MULTICOMPONENT TREATMENT OF RAPID NAMING, READING RATE, AND

VISUAL ATTENTION IN SINGLE AND DOUBLE DEFICIT DYSLEXICS

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MULTICOMPONENT TREATMENT OF RAPID NAMING, READING RATE, AND

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ABSTRACT

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While the relationship between rapid automatic naming (RAN) deficiencies and dyslexia (reading disability) is well developed and supported in the behavioral and medical research literature to date, direct treatment of the specific RAN deficiency in addition to subsequently poor reading outcomes in the lexical skill of reading rate and the sublexical process of visual attention (VA), has not been well considered in the design of treatment studies for reading disorders. As such, the purpose of the present experimental treatment study, designed with a delayed treatment control condition, was to ascertain if a targeted multicomponent reading intervention improved outcomes in the sublexical dependent variables of RAN and VA, as well as outcomes in the lexical skill of reading rate.

After reviewing descriptive statistics and meeting methodological assumptions, inferential statistics were analyzed using the main analyses, a repeated measures MANCOVA to test the difference between treatment and control outcomes, and a repeated measures MANOVA to test the difference between outcomes for participants with single (RAN only) deficit profiles and those with double (RAN and phonological awareness) deficits. While multivariate results indicated there was not a statistically significant difference between treatment and control groups in terms of all dependent variables, evidence was found to support the dissociation of single and double deficit groups.

After each multivariate analysis, univariate outcomes were examined and discriminant analysis (DISCRIM) was implemented to further understand the specific contribution of each

dependent variable (RAN, VA, rate) in terms of variance in the independent variables (treatment versus control; single versus double deficit). In terms of differentiating between treatment and control groups, a combined discriminant function of all dependent variables (RAN, VA, rate) accounted for 22.5% of the variance between groups, indicating the multicomponent reading treatment produced beneficial clinical outcomes for participants. In particular, the univariate contribution of VA to overall treatment outcomes was specifically strong ($d = .43$), representing a substantial mean increase in VA scores posttreatment. In terms of differentiating between single and double deficit groups, a combined discriminant function of all dependent variables accounted for 38% of the variance between groups, reconfirming the existence of bivariate pathways to dyslexia in addition to confirming the additional reading impairment manifested in those with double deficits.

DEDICATION

To Jack – you will always be the first.

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CHAPTER 1

Study Introduction

The present experimental study was designed to ascertain treatment effectiveness of a

new, specifically designed multicomponent reading intervention for individuals with rapid

automatic naming, (RAN-type) sublexical deficits resulting in single and double deficit

developmental dyslexia. Chapter I includes the relevant historical and theoretical background to

this issue, a formal problem statement, the theoretical foundation of the issue, and a rationale for

study. Also included in Chapter I are limitations and delimitations, assumptions, and definitions.

Background of the Problem

As early as 1871, Darwin commented on the division of naturally acquired oral language

competency versus the learned skills needed for literacy. In fact, Darwin theorized humans lack

specific cognitive mechanisms for the relatively modern societal inventions of reading and

writing. (Darwin, 1871). Over a century later, Pinker (1997) reviewed the acquisition of literacy

and arrived at the same conclusion as Darwin. He conceptualized our brains as mentally

hardwired for spoken language, with print learning as optional, much like an additional software

package (Pinker, 1997). Reading and writing, then, must be taught. And sometimes, much like

the process of installing and even later updating complicated computer software, there are

glitches along the way in learning to read and write.

In order to better understand what causes some children to have glitches with reading

acquisition, researchers began looking more specifically at underlying neural mechanisms

responsible for reading development. In 1965, neuroscientist Norman Gerschwind began the first

investigation into the role of letter naming speed in acquisition of a reader's lexicon. Gerschwind

theorized the cognitive processes needed to attach a verbal label to an abstract familiar visual

stimulus, such as giving a name to a color, might predict reading ability (Wolf, 1986). Based on Gerschwind's theory, researchers Denkla and Rudel (1976) created the first psychometric tasks to measure serial rapid automatized naming (RAN) which are still considered the prototype for modern RAN assessment. RAN tasks measure the speed at which readers name letters, numbers, or other symbols in a reading-like array, from left to right and top to bottom. Denkla and Rudel (1976), like Gerschwind, asserted speed on sublexical RAN could differentiate good and poor readers.

