared the performance of a normal group of school-age students with age-matched gifted, learning disabled, and mentally retarded subjects. Intercorrelations among a pattern of increasing scores across the four groups were evidenced by this validity study.

As a measure of general processing speed, the Visual Matching subtest of the WDRB can be used with confidence with demonstrated internal reliability characteristics as well as documented evidence suggesting that the WDRB measures the identified construct used in this current study.

Research Design

The research design of this study utilized a quasi-experimental design that involved both correlation and regression analyses. The correlational research method was used to determine the relationship between the four variables in the study (phonemic awareness, RAN, processing speed, and reading fluency). Multiple regression analyses were used to examine the contribution of total and specific RAN performance in reading fluency beyond phonemic awareness in the prediction of reading fluency. Also, multiple regression analyses were used to examine the contribution of specific RAN tasks in the prediction of reading fluency beyond processing speed.

Utilizing data from the CTOPP, the alphanumeric and non-alphanumeric RAN tasks were used as two independent variables in this study. Alphanumeric RAN performance was operationalized by the letter and digit naming tasks of the CTOPP, which measure the speed with which an individual can name both numbers and digits (Wagner et al., 1999). Non-alphanumeric RAN performance was operationalized using the color and object naming tasks of the CTOPP, which measure the speed at which an individual can name the colors of series of different colored blocks or name a series of objects (Wagner et al., 1999).

The phonemic awareness variable was measured by the Phonemic Awareness cluster of the CTOPP, which includes the Elision subtest and the Blending Words subtest. Phonemic awareness measures an individual's ability to manipulate the sound structure of words presented orally and combine the phonemic sounds of strings into whole words (Wagner et al., 1999). These subtests require the examinee to repeat aloud a target word then identify elements of it on demand and listen to sounds produced on an audiocassette recording.

General processing speed in this study was operationalized by the use of the Visual Matching subtest of the WDRB, and was used as both an independent variable and as a control variable in this study. This test requires the ability to quickly identify matching numbers among a set of distracter items, and is measured by calculating the number of correctly matched items within a three-minute time period.

The dependent variable in this study was performance on the Reading Fluency composite of the GORT-4. Drawing upon modern definitions of the construct (NRP, 2000), reading fluency can be operationalized as the ability to quickly and accurately recite a reading passage. On the GORT-4, a student's reading fluency is calculated based on their Rate and Accuracy performance, and mirrors the type of reading tasks typically associated with passage reading in schools.

Procedure

This study analyzed data from a clinical database of children who were referred for assessment at the Duquesne University Reading Clinic. Upon approval from the Institutional Review Board (IRB), data were obtained from a de-identified SPSS file that contains the participant data. The participants were administered the measures as part of a university reading clinic for school-aged children (ages 7 to 16) with perceived reading difficulties. The data regarding all potential participants was reviewed to establish the cases that contained the proposed measures. Data regarding approximately 79 participants will be examined in this study.

Data Analysis

Initial analyses were conducted to eliminate outliers and influential data points in the test scores. For finding subjects whose predicted scores were significantly different from their actual scores, the standardized residuals (r_i) were examined. If the model is correct, then they should have a normal distribution with a mean of 0 and a standard deviation of 1 (Stevens, 2002). Standardized residuals that are greater than positive or negative 3 are considered outliers (Stevens, 2002) and removed from the analysis. The predictor variables were tested for outliers using Mahalonobis Distance. To determine the degree to which influential data points substantially affects any of the regression coefficients, Cook's Distance was used. Cook’s Distance is an indication of a case’s influence on both the predictors and the dependent variable. Any case determined to be an outlier based on Mahalonobis Distance or standardized residuals and influential based on Cook’s Distance greater than 1 (Stevens, 2002), were removed from the analysis.

For the first research question, data from the descriptive statistics tables and the correlation matrix was analyzed to determine Pearson correlation coefficients found between all continuous variables used in this study. For the second and third research questions, data analysis were conducted using separate multiple regression analyses to determine whether the predictor variables made similar or distinct contributions to the criterion variable. For the fourth research question, data analysis was conducted using a separate hierarchical regression analyses to determine whether the predictor variable made a unique contribution to the criterion variable while controlling for the influence of another variable in the study. All analyses were completed using the Statistical Package for the Social Sciences (SPSS). An alpha level of .05 was used to determine statistical significance. Means and standard deviations for each variable were calculated.

Research Questions and Hypotheses

Research Question One and Analysis. In order to determine the relationships among the RAN variables, phonemic awareness, general processing speed, and the dependent variable in this study, the correlation matrix was examined and the resulting Pearson correlation coefficients were assessed to determine the relative correlation with each value in the matrix. It was hypothesized that phonemic awareness and reading fluency will be highly correlated, and that all RAN measures, processing speed, and reading fluency will be significantly correlated. It was also hypothesized that the correlation between processing speed and phonemic awareness will be low. Additionally, the correlation between RAN and phonemic awareness was hypothesized to be moderate.

Research Question Two and Analysis. The second research question evaluates whether RAN accounts for additional variance in reading fluency beyond phonemic awareness. Using a multiple regression procedure, the overall RAN composite scores and phonemic awareness domain scores were entered as the independent predictor variables in the study. The reading fluency composite score was entered as the dependent variable. It was hypothesized that RAN performance would contribute uniquely to reading fluency performance beyond phonemic awareness.

Research Question Three and Analysis. For the third research question, the alphanumeric RAN subtest domain scores, the non-alphanumeric RAN subtest domain scores, and phonemic awareness domain scores were entered as the three predicator variables in a multiple regression analysis. The reading fluency composite score was entered as the dependent variable. This analysis determined which RAN tasks (i.e., alphanumeric or non-alphanumeric) account for more variance in reading fluency performance, and whether the alphanumeric tasks (letters and digits) are better predictors of reading fluency than non-alphanumeric naming tasks (objects and colors). It was hypothesized that the alphanumeric naming RAN tasks will better explain individual differences in reading fluency performance than non-alphanumeric naming tasks. It was also hypothesized that general naming speed (objects and colors) tasks will not explain additional variance in reading fluency performance after accounting for variance in letter/digit naming tasks.

Research Question Four and Analysis. Lastly, the relationship between general processing speed performance and RAN was evaluated to determine whether alphanumeric RAN task performance explains unique variance in reading fluency beyond what is explained by general processing speed. A hierarchical multiple regression analysis was used to determine the amount of variance explained in reading fluency performance by general processing speed and alphanumeric RAN performance. The predictor variables for this question was the alphanumeric RAN task performance and general processing speed variable, while reading fluency was entered as the dependent variable. This analysis was done while controlling for the predictive value of processing speed. It was hypothesized that RAN will explain additional variance in reading fluency performance beyond what is explained by general processing speed performance. It was also hypothesized that general processing speed will be a significant predictor of reading fluency performance.

Rationale and Assumptions for Analyses

The following study utilized multiple regression analysis in order to exam predictive and theoretical explanations of reading fluency. Multiple regression is a statistical technique useful in explaining complex phenomena by providing multiple indexes of the degree of relationship between predictors and criteria while statistically controlling for alternative explanations of those relationships. The purpose of this study is to determine what aspects of rapid naming (alphanumeric vs. non-alphanumeric tasks) best predict reading fluency, and to further explain the underlying components of reading fluency. While an examination of the bivariate correlations between each predicator variable and reading fluency performance provides a general understanding of these relationships, it does not control for the contribution of the other potentially important variables. Experimental control over confounding variables allows for the examination of the independent contribution of the RAN variables in this study. Hierarchical regression analysis allows the researcher to choose how predictor variables are entered into the regression equation, and examine the unique contribution of new predictors in explaining variance in the outcome variable.

While it is anticipated that a high multiple correlation (*R*) relationship exists between the predictor and the criterion variables, intercorrelations may exist among the predictors variables that affects the strength of their relationship. When there are moderate to high intercorrelations among the predictor variables (i.e., RAN measures), this problem is referred to as multicollinearity (Stevens, 2002). Multicollinearity is problematic when using multiple regression analysis for several reasons. First, it has the potential to severely limit the size of the multiple correlation coefficient (*R*) because the individual predictors are going after much of the same variance on the criterion variable (Stevens, 2002). As a result, the amount of variance explained (R^2) by the predictor variables will be reduced. Secondly, multicollinearity makes it difficult to determine the individual contributions of the predictors in explaining the criterion variable because the effects of the predictors are limited due to their moderate to high correlations. Lastly, multicollinearity increases the variances of the regression coefficients, which may cause the prediction equation to become unstable (Stevens, 2002).

As a result of the multicollinearity problem, the simple correlations among the predictors were examined to determine whether high intercorrelations exist. Correlations above .80 are considered problematic (Stevens, 2002). Also, the variance inflation factors (VIF) were examined for the predictors to determine the strength of the linear relationship among predictor variables. The variance inflation factor determines the squared multiple correlation of regressing all other predictors on each individual predictor (Stevens, 2002). VIF values exceeding 10 will be considered problematic (Stevens, 2002) and necessitate correction to the regression model. It is expected that moderate to high correlations exist among the predictor values in this study, however it is hypothesized that alphanumeric RAN tasks and non-alphanumeric tasks contribute meaningfully to outcomes in reading fluency.

To evaluate whether each of the assumptions of multiple regression analysis are satisfied, plots of residuals were examined. The normality assumption assumes that the residuals are distributed normally and will be evaluated through the use of the histogram of residuals. To satisfy this assumption, the distribution of residuals (predicted minus observed values) should form a normal curve (Stevens, 2002). If this assumption is violated, appropriate transformation of that variable to normalize the distribution may need to occur. The scatterplots of residuals were also examined to determine if the relationships among variables are linear. If this assumption is satisfied, then the data-points should scatter randomly around a horizontal line. If curvature in the relationships is evident, the researcher can either transform the variables, or explicitly allow for nonlinear components (Stevens, 2002). Homoscedasticity assumes the residuals (errors in prediction) are evenly spread around the regression line or the variance of errors across all values of the predictors is constant (Stevens, 2002). This assumption was assessed by examining the residual plots (Stevens, 2002). Data-points should be equally distributed around the regression line indicating that variance is consistent, or that the assumption of homoscedasticity is satisfied. The independence assumption implies that the subjects responded independently of each other. Since each participant in the database was tested individually and did not have contact with any other participants, this assumption is satisfied in the current analyses.

Chapter IV: Results

This chapter reports the results from the statistical analyses that examined this study's four research questions. The current study investigated the relationships among distinct aspects of rapid automatized naming ability (RAN), phonemic awareness, general processing speed, and reading fluency in a sample of clinic referred children. In order to address this, a matrix of Pearson correlation coefficients was computed to evaluate the relationships between the variables under investigation. In order to investigate whether RAN and phonemic awareness uniquely explain reading fluency performance in this sample of clinic referred children, a stepwise multiple regression analysis was conducted. Likewise, a stepwise regression analysis was conducted to determine which RAN tasks (alphanumeric or non-alphanumeric) are most predictive of reading fluency. Finally, a hierarchical regression analysis was conducted to investigate whether RAN performance explains further variance in reading fluency beyond general processing speed.

Descriptive Statistics

The original clinic-referred database contained 79 children and adolescents who received an evaluation for perceived reading difficulties. The participants in this study included both male and female students aged 7.25 years to 15.5 years with an average age of 10 years. Table 1 displays the frequency distribution of the age range in the study.

Table 1

Frequencies of Age in Months

Age (months)	Frequency	Percent	Cumulative Percent
87	1	1.4	1.4
89	2	2.9	4.3

92	1	1.4	5.8
93	1	1.4	7.2
94	1	1.4	8.7
95	1	1.4	10.1
97	2	2.9	13.0
98	2	2.9	15.9
99	1	1.4	17.4
100	1	1.4	18.8
102	1	1.4	20.3
103	1	1.4	21.7
104	3	4.3	26.1
105	1	1.4	27.5
106	2	2.9	30.4
108	2	2.9	33.3
111	4	5.7	39.1
114	1	1.4	40.6
117	4	5.7	46.4
119	1	1.4	47.8
120	1	1.4	49.3
121	1	1.4	50.7
122	2	2.9	53.6
124	2	2.9	56.5
129	2	2.9	59.4

130	2	2.9	59.4
131	1	1.4	63.8
133	1	1.4	65.2
134	1	1.4	66.7
135	2	2.9	69.6
138	1	1.4	71.0
139	1	1.4	72.5
140	1	1.4	73.9
141	1	1.4	75.4
143	1	1.4	76.8
144	2	2.9	79.7
150	1	1.4	81.2
151	1	1.4	82.6
154	1	1.4	84.1
156	1	1.4	85.5
158	1	1.4	87.0
160	1	1.4	88.4
161	1	1.4	89.9
164	1	1.4	91.3
165	1	1.4	92.8
166	1	1.4	94.2
175	1	1.4	95.7
176	1	1.4	97.1

186	1	1.4	98.3
208	1	1.4	100.0

Examination of the data revealed that some participants demonstrated above average reading fluency skills. For the purposes of this study, only individuals whose fluency performance was average or below were included in the final analyses. Therefore, the decision rule for inclusion in the final sample was a scaled score less than or equal to 12 on the Reading Fluency composite subscale of the GORT-4. The final sample contained 64 participants that met the previously stated criteria. Table 2 includes the mean and standard deviations of the variables used in the study.

Table 2

Means and Standard Deviations of Predictor and Criterion Variables

Measure	Mean	SD	Range	n
1. RAN-D	7.97	2.69	3 to 18	65
2. RAN-L	8.14	2.26	5 to 18	66
3. RAN-C	7.11	2.77	1 to 13	66
4. RAN-O	7.20	3.46	1 to 16	65
5. RAN-Alpha Total	88.24	16.35	48 to 165	67
6. RAN-Non-alpha Total	84.36	22.43	41 to 165	64
7. RAN-Total	86.49	17.46	53 to 165	64
8. PA	87.31	12.29	59 to 109	67
9. Fluency	5.53	3.16	1 to 11	70
10. PS	87.15	18.64	11 to 151	68

Note. RAN-D = Rapid Digit Naming; RAN-L = Rapid Letter Naming; RAN-C = Rapid Color Naming; RAN-O = Rapid Object Naming; RAN-Alpha Total = Rapid Naming Alphanumeric Total Score (Digits and Letters); RAN-Non-alpha Total = Rapid Naming Non-alphanumeric Total Score (Colors and Objects); RAN-Total = Total RAN Score (Digits, Letters, Colors, and Objects); PA = Phonemic Awareness; Fluency = Reading Fluency; PS = Processing Speed.

Preliminary Analyses for Outliers and Assumptions

Prior to conducting the proposed analyses, the dataset was examined for multivariate outliers to ensure no cases were exerting excessive influence on the results. Mahalanobis distances were obtained for each case and compared to a chi-square critical value of 29.59 ($df = 10$; $p < 0.001$). There were no values exceeding the chi-square critical value, indicating no outliers according to this criterion. Additionally, an examination of the standardized DFBETAs and Cook‘s Distances tables did not reveal any cases as potential outliers based on the criteria.

In order to examine whether the assumptions for multiple regression are met, plots of the residuals for each analysis were examined. To determine if the assumption of normality of errors was satisfied, a histogram of residuals was examined. Based on the approximately normal distribution of these residuals for each regression, this assumption was determined to be tenable. The assumption of linearity was also satisfied based on the random pattern of standardized residuals around a horizontal line for each regression equation. The homoscedasticity assumption was also satisfied based on the uniform scatter of plotted residuals around each regression line. These histograms (normality assumption) and scatterplots of residuals (linearity and homoscedasticity assumptions) are presented separately with each analysis prior to a discussion of the results.

Research Question One Results

The first research question utilized a correlation matrix in order to examine relationships among the RAN tasks, phonemic awareness, general processing speed, and reading fluency. The correlation matrix also allowed for the examination of multicollinearity for predictor variables that could be problematic in the subsequent regression analyses. Table 3 shows a matrix of Pearson correlation coefficients between the variables under investigation. As anticipated, all RAN task measures demonstrated moderate to large significant intercorrelations. Rapid Digit Naming showed a large, significant correlation with performance on Rapid Letter Naming, $r = .82$, $p < .01$. A large correlation between Rapid Object Naming and Rapid Color Naming, $r = .66$, $p < .01$, was also found. Moderate correlations were found among Rapid Digit Naming and Rapid Color Naming, $r = .39$, $p < .01$, and Rapid Object Naming, $r = .47$, $p < .01$. Additionally, moderate correlations were found among Rapid Letter Naming and Rapid Color Naming, $r = .43$, $p < .01$, and Rapid Object Naming, $r = .50$, $p < .01$. Phonemic awareness demonstrated a small, yet significant correlation with Rapid Letter Naming, $r = .27$, $p < .05$. Reading fluency showed a moderately strong correlation with performance on alphanumeric RAN tasks and phonemic awareness: for Rapid Digit Naming, $r = .39$, $p < .01$; for Rapid Letter Naming, $r = .48$, $p < .01$; for Phonemic Awareness, $r = .41$, $p < .01$ and a small correlation with Rapid Object Naming, $r = .26$, $p < .05$. However, the correlations among Processing Speed and all other variables in the study were very low to low and nonsignificant.

Table 3

Correlations Among RAN Measures, Phonemic Awareness, Reading Fluency, and Processing Speed

Measure	2	3	4	5	6	7	8	9	10

1. RAN-D	.82**	.39**	.47**	.79**	.36**	.61**	.03	.39**	.01
2. RAN-L		.43**	.50**	.76**	.41**	.63**	.27*	.48**	.07
3. RAN-C			.66**	.48**	.61**	.61**	.07	.13	.02
4. RAN-O				.56**	.68**	.71**	.16	.26*	.15
5. RAN-Alpha Total					.59**	.86**	.18	.36**	.03
6. RAN-Non-alpha Total						.92**	.07	.13	.09
7. RAN-Total							.14	.25*	.07
8. PA								.41**	-.07
9. Fluency									.17
10. PS									

Note. *p < .05. **p < .01; RAN-D = Rapid Digit Naming; RAN-L = Rapid Letter Naming; RAN-C = Rapid Color Naming; RAN-O = Rapid Object Naming; RAN-Alpha Total = Rapid Naming Alphanumeric Total Score (Digits and Letters); RAN-Non-alpha Total = Rapid Naming Non-alphanumeric Total Score (Colors and Objects); RAN-Total = Total RAN Score (Digits, Letters, Colors, and Objects); PA = Phonemic Awareness; Fluency = Reading Fluency; PS = Processing Speed.

Multicollinearity

To examine presence of multicollinearity prior to the execution of the subsequent analyses, the correlation matrix was examined to identify independent variables with high (>.80) intercorrelations as recommended by Stevens (2002). An examination of the correlation matrix indicates that the correlation between RAN-D and RAN-L was high (.82), and potentially problematic. In order to address multicollinearity prior to the execution of the regression analyses, two statistical methods were employed to assess the impact of this high correlation. First, tolerance statistics were obtained for each of the predictor variables. Tolerance values less that 0.1 are considered problematic and indicative of notable multicollinearity (Stevens, 2002). Secondly, the variance inflation factor (VIF) for each predictor was examined to determine whether a strong linear relationship exists between each of the predictor variables. VIF values that are greater than 10 are generally problematic (Stevens, 2002). An examination of the tolerance values and VIF are presented separately with each regression analysis prior to a discussion of the results. High correlations were also discovered among individual RAN tasks (i.e., RAN-D, RAN-L, RAN-C, and RAN-O) and the RAN composite measures, RAN-Total, RAN-Alpha Total, and RAN-Alpha Total. However, these measures will not be entered together in the subsequent regression analyses as predictor variables, and therefore multicollinearity will not need to be addressed for these variables.

Research Question Two Results

The second research question explores the amount of variation in reading fluency that is accounted for by both phonemic awareness and total RAN performance. It was hypothesized that total RAN performance would account for unique variance in reading fluency beyond phonemic awareness. Using a stepwise multiple regression procedure, the total RAN score (RAN-Total) and phonemic awareness domain score (PA) were entered as the independent predictor variables. The reading fluency composite score (Fluency) was entered as the criterion variable. When total RAN performance and phonemic awareness were regressed on reading fluency all assumptions including normality of errors (Figure 1), linearity (Figure 2), and homoscedasticity (Figure 3) were satisfied.

Figure 1. *Normal Distribution of Standardized Residuals for Reading Fluency with Phonological Awareness and RAN-Total as Predictors.*

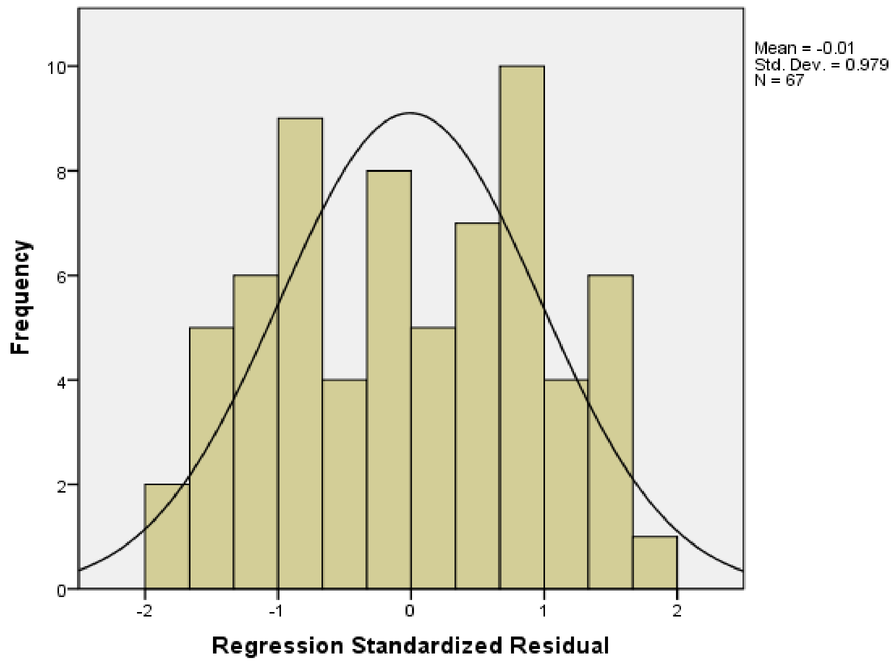


Figure 2. *Scatterplot of Standardized Residuals for Reading Fluency Showing Tenability of Linearity Assumption.*

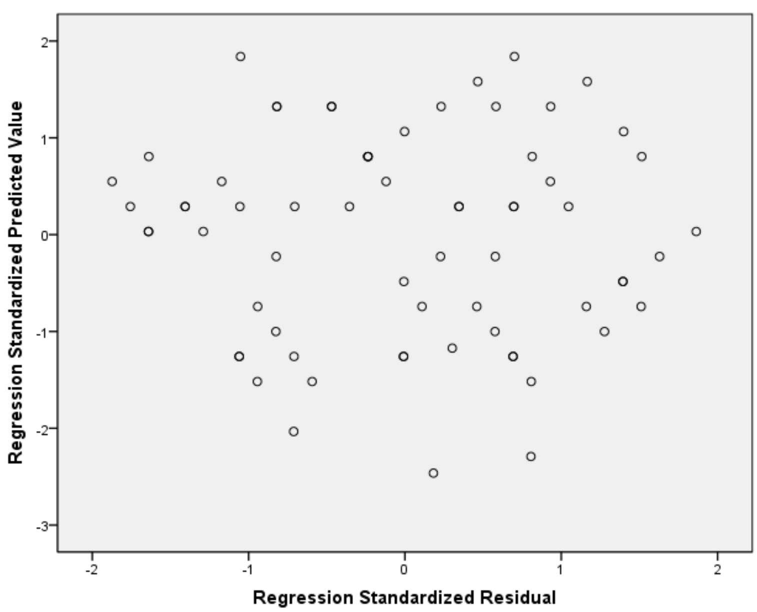
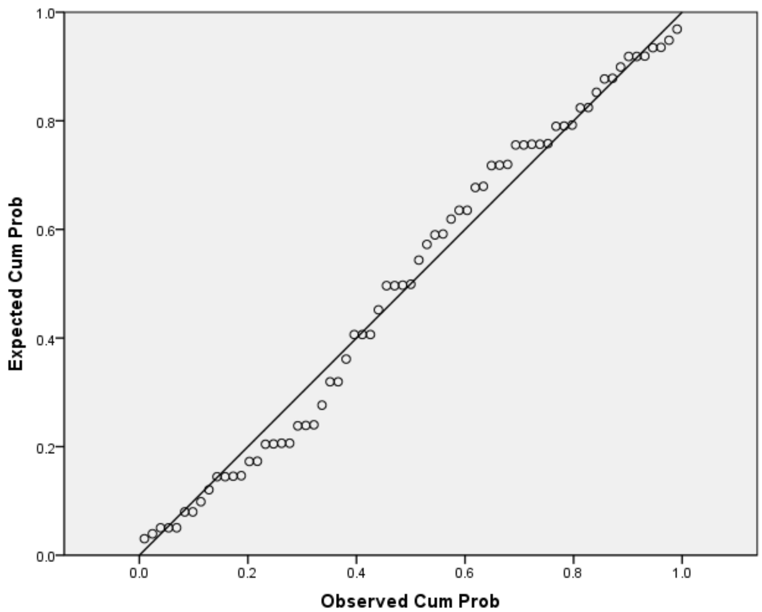


Figure 3. *Scatterplot of Residuals around Regression Line for Reading Fluency Satisfying Homoscedasticity Assumption.*



Results of the regression analysis indicate that phonemic awareness contributes unique variance to reading fluency performance; however total RAN performance did not. The model summary and coefficient table are represented in Table 4 indicating that only phonemic awareness remained in the model after the analysis. The results indicate that phonemic awareness explained a significant 17% of the variance in reading fluency performance (R^2 = .17, F(1, 62) = 12.74, p < .001). An examination of the collinearity statistics indicate VIF values are less that 10 (1.0) and tolerance among the independent variables is adequate since coefficients for all variables included are above .1. Post-hoc power analysis based on a medium effect size (f^2 = .25) indicates a power of .93.