A decade later, Keith Stanovich (1988), reading theorist and researcher noted the, "best candidates for key processing mechanisms for underlying reading disorder are those that are fast, automatic, and informationally encapsulated." (p. 158). He asserted reading disability resulted from a failure to automatically recognize words, an outcome due to a core deficit in the visual orthographic skills required to effortlessly map letters to sounds (Stanovich, 1988). While many researchers of the time believed auditory processing of sounds or phonemes (phonological awareness, PA) was the singular deficit involved in disordered reading, Stanovich (1988) maintained phonological theories were oversimplified as the potential contribution of deficiently automatized orthographic processes was overlooked.

At roughly the same time, researchers began to connect prowess on the RAN assessment task to fluent word recognition, oral reading, and silent reading (Wolf, 1991; Wolf, Bally, & Morris, 1986). According to Wolf (1991), four conclusions can be drawn from the RAN research of the 1970's and 1980's. First, there is a direct relationship between the time it takes to name a letter and the time it takes to retrieve a word. Second, naming time is directly linked to higher lexical processes, specifically reading fluency. Third, naming speed is an index of automaticity and most likely related to underlying cognitive processes responsible for skill automatization (i.e.

attentional and other executive processes). And finally, RAN skill can be used to differentiate between average readers and struggling readers with dyslexia (Wolf, 1991).

Problem Statement

While the correlation between RAN deficiencies and dyslexia (reading disability) are well developed and supported in the behavioral and medical research literature to date, direct treatment of the specific RAN deficiency, and subsequently poor reading outcomes, has not been well considered in the design of treatment studies for reading disorders (Holland, 2007). While behavioral intervention studies in general account for less than 1% of the total research literature conducted on the topic of dyslexia and reading disorder (Bakker, 2006), the research on treatments for nonphonological type dyslexia are even more limited in nature (Wolf & Bowers, 2000). In fact, Kirby, Georgiou, Martinussen, and Parilla (2010) reviewed the reading treatment literature and found only a handful of studies targeting individuals with letter naming deficiencies. This gap in the literature, in terms of lack of treatment evidence for single (RAN only) and double deficit (RAN + PA) type dyslexia, presents a strong rationale for investigating how to best treat dyslexic individuals with RAN core deficits.

The skewed research focus on treatments for PA-type dyslexia has perhaps occurred because previous and current definitions of dyslexia, promoted by the International Dyslexia Association (1994, 2002) and the National Institute for Child Health and Human Development (1994, 2002), only reference dyslexia as resultant from phonological impairment. The resulting narrow educational focus on PA as a singular core deficit, despite contrary evidence in the research literature, has caused system-wide problems beyond a lack of available information on treating RAN-type dyslexia. First, the limited definition of dyslexia with a PA-only focus has resulted in systemic educational implementation of PA-only screening for children learning to

read, causing wide-scale failure in identification of young children with RAN-only dyslexia in need of early intervention (Meisinger, Bloom, & Hynd, 2010; Wolf & Katzir-Cohen, 2001). Second, for individuals with RAN-type deficits (RAN-type or RAN+PA type) who are afforded dyslexia intervention, the instructional materials available for treatment were most likely designed for individuals with PA-only impairment, resulting in inadequate response to intervention (Holland, 2007; Wolf & Katzir-Cohen, 2001).