Table 4

Effect of RAN-Total and Phonemic Awareness (PA) on Reading Fluency

Model	*B*	*β*	*t*	*p*
(1) PA	.110	.413	3.569	.001

Note. $R^2 = .17$, $F(1, 62) = 12.74$, $p < .001$; RAN-Total = Total RAN Score (Digits, Letters, Colors, and Objects).

Research Question Three Results

As a result of the findings in research question two, a follow up analysis was conducted to determined whether the effect of total RAN on reading fluency was diminished because total RAN is an aggregate score (i.e., performance across all four RAN tasks) and does not allow for the independent influence of different RAN tasks. To determine whether alphanumeric RAN performance, non-alphanumeric RAN performance, and phonemic awareness explain variance in reading fluency performance, a stepwise multiple regression analysis was conducted. It was hypothesized that alphanumeric RAN tasks will better explain individual differences in reading fluency performance than non-alphanumeric RAN tasks, and that non-alphanumeric RAN tasks will not explain additional variance in reading fluency performance after accounting for variance in alphanumeric RAN tasks. For this analysis, the alphanumeric RAN scores (RAN-Alpha Total), the non-alphanumeric RAN (RAN-Non-alpha Total) scores, and the phonemic awareness scores (PA) were entered as the three predicator variables in a multiple regression analysis. Reading fluency performance (Fluency) was entered as the criterion variable. When these three independent variables were regressed on reading fluency all assumptions including normality of errors (Figure 4), linearity (Figure 5), and homoscedasticity (Figure 6) were satisfied.

Figure 4. *Normal Distribution of Standardized Residuals for Reading Fluency with RAN-Alpha Total, RAN-Non-alpha Total, and PA as Predictors.*

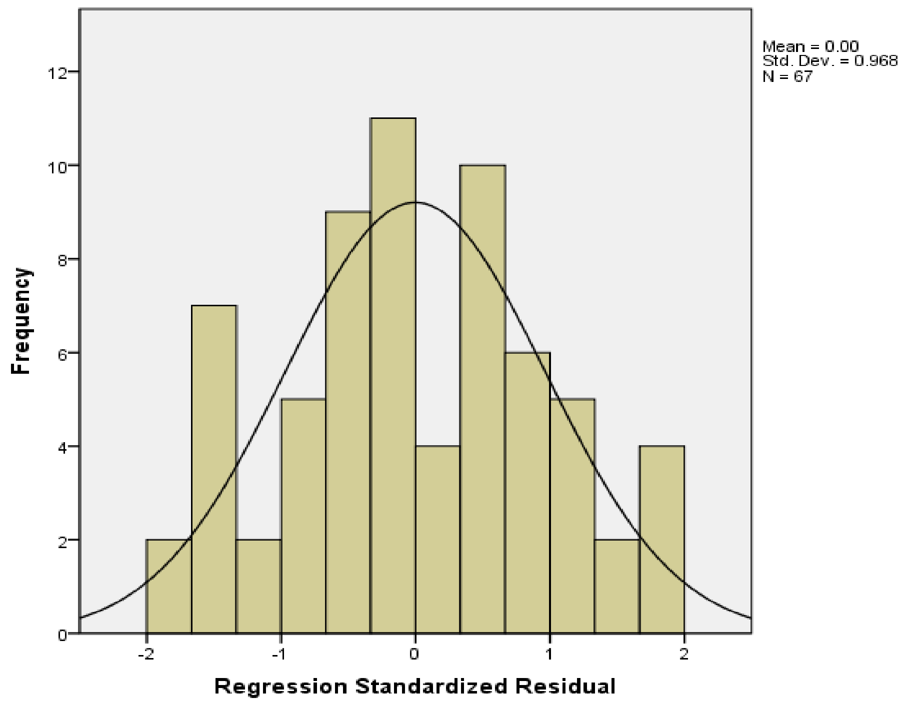


Figure 5. *Scatterplot of Standardized Residuals for the Criterion Variable Reading Fluency Showing Tenability of Linearity Assumption.*

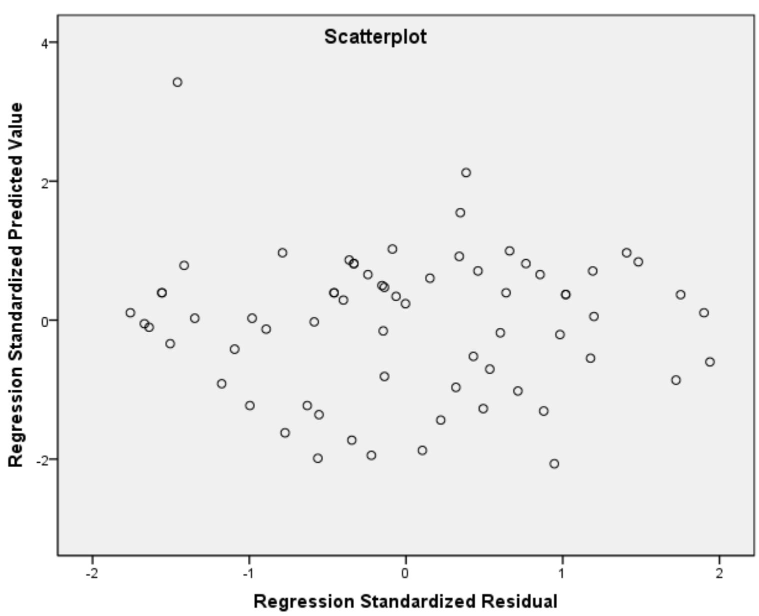
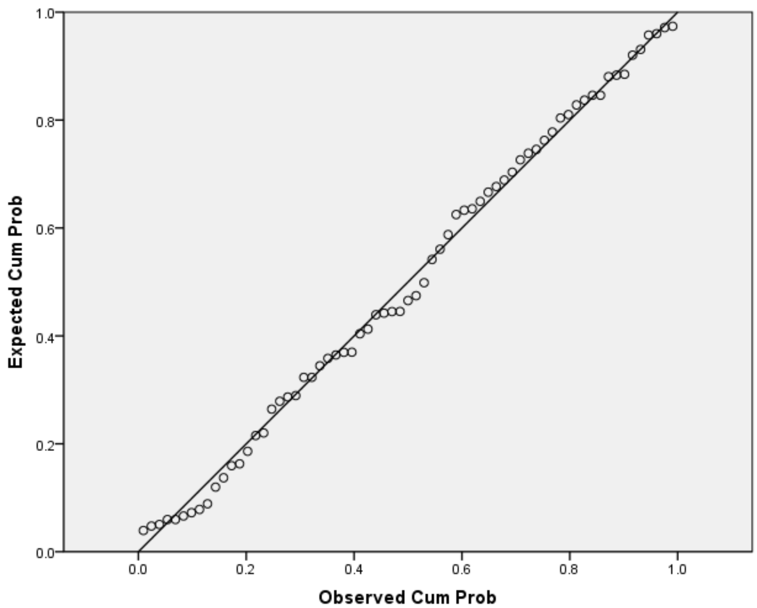


Figure 6. *Scatterplot of Residuals around Regression Line for Criterion Variable Reading Fluency Satisfying Homoscedasticity Assumption.*



The results of the analysis including the model and coefficients are represented in Table 5. Results of this regression analysis indicate that both phonemic awareness and alphanumeric RAN performance contribute uniquely to reading fluency performance in this sample of clinic-referred children. The model summary and coefficient table indicates that non-alphanumeric RAN performance did not contribute significantly to reading fluency performance and was excluded from the final model. Phonemic awareness explained 17% of the variance in reading fluency performance (R^2 = .17, F(1, 62) = 12.74, p < .001) and alphanumeric RAN performance explained a significant 8% of reading fluency performance beyond phonemic awareness (R^2 = .08, F(2, 61) = 10.28, p < .001). The final model that included phonemic awareness and alphanumeric RAN accounted for 25% of the variance in reading fluency. Collinearity statistics indicate VIF values are less that 10 (1.039) and tolerance among the independent variables is adequate since coefficients for all variables included are above .1. Post-hoc power analysis based on a medium effect size (f^2 = .25) indicates a power of .91.

Table 5

Effect of RAN-Alpha Total, RAN-Non-alpha Total, and Phonological Awareness on Reading Fluency

Model	*B*	*β*	*t*	*p*
(1) PA	.110	.413	3.569	.001
(2) PA	.095	.356	3.156	.002
RAN-Alpha Total	.055	.291	2.58	.012

Note. R^2 = .17, $F(1, 62)$ = 12.74, $p < .001$; ΔR^2 = .08, $F(2, 61)$ = 10.28, $p < .001$; RAN-Alpha Total = Rapid Naming Alphanumeric Total Score (Digits and Letters); RAN-Non-alpha Total = Rapid Naming Non-alphanumeric Total Score (Colors and Objects).

Considering that alphanumeric RAN performance remained a significant predictor of reading fluency performance, an additional analysis was conducted to better understand the predictive value of specific alphanumeric RAN tasks (i.e., RAN of letters or RAN of digits) in light of phonemic awareness by considering the effects of RAN of letters, RAN of digits, and phonemic awareness on reading fluency performance. For this analysis, the RAN of letters scores (RAN-L), the RAN of digits (RAN-D) scores, and the phonemic awareness scores (PA) were entered as the three predicator variables in a stepwise multiple regression analysis. Reading fluency performance (Fluency) was entered as the criterion variable. When these three independent variables were regressed on reading fluency all assumptions including normality of errors (Figure 7), linearity (Figure 8), and homoscedasticity (Figure 9) were satisfied.

Figure 7. *Normal Distribution of Standardized Residuals for Reading Fluency with RAN-L, RAN-D, and PA as Predictors.*

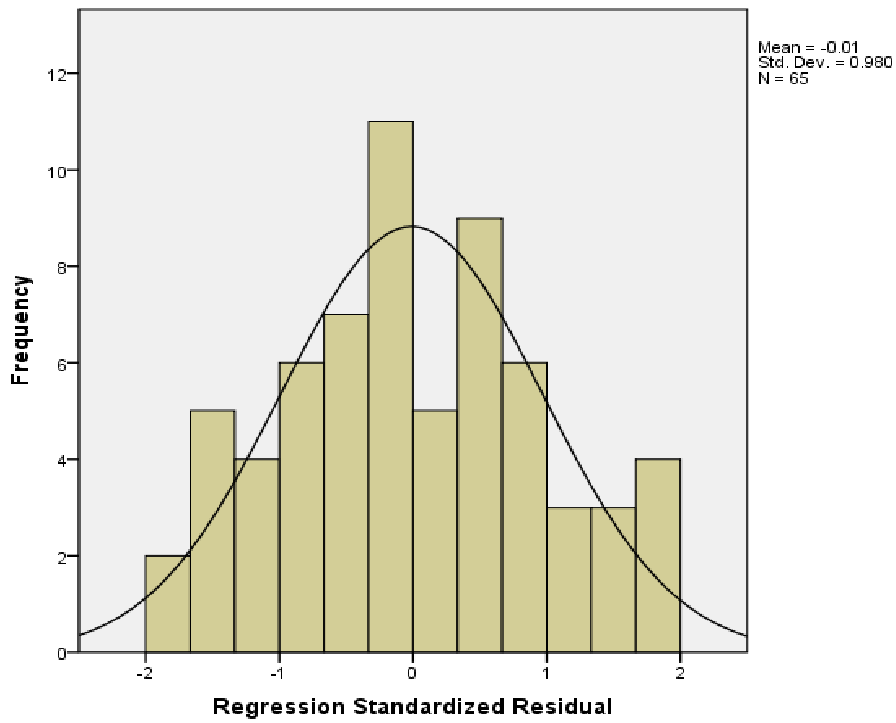


Figure 8. *Scatterplot of Standardized Residuals for Reading Fluency Demonstrating Tenability of Linearity Assumption.*

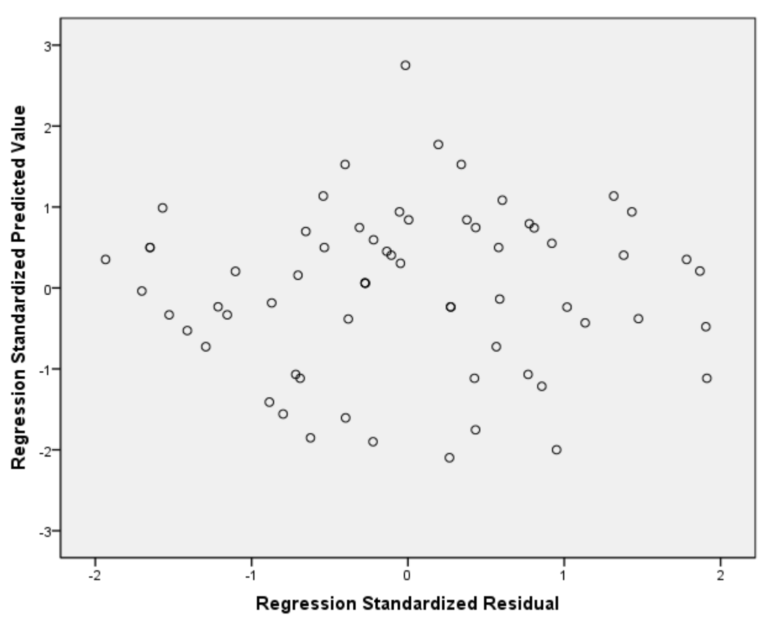
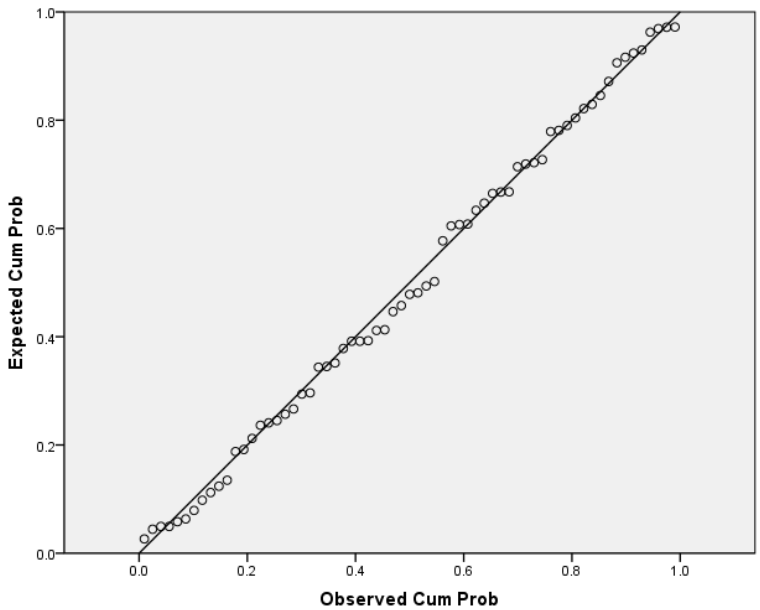


Figure 9. *Scatterplot of Residuals around Regression Line for Reading Fluency Satisfying Homoscedasticity Assumption.*



The results of the analysis including the model and coefficients are represented in Table 6. Results of this regression analysis indicate that RAN of letters was the most significant predictor of reading fluency performance followed by phonemic awareness. The model summary and coefficient table indicates that RAN of digits performance did not contribute significantly to reading fluency performance and was excluded from the final model. RAN of letters explained a significant 18% of the variance in reading fluency performance (R^2 = .18, F(1, 62) = 13.14, p < .001), and phonemic awareness performance explained an additional 9% of the variance in reading fluency performance (R^2 = .09, F(2, 61) = 11.14, p < .000). The final model that included RAN of letters and phonemic awareness accounted for 27% of the variance in reading fluency performance. An examination of the collinearity statistics indicate VIF values are less that 10 (1.070) and tolerance among the independent variables is adequate since coefficients for all variables included are above .1. Post-hoc power analysis based on a medium effect size (f^2 = .25) indicates a power of .91.

Table 6

Effect of RAN-L, RAN-D, and Phonemic Awareness (PA) on Reading Fluency

Model	*B*	*β*	*t*	*p*
(1) RAN-L	.678	.418	3.625	.001
(2) RAN-L	.547	.337	2.976	.004
PA	.079	.315	2.778	.007

Note. R^2 = .18, $F(1, 62) = 13.14$, $p < .001$; ΔR^2 = .09, $F(2, 61) = 11.14$, $p < .001$
Note. RAN-L = Rapid Letter Naming; RAN-D = Rapid Digit Naming.

Research Question Four Results

Considering that RAN of letters was shown to have significant predictive value, the final research question examined the relationship between general processing speed performance and RAN to determine whether RAN of letters performance explains unique variance in reading fluency beyond what is explained by general processing speed. A hierarchical multiple regression analysis was conducted to test the hypothesis that RAN of letters will account for additional variance in reading fluency performance beyond general processing speed performance. For this analysis, general processing speed (PS) was entered at Block 1 as a predictor variable, and RAN of letters scores (RAN-L) was entered at Block 2 as the second independent variable. Reading fluency performance (Fluency) was entered as the criterion variable. When these independent variables were regressed on reading fluency all assumptions including normality of errors (Figure 10), Linearity (Figure 11), and Homoscedasticity (Figure 12) were satisfied.

Figure 10. *Normal Distribution of Standardized Residuals for Reading Fluency with RAN-L and PS as Predictors.*

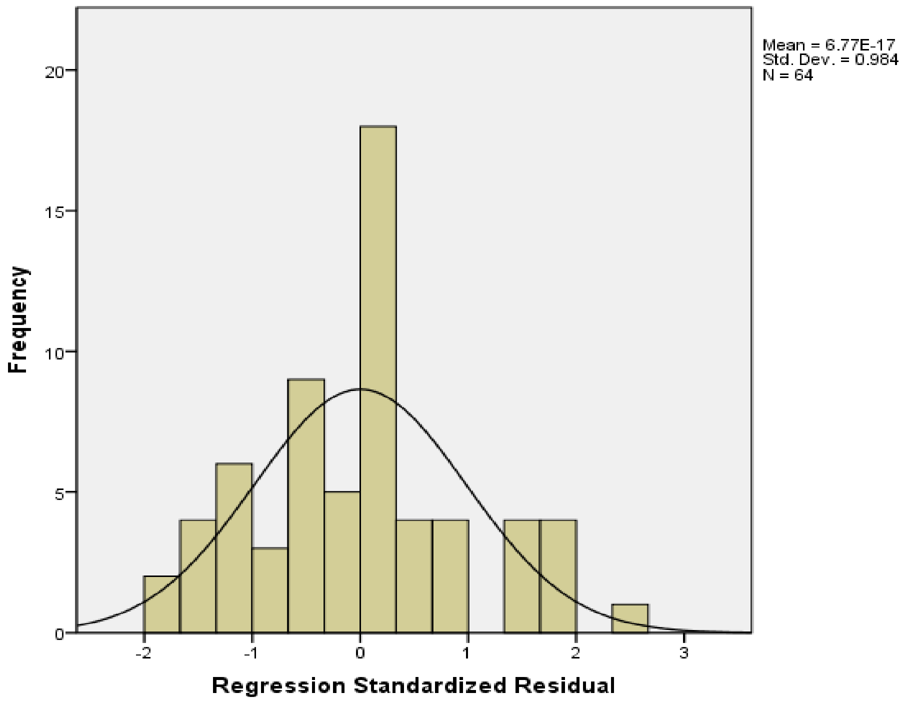


Figure 11. *Scatterplot of Standardized Residuals for Reading Fluency Demonstrating Tenability of the Linearity Assumption.*

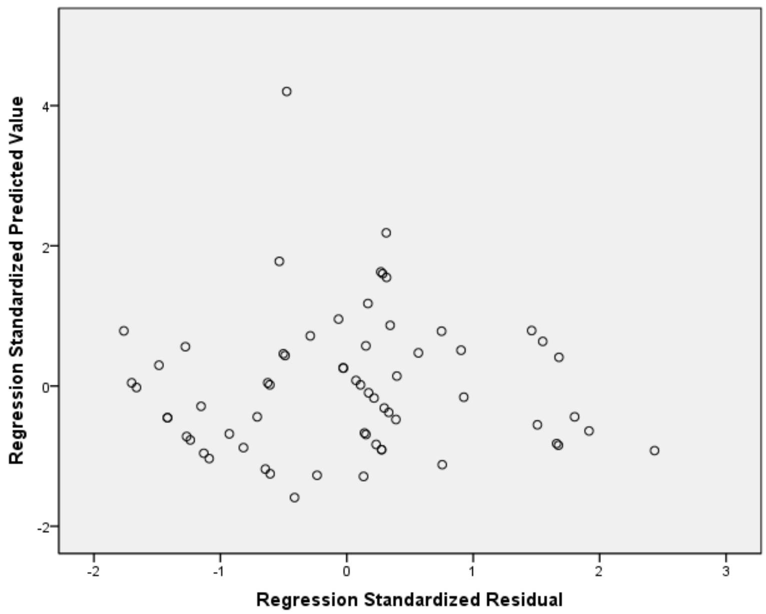
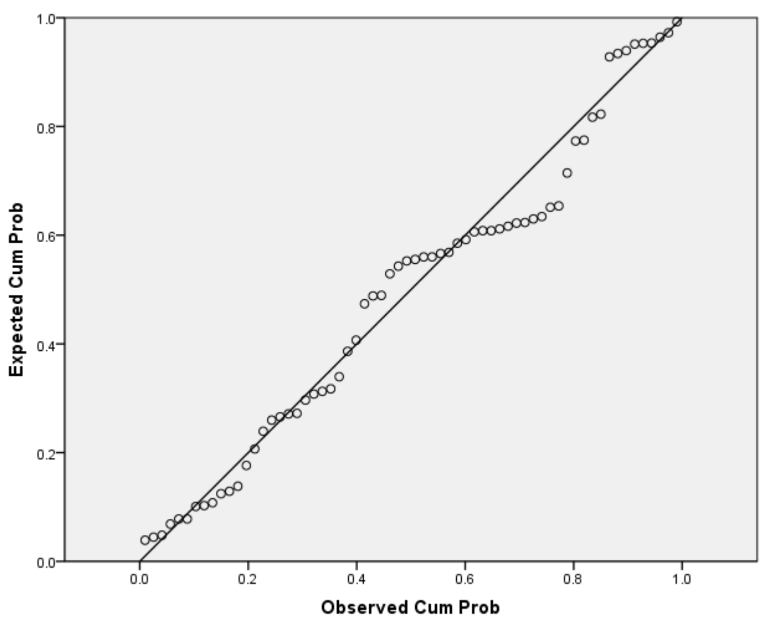


Figure 12. *Scatterplot of Residuals around Regression Line for Reading Fluency Satisfying Homoscedasticity Assumption.*



Results of the hierarchical regression analysis indicate that RAN of letters was the most significant predictor of reading fluency performance. The model summary and coefficient table (Table 7) indicates that RAN of letters explained a significant 23% of the variance in reading fluency performance ($R^2 = .23$, $F(2, 62) = 10.16$, $p < .000$), and general processing speed performance explained an insignificant 2% of the variance in reading fluency performance ($R^2 = .02$, $F(1, 61) = 1.46$, $p = .232$). Tolerance among the independent variables is adequate since coefficients for all variables included are above .1. Collinearity statistics indicate VIF values are less that 10 (1.005) and tolerance among the independent variables is adequate since coefficients for all variables included are above .1. Post-hoc power analysis based on a medium effect size ($f^2 = .25$) indicates a power of .91.