By following the PA-only singular definition of dyslexia, reading instruction in the public school setting is not designed with sublexical difficulties in RAN and resultant reading fluency problems in mind. For instance in one recent study, authors noted struggling readers served in general education primary classrooms received less than one minute per day in the fluency building practice of orally reading connected text (Kent, Wanzek, & Al Otaiba, 2012). Not surprisingly, these same individuals later present with lexical deficits, specifically in fluency, with underlying sublexical deficits in RAN (Shaywitz, Morris, & Shaywitz, 2008). Moreover, individuals who are identified with RAN deficits are particularly resistant to intervention with phonological-based instruction, as there is no emphasis on needed outcomes in decoding, automatization, and fluency within these treatment regimes (Al Otaiba & Fuchs, 2002, 2006; Torgeson, Wagoner, & Rashotte, 1994).

Dyslexia is a heterogeneous disorder with underlying causality beyond PA only, necessitating varied heterogeneous interventions (Berninger & May, 2011). Creation of a multimodal treatment for RAN-based reading problems and testing of this treatment within an experimental condition is one necessary step in uncovering how best to assist students with RAN-type single and double deficit dyslexia. Investigation into if and how treatment can improve the sublexical processes naming speed (RAN) and related sublexical difficulty in visual

attention (VA), as well as, the lexical outcome of reading rate is essential in terms of assisting many dyslexic learners who are currently not receiving adequate treatment.

Theoretical Foundation: How Reading Works

Bowers, Kirby, and Deacon's (2010) leveled model of reading acquisition (Figure 1) is a compact yet comprehensive theoretical model utilized in the present study. According to this reading model, there are three basic levels of reading skill: sublexical, lexical and supralexical. These reading levels are built from the ground up much like a house, with lower level sublexical proficiencies creating a much needed foundation for the building of outward reading ability in terms of lexical and supralexical outcomes.

Underlying the reading process are sublexical precursors to word reading located at the bottom of the acquisition model (Bowers et al., 2010). Sublexical skills are those below the level of a word and include capacities in phonological awareness (PA), morphological awareness, rapid automatized naming (RAN), visual attention (VA), and working memory (Katzir et al., 2006). Typically, a fluent reader has intuitively learned to orchestrate previously acquired sublexical skills in order to read and is not aware of underlying sublexical processes while reading. Readers who struggle, though, have difficulties in the acquisition of one or more of these sublexical areas, resulting in a weak reading foundation (Bowers, Kirby, & Deacon, 2010).

At the middle or lexical level of reading acquisition are word-level skills such as single word decoding (phonics), sight word recognition, vocabulary knowledge, and word encoding (spelling) (Bowers et al., 2010). Lexical prowess is dependent on the correct, automatic, and efficient functioning of the foundational sublexical skills. And, well developed lexical skills are necessary, but not sufficient, to becoming proficient in the supralexical competencies characterizing "good" readers (Adams, 1990). Within the lexical level, there is also an assumed

shift from slower sequential decoding (sounding out) of words to faster automatic processing of

orthographic word forms as whole units (Adams, 1990; Vaessen & Blomert, 2010). If one or

more skills within the sublexical level are not functioning properly, this shift may not occur,

resulting in manifestation of some or all of the outward indicators of dyslexia including poor

word decoding, lack of automaticity, slow reading rate, and poor spelling (Shaywitz, 2003).

Finally, the most complex domain in Bowers et al.'s 2010 reading acquisition model is

the supralexical level, comprised of comprehension abilities. Often, in dyslexic readers, the

supralexical level (reading and listening comprehension) remains intact. Although

comprehension abilities are intact, reading growth, especially as a child progresses into upper

elementary and beyond, may be slow and halting due to deficits sublexical and lexical

functioning. Sadly, underachievement and failure may occur due to poorly developed underlying