Table 7

Effect of RAN-L on Reading Fluency While Controlling for Processing Speed (PS)

Model	*B*	*β*	*t*	*p*
(1) PS	.026	.151	1.206	.232
(2) PS	.020	.118	1.060	.293
RAN-L	.663	.478	4.296	.000

Note. $R^2 = .02$, $F(1, 62) = 1.46$, $p = .232$; $\Delta R^2 = .23$, $F(2, 61) = 10.16$, $p < .001$
Note. RAN-L = Rapid Letter Naming.

Chapter V: Discussion

Existing research has established that RAN is a cognitive skill important for the development of reading fluency skills. Although it has been suggested that alphanumeric RAN effects are more robust than non-alphanumeric naming tasks (e.g., Compton, 2003; Van Den Bos et al., 2002), not well established was which RAN task is most predictive of reading fluency performance in children with reading difficulties. Additionally, the relationships among RAN, general processing speed, and reading fluency had not been thoroughly investigated. Similarly, some evidence existed to suggest that RAN and general processing offer unique connections with reading, but these relationships had not been investigated in a sample of children suspected of reading fluency deficits. Therefore, the purpose of the current study was to examine the relationships among RAN, phonemic awareness, processing speed, and reading fluency in a clinic-referred sample of children. The results suggest that alphanumeric RAN task performance —and letter naming in particular— is most predictive of reading fluency in dysfluent readers. Further, the results indicate that this contribution to reading fluency extends beyond that of other theoretical components of fluency (i.e., phonemic awareness and general processing speed).

The first research question regarded the intercorrelations among RAN tasks (digits, letters, colors, and objects), phonemic awareness, general processing speed, and a reading fluency measures. The results of the correlational analyses supported the hypothesis that phonological awareness is strongly related to reading fluency skills in this sample. This finding is consistent with previous research supporting phonemic awareness as an important factor in the development of word reading and fluency skills. For example, Morris et al. (1998) and Vanderwood, McGew, Flanagan, and Keith (2002) found phonemic awareness to be strongly related to word reading. Additionally, Meisinger et al. (2009) found a significant correlation (.43) between phonemic awareness and reading fluency in a clinic-referred sample. Given that proficient word reading skills are necessary for reading fluency at the connected text, or passage, level (LaBerge & Samuels, 1974), these findings further confirm that phonemic awareness is a core skill necessary for word reading and ultimately fluent reading.

As expected, measures of the RAN construct were significantly and positively inter-correlated. However, the findings suggest the clear need to distinguish between alphanumeric and non-alphanumeric naming tasks when considering reading fluency. A large body of research exists supporting the finding that alphanumeric RAN and non-alphanumeric RAN are correlated, but also account for different amounts of variance in reading skills (e.g., Bowey et al., 2005; Meyer et al., 1998; Powell et al., 2007; Savage & Frederickson, 2005; Wolf et al., 1986). Consistent with these findings, the composite measure of alphanumeric naming speed and object naming in the current study were each significantly, positively correlated with reading fluency, but the association was considerably stronger for alphanumeric naming speed - and letter naming in particular. Although naming speed for letters explained 23% of the variance in reading fluency, naming speed of objects explained only 7%. Further, the composite measure of non-alphanumeric naming and color naming did not significantly correlate with reading fluency skills. Replicating previous work (e.g., Bowers, 1995; Morris et al., 1998; Pennington et al., 2001), these results provide support for the hypothesis that RAN tasks, and alphanumeric naming tasks in particular, are highly related to reading fluency skills. Given the research suggesting that the connection between RAN and reading is stronger in reading delayed populations (Meyer et al., 1998), the strong correlations found in this sample may reflect the level of impairment associated with the participants' reading fluency skills.

The hypothesis that low to moderately low correlations will be found between phonemic awareness and RAN tasks is supported by the current study. This finding is consistent with existing research (Bowers et al., 1994; Bowers & Ishaik, 2004; Wolf et al., 2000; Wolf & Bowers, 1999) and demonstrates that phonemic awareness and RAN are similar, yet distinct constructs that are differently related to reading skills (Wolf & Bowers, 1999). However, unlike the previously mentioned studies, only letter naming was found to correlate with phonemic awareness in this clinic-referred sample. In contrast, digit naming and non-alphanumeric RAN tasks were not significantly correlated with phonemic awareness. Despite digit naming’s strong relationship with letter naming (r = .82), digit naming was not found to have a high, significant correlation with phonemic awareness in this sample. This could be an artifact of the different samples or psychometric instruments used in the studies. The sample in the current study comprises poor readers, whereas the aforementioned studies include children with normal reading skills or containing only a few poor readers. This may also suggest that letter naming shares more similar language-based processing demands as phonemic awareness and reading fluency. In other words, unlike digit naming, phonological awareness involving sounds that correspond to letters, letter naming, and reading fluency all involve the notion that sounds and letters can be sequenced to represent words. Further, it may suggest that other cognitive correlates of reading fluency not used in this study could be influencing these relationships. For example, working memory has been found to be moderately to strongly related to reading skills (Evans, Floyd, McGrew, & Leforgee, 2002; Swanson, Zheng, & Jerman, 2009) and RAN abilities in particular (Wagner et al., 1994). Additional executive processes, such as attention and inhibition, have also be found to be related to RAN and reading disabilities (e.g., Amtmann, Abbott, & Berninger; Reiter et al., 2004). Therefore, other cognitive correlates of reading fluency and RAN may mediate the relationships between letter and digit naming which may help explain the differential relationships found in this sample's phonemic awareness performance. Additional research is necessary to further investigate the role of other cognitive variables that may help explain reading fluency skills.

The general processing speed of this sample did not correlate with any of the variables in this study. Although this finding was unexpected, it is consistent with the mixed results found in the existing literature, For example, some research suggests that general processing speed has a moderate relationship with reading achievement during childhood (Evans et al., 2002), whereas other research suggests that it not associated with phonemic awareness skills or reading achievement (McBride-Chang & Kail, 2002; Vanderwood et al., 2002). Powell and colleagues (2007) found a weak, yet significant correlation between general processing speed and both word reading skills (.29) and alphanumeric RAN (.27). Using similar measures, Benson (2008) found that general processing speed does not have a significant effect on word reading skills, but does have a relationship with reading fluency that becomes stronger in later elementary grades (4-6).

One hypothesis that Wolf and colleagues (Bowers & Wolf, 1993; Wolf & Bowers, 1999) have advanced to explain the relationship between RAN and reading is that RAN is a complex cognitive skill at the intersection of speeded operations in the lexical system. Therefore, it stands to reason that RAN should be at least moderately correlated with general processing efficiency given that they both require speeded performance. This conjecture was not supported by the findings of this study that showed low correlations among general processing speed, RAN, and reading fluency. One possible explanation for this finding is the large difference in age-range used in the study. Whereas some existing studies included relatively small samples of children with a focused age-range, the current study's participants ranged from elementary school aged readers to adolescent readers. This may have weakened the association between general processing speed and reading fluency if the relationship is only significant in older readers (Benson, 2008). Additionally, this study utilized a sample of children referred to a clinic due to parent and/or teacher perceived reading problems. As stated previously, many existing studies included children in their samples with normal reading skills or containing only a few poor readers (e.g., Benson, 2008; Bowey et al., 2004; Neuhaus et al., 2001; Powell et al., 2007). Results of this study suggest that for children with reading problems, difficulty with the efficient retrieval of lexical information, such as retrieval of letter and sound connections (RAN of letters), better explains the presence of reading problems than general processing speed.

As a test of Wolf and Bowers' (1999) double-deficit hypothesis, the second research question investigated whether RAN accounts for unique variance in reading fluency performance beyond phonemic awareness in a clinic-referred sample. The current analysis is consistent with the great body of literature that indicates phonemic awareness is the most significant predictor of reading fluency performance. That being said, the first round of regression analyses used a composite of all four CTOPP RAN tasks as a predictor variable along with the phonemic awareness composite score available on the CTOPP. Phonemic awareness accounted for 17% of the variance in reading fluency performance and total RAN performance was unexpectedly excluded from the final model. As previously discussed, alphanumeric RAN and non-alphanumeric RAN account for different amounts of variance in reading, and may best be understood as separate, but related constructs. It appears that the effect of alphanumeric and non-alphanumeric RAN performance on reading fluency, in this sample, was diminished as a result of using a composite RAN measure (combined effects of alphanumeric and non-alphanumeric RAN).

In order to investigate the independent influence of different RAN tasks, the third research question sought to better understand RAN's specific relationship with fluency by examining which RAN task best predicts reading fluency performance. The findings here further support the argument that RAN effects are more robust when alphanumeric RAN tasks are considered. In the subsequent regression analysis, phonemic awareness continued to predict a significant amount of the variance in reading fluency performance (17%), however, the alphanumeric RAN tasks composite explained an additional 8% of the variance in reading fluency. The final combined model that included both predictors accounted for 25% of the variance in reading fluency performance. Given that phonemic awareness and alphanumeric RAN performance each explained unique variance in reading fluency performance, the double-deficit hypothesis (Wolf & Bowers, 1999) was supported by the current study.

Considering that alphanumeric RAN performance remained a significant predictor of reading fluency performance, an additional analysis was conducted using letter naming speed only because of the known stronger association between letter naming and reading fluency. Results of this regression analysis indicate that RAN of letters was the most significant predictor of reading fluency performance followed by phonemic awareness. RAN of letters explained a significant 18% of the variance in reading fluency performance, and phonemic awareness performance explained an additional 9% of the variance in reading fluency performance. The final model that included RAN of letters and phonemic awareness accounted for 27% of the variance in reading fluency performance. Considering these findings, the effect of letter naming on reading fluency appears to be diminished when considering both RAN of letters and RAN of digits together (alphanumeric RAN). RAN of letters predicted more variance in reading fluency than phonemic awareness when not combined with digit naming. Consistent with the findings of Neuhaus et al. (2001), who found a similar relationship with word reading skills in normal readers, the current findings suggest that letter naming is a more significant predictor of reading fluency skill. The tasks of rapidly naming letters and digits and colors and pictures obviously include similar sub-processes, and the composite measures of these tasks shared 35% of variance in this sample. However, the strongest association between RAN and reading fluency performance lies with letter naming. It appears reasonable to speculate that the specific demands of letter processing are what best predict reading fluency skills.

The final research question extended existing research by examining if RAN would explain additional variance in reading fluency beyond general processing speed.

After general processing speed was entered into the regression model, RAN of letters explained a significant 23% of the variance in reading fluency performance. Powell et at., (2007) and Bowey and colleagues (2004, 2005) reported similar findings when word reading was used as the criterion. However, as Powell et al. speculated, the current findings suggest a stronger relationship when reading fluency performance is used as the criterion. As discussed earlier, general processing speed did not account for unique variance in reading fluency performance in this sample of clinic-referred children. Kail and colleagues (e.g. Kail & Hall, 1994; Kail et al., 1999) suggested that both skilled reading and naming speed require rapid serial processing. However, in the current study, the hierarchical regression analysis indicated that RAN of letters was the most significant predictor of reading fluency performance. When entered first, general processing speed performance explained an insignificant 2% of the variance in reading fluency performance. After controlling for the variance contributed by general processing speed, RAN of letters was entered and explained a significant 23% of the variance in reading fluency performance. Therefore, this finding suggests that the additional processing components inherent in letter naming contribute substantively to the association between naming speed and reading fluency skills in clinic-referred children. Although general processing speed and RAN tasks include several common components, such as stimulus recognition and rapid visual processing, they differ in the amount of phonological processing involved. The ability to rapidly retrieve phonologically-based information by articulating a continuous series of letter names, are the basis of RAN task performance. In contrast, the phonological processing demands of general processing speed tasks are minimal, typically involving efficient recognition of visually presented stimuli.

Consistent with existing findings (e.g. Bowey et al., 2005; Neuhaus et al., 2001; Powell et al., 2007), the results of this study suggests that the additional variation in reading fluency explained by letter naming reflects the phonological processing components of this task - namely letter knowledge and the ability to retrieve lexical information quickly.

Conclusions and Implications for School Psychologists

This study sought to determine which RAN tasks are most predictive of reading fluency and whether RAN predicts variance in reading beyond processing speed. By exploring these questions using a sample of clinic referred children, the results of this study may help further theories of reading disabilities, as well as inform applied practice. Overall, these results show that phonemic awareness and RAN are each significant correlates of reading fluency skills across a wide age-range and are closely related to each other. More specifically, letter naming emerged as the most significant contributor to reading fluency skills in this sample of clinic-referred children. In contrast, general processing speed was not correlated with phonemic awareness, reading fluency skills, or RAN performance measures. General processing speed did not emerge as a key influence on RAN or reading fluency within the age-range and reading fluency levels of this sample. Although previous research has demonstrated that generalized processing speed is associated with RAN performance, it cannot account for the relationship between RAN and reading fluency in this sample.

The findings also revealed quite different patterns of results for naming speed for letters and digits and naming speed for colors and pictures in children of this age. Relative to the latter, alphanumeric naming speed — and especially letter naming— better assesses an underlying phonological processing ability that is common to fluent reading. It appears reasonable to conclude that letter naming may be an important factor related to reading fluency. If letter naming is not fast enough, the quality of the orthographic representations will also be compromised, which in turn will contribute to slow and inaccurate reading (Bowers & Wolf, 1993).

School psychologists and other assessment professionals should consider the results of this study when selecting instruments to identify fluency-based reading difficulties. School psychologists should consider including reliable measures of phonemic awareness and letter naming in their assessment batteries when assessing for fluency-based reading difficulties. As suggested by the current research, these measures appear to offer the best explanation of reading fluency difficulties in students suspected of reading problems.

Limitations

The current study sought to forward several issues in the existing RAN research. Unlike previous research, this study utilized a sample of clinic-referred students rather than a random sample. Secondly, this study sought to examine the predictive nature of RAN by including all RAN task performance measures in the study. Further, this study focused on the reading fluency skills of participants covering a wide age-range rather than only examining word reading or decoding skills in a circumscribed age-range. Despite this attempt to advance key issues related to the existing research, several limitations of the current study warrant discussion.

The focus of the current study was to investigate the reading fluency skills in clinic-referred children. As a result, these findings may not generalize to the general population of students with normal reading ability. Additionally, the sample used in this study covered a wide age-range, which resulted in a sample with relatively few participants per each age level. It is possible that smaller effects could have been detected if a larger number of participants were represented at different age-ranges. Considering that the sample was heterogeneous with respect to age and severity of reading problems, the results may not translate to focused age-ranges of students or students with specific reading issues.

Another limitation of the current study is that only one measure of general processing speed was used as a predictor in the study. Related studies have employed multiple measures of general processing speed (e.g. cross-out tasks) in addition to the measure used in this study. The outcomes reported here could differ if multiple measures were used given the separate, but related, cognitive processing demands of different tasks. Additionally, the strength of general processing speed's relationship with the other variables found in the current study could change if different measures were used or if composite scores were considered.

Finally, the results of the current study are specific to the task demands of the instruments used, and there are instruments that measure these constructs differently. For example, the reading fluency subtest of the Woodcock-Johnson III Tests of Achievement (WJ-III ACH; Woodcock et al., 2001, 2007) measures an individual's ability to quickly read simple statements and decide whether they are accurate (i.e. includes comprehension), whereas the measure used in this study characterizes fluency as an individual's ability quickly and accurately read larger blocks of text. The WJ-III ACH also contains similar tests that measure phonemic awareness, but also includes measures of rhyming and phoneme substitution. Given the differences found in the task demands of these tests, it is possible that these differences could affect the relationships found among the test-specific variables in the current study.

Recommendations for Future Research

These results need to be replicated and expanded upon to better understand the role of letter naming deficits in identifying children who experience difficulty obtaining typical levels of reading fluency. Considering the age-range of the current study, future research should further examine these relationships at different age intervals. This could help establish whether the strength of the relationship among phonemic awareness, RAN, general processing speed, and reading fluency vary at different developmental periods. Phonemic awareness may be a more important factor in beginning readers, while the strength of RAN, and general processing speed, may become more important as students grow in reading skills (Benson, 2008; Kirby et al., 2003). In addition to exploring the participant's age, other potentially important variables should be explored in a larger clinical sample. While phonemic awareness and letter naming accounted for a large portion of the variance in reading fluency, working memory —or the ability to manipulate and hold information in short term memory— may be an additional important factor for reading fluency (Perfetti, 1985). Additionally, the effects of other potentially important variables (e.g., working memory) may help explain the

Considering that the ultimate goal of reading is comprehension, future studies should investigate these variables in a model that includes reading comprehension as a criterion measure. Several studies have demonstrated RAN's direct and indirect effects on reading comprehension (Compton et al., 2001; Kirby et al., 2003; Manis et al., 2000), however the relationship remains unclear. For example, some studies suggest that object naming is a better predictor of reading comprehension than other naming speed tasks (e.g., Wolf & Goodglass, 1986; Wolf & Obregón, 1992) given the added semantic requirements of these tasks. Whereas other studies have demonstrated that alphanumeric RAN tasks are related to reading comprehension through the shared variance with word identification (Bowers et al., 1988, Spring & Davis, 1988; Wolf, 1991). As demonstrated in the current study and others (Georgiou et al., 2008; Young & Bowers, 1995), reading fluency is highly related to alphanumeric RAN. Therefore, there may be a stronger indirect effect between letter naming and reading comprehension that is mediated by reading fluency, in that reading comprehension requires the efficient recognition of many words in reading passages. However, existing research has not confirmed this relationship in a clinic referred sample that considers all the variables in the current study (i.e., all RAN tasks, phonemic awareness, general processing speed).

As it has been previously established that children's reading fluency skills can by improved through intervention (Meyer & Felton, 1999), the results of the current study could aid in the early identification of those students who could benefit from fluency intervention. RAN's unique connection with reading fluency may provide insight into the importance of RAN as a future indicator of reading fluency skill development. Additionally, the findings support letter naming as the best predictor of reading fluency among all RAN tasks. This finding may inform the test selection practices of assessment professionals needing efficient, yet valid and reliable, indicators of reading fluency development.

References

Ackerman, P. T., Holloway, C. A., Youngdahl, P. L., & Dykman, R. A. (2001). The double-deficit theory of reading disability does not fit all. *Learning Disabilities Research & Practice, 16*(3), 152-160.

Ackerman, P. T., & Dykman, R. A. (1993). Phonological processes, confrontational naming, and immediate memory in dyslexia. *Journal of Learning Disabilities, 26*(9), 597-609.

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders (4th ed., text rev.)*. Washington, DC: Author.

Amtmann, D., Abbott, R. D., & Berninger, V. W. (2006). Mixture growth models of RAN and RAS row by row: insight into the reading system at work over time. *Reading and Writing*, *20*(8), 785-813.

Anastasi, A. & Urbina, S. (1997*). Psychological testing (7th ed.)*. Upper Saddle River, NJ: Prentice Hall.

Bennett, K. J., Brown, K. S., Boyle, M., Racine, Y., & Offord, D. (2003). Does low reading achievement at school entry cause conduct problems*? Social Science & Medicine, 56*(12), 2443-8.

Benson, N. (2008). Cattell-Horn-Carroll cognitive abilities and reading achievement. *Journal of Psychoeducational Assessment, 26*(1), 27-41.

Berninger, V. W., Abbott, R. D., Billingsley, F., & Nagy, W. (2001). Processes underlying timing and fluency of reading: Efficiency, automaticity, coordination, and morphological awareness. In M. Wolf (Ed.), *Dyslexia, Fluency, and the Brain*. York Press.

Blachman, B. A. (1984). Relationship of rapid naming ability and language analysis skills to kindergarten and first-grade reading achievement. *Journal of Educational Psychology, 76*(4), 610-622.

Bowers, P. G. (1995). Tracing symbol naming speed's unique contributions to reading disabilities over time. *Reading and Writing, 7*(2), 189-216.

Bowers, P. G., Golden, J., Kennedy, A., & Young, A. (1994). Limits upon orthographic knowledge due to processes indexed by naming speed. *The Varieties of Orthographic Knowledge: Theoretical and Developmental Issues, 1*, 173-218.

Bowers, P. G., & Ishaik, G. (2003). RAN's contribution to understanding reading disabilities. In H.L. Swanson, K. Harris, & S. Graham (Eds.), *Handbook of Learning Disabilities*. (140-157). New York, NY, US: Guilford Press.

Bowers, P. G., & Kennedy, A. (1993). Effects of naming speed differences on fluency of reading after practice. *Annals of the New York Academy of Sciences, 682*, 318-320.

Bowers, P. G., & Newby-Clark, E. (2002). The role of naming speed within a model of reading acquisition. *Reading and Writing, 15*(1), 109-126.

Bowers, P. G., Steffy, R. A., & Swanson, L. B. (1986). Naming speed, memory, and visual processing in reading disability. *Canadian Journal of Behavioural Science, 18*(3), 209-223.

Bowers, P. G., Sunseth, K., & Golden, J. (1999). The route between rapid naming and reading progress. *Scientific Studies of Reading, 3*, 31-53.

Bowers, P. G., Steffy, R. A., & Tate, E. (1988). Comparison of the effects of IQ control methods on memory and naming speed predictors of reading disability. *Reading Research Quarterly, 23*(3), 304-319.

Bowers, P. G., & Swanson, L. B. (1991). Naming speed deficits in reading disability: Multiple measures of a singular process. *Journal of Experimental Child Psychology, 51*(2), 195-219.

Bowers, P. G., & Wolf, M. (1993). Theoretical links among naming speed, precise timing mechanisms and orthographic skill in dyslexia. *Reading and Writing, 5*(1), 69-85.

Bowey, J. A., McGuigan, M., & Ruschena, A. (2005). On the association between serial naming speed for letters and digits and word-reading skill: Towards a developmental account. *Journal of Research in Reading, 28*(4), 400-422.

Bowey, J. A., Storey, T., & Ferguson, A. N. (2004). The association between continuous naming speed and word reading skill in fourth-to sixth-grade children. *Australian Journal of Psychology, 56*(3), 155-163.

Breier, J. I., Gray, L. C., Fletcher, J. M., Foorman, B., & Klaas, P. (2002). Perception of speech and nonspeech stimuli by children with and without reading disability and attention deficit hyperactivity disorder. *Journal of Experimental Child Psychology, 82*(3), 226-250.

Brosnan, M., Demetre, J., Hamill, S., Robson, K., Shepherd, H., & Cody, G. (2002). Executive functioning in adults and children with developmental dyslexia. *Neuropsychologia, 40*(12), 2144-2155.

Burt, J. S. (2005). What is orthographic processing skill and how does it relate to word identification in reading? *Journal of Research in Reading, 29*(4), 400-417.

Cardoso-Martins, C., & Pennington, B. F. (2004). The relationship between phoneme awareness and rapid serial naming skills and literacy acquisition: The role of developmental period and reading ability. *Scientific Studies of Reading, 8*(1), 27-52.

Castles, A. & Coltheart, M. (2004). Is there a link from phonological awareness to success in learning to read? *Cognition, 91*(1), 77–11.

Catts, H. W. (1989). Defining dyslexia as a developmental language disorder. *Annals of Dyslexia, 39*(1), 50-64.

Catts, H. W., Fey, M. E., Zhang, X., & Tomblin, J. B. (1999). Language basis of reading and reading disabilities: Evidence from a longitudinal investigation. *Scientific Studies of Reading, 3*(4), 331-361.

Catts, H. W., Gillispie, M., Leonard, L. B., Kail, R. V., & Miller, C. A. (2002). The role of speed of processing, rapid naming, and phonological awareness in reading achievement. *Journal of Learning Disabilities, 35*(6), 509-24.

Chandarina, A. S. (2003). Acquisition of reading skills in russian-speaking ESL children. (Unpublished doctoral dissertation). University of Toronto, Canada.

Chase, C., Ashourzadeh, A., Kelly, C., Monfette, S., & Kinsey, K. (2003). Can the magnocellular pathway read? Evidence from studies of color. *Vision Research, 43*(10), 1211-1222.

Clarke, P., Hulme, C., & Snowling, M. (2005). Individual differences in RAN and reading: A response timing analysis. *Journal of Research in Reading, 28*(2), 73-86.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences (2nd ed.).* Hillsdale, NJ: Erlbaum.

Coltheart, M., & Rastle, K. (1994). Serial processing in reading aloud: Evidence for dual-route models of reading. Journal of Experimental Psychology: *Human Perception and Performance, 20*(6), 1197-1211.

Compton, D. L. (2003). The influence of item composition on RAN letter performance in first-grade children. *The Journal of Special Education, 37*(2), 81–94.

Compton, D. L., Defries, J. C., & Olson, R. K. (2001). Are RAN- and phonological awareness-deficits additive in children with reading disabilities? *Dyslexia, 7*(3), 125-149.

Compton, D. L., Olson, R. K., DeFries, J. C., & Pennington, B. F. (2002). Comparing the relationships among two different versions of alphanumeric rapid automatized naming and word level reading skills. *Scientific Studies of Reading, 6*(4), 343–368.

Cornelissen, P. L., Hansen, P. C., Hutton, J. L., Evangelinou, V., & Stein, J. F. (1998). Magnocellular visual function and children's single word reading. *Vision Research, 38*(3), 471-482.

Critchley, M. (1970). *The dyslexic child (2nd ed.)*. London: Heinemann Medical.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16*(3), 297-334.

Cutting, L. B., & Denckla, M. B. (2001). The relationship of rapid serial naming and word reading in normally developing readers: An exploratory model. *Reading and Writing, 14*(7), 673-705.

Daniel, S. S., Walsh, A. K., Goldston, D. B., Arnold, E. M., Reboussin, B. A., & Wood, F. B. (2006). Suicidality, school dropout, and reading problems among adolescents. *Journal of Learning Disabilities, 39*(6), 507.

Denckla, M. B. (1972). Color-naming defects in dyslexic boys. *Cortex, 8*(2), 164-76.

Denckla, M. B., & Cutting, L. E. (1999). History and significance of rapid automatized naming. *Annals of Dyslexia, 49*(1), 29-42.

Denckla, M. B., & Rudel, R. G. (1974). Rapid 'automatized' naming of pictured objects, colors, letters and numbers by normal children. *Cortex, 10*(2), 186-202.

Denckla, M. B., & Rudel, R. G. (1976a). Rapid "automatized" naming (R.A.N): Dyslexia differentiated from other learning disabilities. *Neuropsychologia, 14*(4), 471-79.

Denckla, M. B., & Rudel, R. G. (1976b). Naming of pictured objects by dyslexic and other learning disabled children. *Brain and Language, 3*(1), 1-15.

Eden, G. F., Stein, J. F., Wood, H. M., & Wood, F. B. (1995). Temporal and spatial processing in reading disabled and normal children. *Cortex, 31*(3), 451-68.

Eden, G. F., VanMeter, J. W., Rumsey, J. M., & Zeffiro, T. A. (1996). The visual deficit theory of developmental dyslexia. *NeuroImage, 4*(3), S108-S117.

Ehri, L. C. (2005). Learning to read words: Theory, findings, and issues. *Scientific Studies of Reading, 9*(2), 167–188.

Evans, J., Floyd, R., & McGrew, K. (2002). The relations between measures of Cattell-Horn-Carroll (CHC) cognitive abilities and reading on childhood and adolescence. *School Psychology Review*, *31*(2), 246-262.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175-191.

Fawcett, A. J., & Nicolson, R. I. (1994). Naming speed in children with dyslexia. *Journal of Learning Disabilities, 27*(10), 641-46.

Felton, R. H., & Brown, I. S. (1990). Phonological processes as predictors of specific reading skills in children at risk for reading failure. *Reading and Writing, 2*(1), 39–59.

Felton, R. H., Naylor, C. E., & Wood, F. B. (1990). Neuropsychological profile of adult dyslexics. *Brain and Language, 39*(4), 485-97.

Fletcher, J. M., Foorman, B. R., Shaywitz, S. E., & Shaywitz, B. A. (1999). Conceptual and methodological issues in dyslexia research: A lesson for developmental disorders. In H. Tager-Flusberg (Ed.), *Neurodevelopmental disorders*, 271–306. The MIT Press

Fuchs, L. S., Fuchs, D., Hosp, M., & Jenkins, J. R. (2001). Oral reading fluency as an indicator of reading competence: A theoretical, empirical, and historical analysis. *Scientific Studies of Reading, 5*(3), 239-256.

Georgiou, G. K., Parrila, R., & Kirby, J. (2006). Rapid naming speed components and early reading acquisition. *Scientific Studies of Reading, 10*(2), 199-220.

Georgiou, G. K., Parrila, R., Kirby, J. R., & Stephenson, K. (2008). Rapid naming components and their relationship with phonological awareness, orthographic knowledge, speed of processing, and different reading outcomes. *Scientific Studies of Reading, 12*(4), 325-350.

Geschwind, N. (1965). Disconnection syndrome in animals and man (Parts I, II). *Brain, 88*, 237-294, 585-644.

Geschwind, N., & Fusillo, M. (1966). Color-naming defects in association with alexia. *Archives of Neurology, 15*(2), 137-46.

Hammill, D. D., Mather, N., Allen, E. A., & Roberts, R. (2002). Using semantics, grammar, phonology, and rapid naming tasks to predict word identification. *Journal of Learning Disabilities, 35*(2), 121.

Helland, T., & Asbjornsen, A. (2000). Executive functions in dyslexia. *Child Neuropsychology, 6*(1), 37-48.

Hinshelwood, J. (1917). *Congenital word-blindness*. HK Lewis & Co., ltd.

The Individuals with Disabilities Education Improvement Act of 2004, Pub. L. No. 108-446, §632, 118 Stat. 2744 (2004).

Ingesson, & Gunnel, S. (2007). Growing up with dyslexia. *School Psychology International, 28*(5), 574.

Jastak, S., & Wilkinson, G. S. (1984). Wide Range Achievement Test–Revised. Wilmington, DE: Jastak Associates.

Kail, R., & Hall, L. K. (1994). Processing speed, naming speed, and reading. *Developmental Psychology, 30*(6), 949-54.

Kail, R., Hall, L. K., & Caskey, B. J. (1999). Processing speed, exposure to print, and naming speed. *Applied Psycholinguistics, 20*(2), 303-14.

Kaufman, A.S., & Kaufman, N.L. (1985). Kaufman Test of Educational Achievement. Circle Pines, MN: American Guidance Service.

Kirby, J. R., Parrila, R. K., & Pfeiffer, S. L. (2003). Naming speed and phonological awareness as predictors of reading development. *Journal of Educational Psychology, 95*(3), 453-464.

Korhonen, T. T. (1995). The persistence of rapid naming problems in children with reading disabilities: A nine-year follow-up. *Journal of Learning Disabilities, 28*(4), 232-39.

LaBerge, D. & Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology, 6*(2), 293-323.

Lervåg, A., & Hulme, C. (2009). Rapid automatized naming (RAN) taps a mechanism that places constraints on the development of early reading fluency. *Psychological Science, 20*(8), 1040-8.

Levy, B.A., & Bourassa, D.C., & Horn, C. (1999). Fast and slow namers: Benefits of segmentation and whole word training. *Journal of Experimental Child Psychology, 73*(2), 115-138.

Lovegrove, W. J., Martin, F., & Slaghuis, W. (1986). A theoretical and experimental case for a visual deficit in specific reading disability. *Cognitive Neuropsychology, 3*(2), 225-267.

Lyon, G. R., Fletcher, J. M., & Barnes, M. C. (2003). Learning disabilities. In E. Marsh & R. Barkley (Eds.), *Child Psychopathology – Second Edition* (520-586). New York: Guilford.

Lyon, G. R. (1995). Toward a definition of dyslexia. *Annals of Dyslexia, 45*(1), 3-27.

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia, 53*(1), 1-14.

Manis, F., & Doi, L. (1995). Word naming speed, phonological coding and orthographic knowledge in dyslexic and normal readers. Symposium paper presented at the *Society for Research in Child Development*. Indianapolis, IN.

Manis, F. R., Doi, L. M., & Bhadha, B. (2000). Naming speed, phonological awareness, and orthographic knowledge in second graders. *Journal of Learning Disabilities, 33*(4), 325-333, 374.

Manis, F. R., Seidenberg, M. S., & Doi, L. M. (1999). See dick RAN: Rapid naming and the longitudinal prediction of reading subskills in first and second graders. *Scientific Studies of Reading, 3*(2), 129-157.

McBride-Chang, C., & Ho, C. S. H. (2000). Naming speed and phonological awareness in chinese children: Relations to reading skills. *Journal of Psychology in Chinese Societies, 1*(1), 93-108.

McBride-Chang, C., & Manis, F. R. (1996). Structural invariance in the associations of naming speed, phonological awareness, and verbal reasoning in good and poor readers: A test of the double deficit hypothesis. *Reading and Writing, 8*(4), 323-339.

Meisinger, E. B., Bloom, J. S., & Hynd, G. W. (2009). Reading fluency: Implications for the assessment of children with reading disabilities. *Annals of Dyslexia, 60*(1), 1-17.

Meyer, M. S. & Felton, R. H. (1999). Repeated reading to enhance fluency: Old approaches and new directions. *Annals of Dyslexia, 49*(1), 283-306.

Meyer, M. S., Wood, F. B., Hart, L. A., & Felton, R. H. (1998). Selective predictive value of rapid automatized naming in poor readers. *Journal of Learning Disabilities, 31*(2), 106-17.

Mitchell, J. (2001). Comprehensive test of phonological processing. *Assessment for Effective Intervention, 26*(3), 57-63.

Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology, 64*(2), 199-231.

Morgan, W. P. (1896). A case of congenital word blindness. *British Medical Journal, 2* (1871), 1378.

Morris, R. D., Stuebing, K. K., Fletcher, J. M., Shaywitz, S. E., Lyon, G. R., Shankweiler, D. P., et al. (1998). Subtypes of reading disability: Variability around a phonological core. *Journal of Educational Psychology, 90*(3), 347-73.

Närhi, V., Ahonen, T., Aro, M., Leppäsaari, T., Korhonen, T. T., Tolvanen, A., et al. (2005). Rapid serial naming: Relations between different stimuli and neuropsychological factors. *Brain and Language, 92*(1), 45-57.

National Center for Education Statistics (2004). The nation's report card: Reading highlights 2003. Washington, DC: US Department of Education.

National Reading Panel. (2000). Report of the national reading panel. Washington: National Reading Panel.

Neuhaus, G., Foorman, B. R., Francis, D. J., & Carlson, C. D. (2001). Measures of information processing in rapid automatized naming (RAN) and their relation to reading. *Journal of Experimental Child Psychology, 78*(4), 359-373.

Nicolson, R. I., & Fawcett, A. J. (1994). Reaction times and dyslexia. *The Quarter Journal of Experimental Psychology Section A, 47*(1), 29-48.

Nicolson, R. I. (1996). Developmental Dyslexia: Past, present and future. *Dyslexia, 2*(3), 190-207.

Nicolson, R. I., & Fawcett, A. J. (1996). Dyslexia screening test. London: The Psychological Corporation.

Nicolson, R. I., Fawcett, A. J., & Dean, P. (1999). Developmental dyslexia: The cerebellar deficit hypothesis. *Trends in Neurosciences, 24*(9), 508-511.

Novoa, L. (1988). Word-retrieval process and reading acquisition and development in bilingual and monolingual children. (Unpublished doctoral dissertation). Harvard University, Cambridge, MA.

Pinnell, G. S., Pikulski, J. J., Wixson, K. K., Campbell, J. R., Gough, P. B., & Beatty, A. S. (1995). Listening to children read aloud: Oral fluency. Washington, DC: U.S. Department of Education, National Center for Education Statistics. Retrieved February 6, 2011, from http://nces.ed.gov/pubs95/web/95762.asp

Powell, D., Stainthorp, R., Stuart, M., Garwood, H., & Quinlan, P. (2007). An experimental comparison between rival theories of rapid automatized naming performance and its relationship to reading. *Journal of Experimental Child Psychology, 98*(1), 46-68.

Pennington, B. F., Cardoso-Martins, C., Green, P. A., & Lefly, D. L. (2001). Comparing the phonological and double deficit hypotheses for developmental dyslexia. *Reading and Writing, 14*(7), 707-755.

Perfetti, C. A. (1985). *Reading ability*. Oxford University Press New York.

Posner, M. I., & Snyder, C. R. R. (1975). Facilitation and inhibition in the processing of signals. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance – Volume 5* (669–682). New York: Academic.

Posner, M.I., & Synder, C.R.R. (1975). Attention and cognitive control. In R.L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (55-58). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., et al. (2003). Theories of developmental dyslexia: insights from a multiple case study of dyslexic adults. *Brain, 126*(4), 841.

Reed, M. A. (1989). Speech perception and the discrimination of brief auditory cues in reading disabled children. *Journal of Experimental Child Psychology, 48*(2), 270-92.

Reiter, A., Tucha, O., & Lange, K. W. (2005). Executive functions in children with dyslexia. *Dyslexia: An International Journal of Research and Practice, 11*(2), 116-131.

Roberts, R., & Mather, N. (1997). Orthographic dyslexia: The neglected subtype. *Learning Disabilities Research and Practice, 12*(4), 236-50.

Rutter, M. (1978). Dyslexia. In A. Benton & D. Pearl (Eds.), *Dyslexia: An appraisal of current knowledge* (3–28). New York: Oxford.

Savage, R. (2004). Motor skills, automaticity and developmental dyslexia: A review of the research literature. *Reading and Writing, 17*(3), 301-324.

Savage, R., & Frederickson, N. (2005). Evidence of a highly specific relationship between rapid automatic naming of digits and text-reading speed. *Brain and Language, 93*(2), 152-159.

Savage, R., Frederickson, N., Goodwin, R., Patni, U., Smith, N., & Tuersley, L. (2005). Evaluating current deficit theories of poor reading: role of phonological processing, naming speed, balance automaticity, rapid verbal perception and working memory. *Perceptual and Motor Skills, 101*(2), 345.

Savage, R. S., Frederickson, N., Goodwin, R., Patni, U., Smith, N., & Tuersley, L. (2005b). Relationships among rapid digit naming, phonological processing, motor automaticity, and speech perception in poor, average, and good readers and spellers. *Journal of Learning Disabilities, 38*(1), 12-28.

Savage, R., Pillay, V., & Melidona, S. (2007). Deconstructing rapid automatized naming: Component processes and the prediction of reading difficulties. *Learning and Individual Differences, 17*(2), 129-146.

Scarborough. (1998). Predicting the future achievement of second graders with reading disabilities: Contributions of phonemic awareness, verbal memory, rapid naming, and IQ. *Annals of Dyslexia, 48*(1), 115-136.

Scarborough, H., & Domgaard, R. M. (1998, April). An exploration of the relationship between reading and rapid serial naming. Poster presented at the meeting of the *Society for Scientific Study of Reading*, San Diego, CA.

Schatschneider, C., Carlson, C. D., Francis, D. J., Foorman, B. R., & Fletcher, J. M. (2002). Relationship of rapid automatized naming and phonological awareness in early reading development: Implications for the double-deficit hypothesis. *Journal of Learning Disabilities, 35*(3), 245-56.

Schatschneider, C., Fletcher, J. M., Francis, D. J., Carlson, C. D., & Foorman, B. R. (2004). Kindergarten prediction of reading skills: A longitudinal comparative analysis. *Journal of Educational Psychology, 96*(2), 265-282.

Shaywitz, S. (2003*). Overcoming dyslexia: A new and complete science-based program for reading problems at any level*. AA Knopf New York: Random House, New York.

Shaywitz, S. E., & Shaywitz, B. A. (2005). Dyslexia (specific reading disability). *Biological Psychiatry, 57*(11), 1301-1309.

Shaywitz, S. E., & Shaywitz, B. A. (2008). Paying attention to reading: The neurobiology of reading and dyslexia. *Development and Psychopathology, 20*(4), 1329-49.

Skottun, B. C., & Parke, L. A. (1999). The possible relationship between visual deficits and dyslexia: examination of a critical assumption. *Journal of Learning Disabilities, 32*(1), 2-5.

Snowling, M., Bishop, D. V. M., & Stothard, S. E. (2000). Is preschool language impairment a risk factor for dyslexia in adolescence? *Journal of Child Psychology and Psychiatry, 41*(5), 587-600.

Snowling, M. J. (1990). *Dyslexia: A cognitive developmental perspective*. Cambridge, MA: Basil Blackwell.

Snowling, M. J. (2000). *Dyslexia*. Blackwell Publishers.

Sofie, C.A., & Riccio, C.A., (2002). A comparison of multiple methods in the identification of children with reading disabilities. *Journal of Learning Disabilities, 35*(3), 234-244.

Spring, C., & Davis, J. (1988). Relations of digit naming speed with three components of reading. *Applied Psycholinguistics, 9*(4), 315-334.

Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly, 21*(4), 360-407.

Stanovich, K. E., & Siegel, L. S. (1994). Phenotypic performance profile of children with reading disabilities: A regression-based test of the phonological-core variable-difference model. *Journal of Educational Psychology, 86*(1), 24-24.

Stein, J., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia. *Trends in Neurosciences, 20*(4), 147-152.

Stevens, J. (2002). *Applied multivariate statistics for the social sciences (4th ed.).* Mahwah, NJ: Lawrence Erlbaum Associates.

Stringer, R., & Stanovich, K. E. (2000). The connection between reaction time and variation in reading ability: Unraveling covariance relationships with cognitive ability and phonological sensitivity. *Scientific Studies of Reading, 4*(1), 41-53.

Stringer, R. W., Toplak, M. E., & Stanovich, K. E. (2004). Differential relationships between RAN performance, behaviour ratings, and executive function measures: Searching for a double dissociation. *Reading and Writing, 17*(9), 891-914.

Swanson, H. L., Trainin, G., Necoechea, D. M., & Hammill, D. D. (2003). Rapid naming, phonological awareness, and reading: A meta-analysis of the correlation evidence. *Review of Educational Research, 73*(4), 407-440.

Swanson, H. L., Zheng, X., & Jerman, O. (2009). Working memory, short-term memory, and reading disabilities: a selective meta-analysis of the literature. *Journal of learning disabilities*, *42*(3), 260-87.

Swanson, L. (1986, June). Training automaticity of letter-sound correspondence in poor readers. Paper presented at the annual meeting of the *Canadian Psychological Association*, Toronto, Canada.

Tallal, P. (1980). Auditory temporal perception, phonics and reading disability in children. *Brain and Language, 9*(2), 182-198.

Torgesen, J. K., Alexander, A. W., Wagner, R. K., Rashotte, C. A., Voeller, K. K. S., & Conway, T. (2001). Intensive remedial instruction for children with severe reading disabilities: Immediate and long-term outcomes from two instructional approaches. *Journal of Learning Disabilities, 34*(1), 33-58.

Torgesen, J. K., Rashotte, C. A., & Alexander, A. W. (2001). Principles of fluency instruction in reading: Relationships with established empirical outcomes. In M. Wolf (Ed.), *Dyslexia, fluency, & the brain*. Timonium: New York Press.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1994). Longitudinal studies of phonological processing and reading. *Journal of Learning Disabilities, 27*(5), 276-86.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1999). Test of Word Reading Efficiency. Austin, TX: Pro-Ed., Inc.

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Burgess, S., & Hecht, S. (1997). Contributions of phonological awareness and rapid automatic naming ability to the growth of word-reading skills in second-to fifth-grade children. *Scientific Studies of Reading, 1*(2), 161-85.

Vaessen, A., & Blomert, L. (2010). Long-term cognitive dynamics of fluent reading development. *Journal of Experimental Child Psychology, 105*(3), 213-31.

van den Bos, K. P. (1998). IQ, phonological awareness and continuous-naming speed related to Dutch poor decoding children's performance on two word identification tests. *Dyslexia, 4*(2), 73-89.

van den Bos, K. P., Zijlstra, B. J. H., & Lutje Spelberg, H. C. (2002). Life-Span data on continuous-naming speeds of numbers, letters, colors, and pictured objects, and word-reading speed. *Scientific Studies of Reading, 6*(1), 25-49.

Vanderwood, M. L., McGrew, K. S., Flanagan, D. P., & Keith, T. Z. (2002). The contribution of general and specific cognitive abilities to reading achievement. *Learning and individual differences*, 13(2), 159–188.

Vellutino, F. R., & Scanlon, D. M. (1987). Phonological coding, phonological awareness, and reading ability: Evidence from a longitudinal and experimental study. *Merrill-Palmer Quarterly, 33*(3), 321-63.

Vellutino, F. R. (1979). *Dyslexia: theory and research*. MIT Press, Cambridge, Mass.

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*(1), 2-40.

Vitu, F., & McConkie, G. W. (2000). Regressive saccades and word perception in adult reading. In A. Kennedy, D. Heller, J. Pynte, & R. Radach (Eds.), *Reading as a perceptual process* (301–26). North-Holland.

Waber, D. P., Weiler, M. D., Wolff, P. H., Bellinger, D., Marcus, D. J., Ariel, R., et al. (2001). Processing of rapid auditory stimuli in school-age children referred for evaluation of learning disorders. *Child Development, 72*(1), 37-49.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*(2), 192-212.

Wagner, R. K., Torgesen, J. K., Laughon, P., Simmons, K., & Rashotte, C. A. (1993). Development of young readers' phonological processing abilities. *Journal of Educational Psychology, 85*(1), 83-103.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psychology, 30*(1), 73-87.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1999). Comprehensive Test of Phonological Processing. Austin, TX: Pro-Ed., Inc.

Wechsler, D. (1974). Wechsler Intelligence Scale for Children–Revised. San Antonio, TX: Psychological Corp.

Wiederholt, J., & Bryant, B. (2001). Gray Oral Reading Test, Fourth Edition. Austin, TX: Pro-Ed., Inc.

Willburger, E., Fussenegger, B., Moll, K., Wood, G., & Landerl, K. (2008). Naming speed in dyslexia and dyscalculia. *Learning and Individual Differences, 18*(2), 224-236.

Wilson, J., & Frederickson, N. (1995). Phonological awareness training: An evaluation. *Educational and Child Psychology, 12*, 68-79.

Wimmer, H., & Goswami, U. (1994). The influence of orthographic consistency on reading development: Word recognition in english and german children. *Cognition, 51*(1), 91-103.

Wimmer, H., & Mayringer, H. (2002). Dysfluent reading in the absence of spelling difficulties: A specific disability in regular orthographies. *Journal of Educational Psychology, 94*(2), 272-77.

Wolf, M. (1991). Naming speed and reading: The contribution of the cognitive neurosciences. *Reading Research Quarterly, 26*(2), 123-41.

Wolf, M. (1999). What time may tell: Towards a new conceptualization of developmental dyslexia. *Annals of Dyslexia, 49*(1), 3-28.

Wolf, M., Bally, H., & Morris, R. (1986). Automaticity, retrieval processes, and reading: A longitudinal study in average and impaired readers. *Child Development, 57*(4), 988-1000.

Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology, 91*(3), 415-438.

Wolf, M., Bowers, P. G., & Biddle, K. (2000). Naming-speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities, 33*(4), 386-407.

Wolf, M., & Goodglass, H. (1986). Dyslexia, dysnomia, and lexical retrieval: A longitudinal investigation. *Brain and Language, 28*(1), 154-68.

Wolf, M., & Katzir-Cohen, T. (2001). Reading fluency and its intervention. *Scientific Studies of Reading, 5*(3), 211–239.

Wolf, M., & Obregón, M. (1992). Early naming deficits, developmental dyslexia, and a specific deficit hypothesis. *Brain and Language, 42*(3), 219-247.

Wolf, M., O'Rourke, A. G., Gidney, C., Lovett, M., Cirino, P., & Morris, R. (2002). The second deficit: An investigation of the independence of phonological and naming-speed deficits in developmental dyslexia. *Reading and Writing, 15*(1), 43-72.

Wolf, M., Pfeil, C., Lotz, R., & Biddle, K. (1994). Towards a more universal understanding of the developmental dyslexias: The contribution of orthographic factors. In V. Berninger (Ed.), *The varieties of orthographic knowledge I: Theoretical and developmental issues* (137–171). Dordrecht, The Netherlands: Kluwer.

Wolff, P. H. (1990). Rate and timing precision of motor coordination in developmental dyslexia. *Developmental Psychology, 26*(3), 349-59.

Wolff, P. H., Michel, G. F., & Ovrut, M. (1990). The timing of syllable repetitions in developmental dyslexia. *Journal of Speech, Language and Hearing Research, 33*(2), 281-289.

Woodcock, R.W., (1987) Woodcock Reading Mastery Tests - revised, Circle Pines, MN: American Guidance Service.

Woodcock, R. W. (1997). Woodcock Diagnostic Reading Battery. Itasca, IL: Riverside.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001, 2007). Woodcock-Johnson III. Rolling Meadows, IL: Riverside Publishing.

Young, A., & Bowers, P. G. (1995). Individual difference and text difficulty determinants of reading fluency and expressiveness. *Journal of Experimental Child Psychology, 60*(3), 428-454.