sublexical and lexical skills, regardless of functioning supralexical abilities.
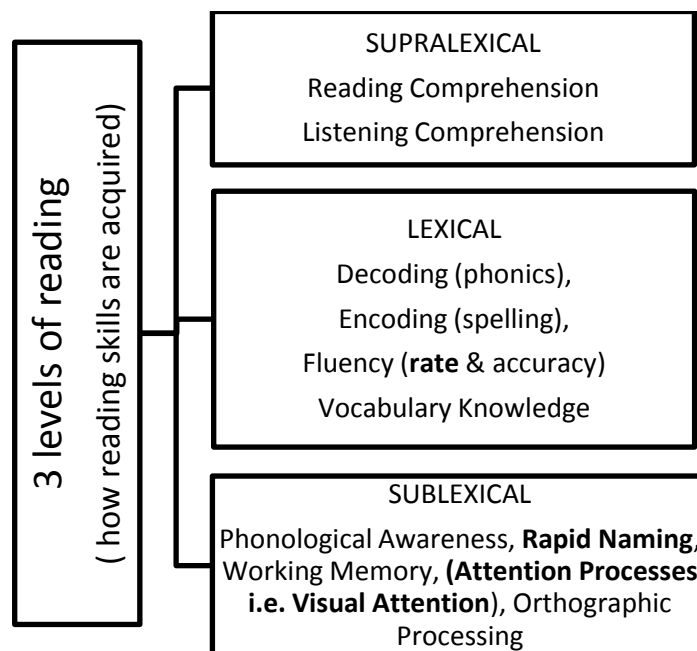
Figure 1. This figure shows the method of reading acquisition proposed by Bowers, Kirby, and Deacon (2010). Again, note the causal issues in dyslexia are attributed to sublexical level; the visible outcomes are those occurring at the lexical level; yet the supralexical level often remains intact. "Attention processes" were added at the sublexical level for purposes of this study. Bolded words represent dependent variables examined in this study.

Statement of Purpose

The purpose of this study was to ascertain if a multicomponent reading treatment, developed specifically for those with single deficit (RAN only) and double deficit (RAN + PA) underlying dyslexic deficiencies, improved sublexical skills in RAN and VA, as well as, the lexical skill of reading rate. Sublexical treatments in isolation are notably less effective than multicomponent treatments which also address lexical and supralexical deficiencies (Bowers et al., 2010; Kirby et al., 2010). As such, the reading treatment investigated was multicomponent in nature, including both lexical and sublexical components. Beyond discovering if treatment works or does not work by comparing end results of participants in treatment and control conditions, the current study also investigated whether or not the multicomponent treatment conveyed specific univariate improvement in terms of the three dependent variables (RAN, VA, reading rate). By designing an experimental study with pretreatment and posttreatment multivariate repeated measures assessment, the researcher was able to deeply explore the variance in multivariate treatment response by participant level characteristics (treatment or control; single or double deficit) and by specific univariate outcomes (RAN, VA, reading rate).

Null Hypotheses

H_o1: There will be no difference between treatment and control groups (IV 1) on overall multivariate treatment response.

H_o2: There will be no difference between treatment and control groups (IV 1) on all dependent variables (RAN, VA, rate).

H_o3: There will be no difference in treatment response between single and double deficit groups (IV 2) on overall multivariate treatment response.

H_o4: There will be no difference in treatment response between single and double deficit groups (IV 2) on all dependent variables (RAN, VA, rate).

Rationale/Significance of the Study

For most typically developing children, the learning to read process is seamless and without difficulty. In the United States, most children enter school at age five and learn to read in a classroom setting during the first years of school. In grades K-2, children are taught and expected to acquire the basic sublexical and lexical components of the reading process: identification of letters names and sounds (alphabetic knowledge), the ability to blend and segment sounds in spoken language (phonological processing), the ability to match letters to sounds (grapheme-phoneme correspondence or orthographic processing), and finally the ability to apply these sublexical skills to the lexical skill most often associated with beginning to read – the ability to decode or sound out words. Again, for the majority of children, this process is seamless, occurring developmentally during the first years of formal schooling (Adams, 1990; Shaywitz, 2003).

This is not the case, though, for the 5-17% of individuals, who, according to meta-analytic studies, have dyslexia (Bishop, 2010; Shaywitz et al., 2008; Shaywitz & Shaywitz, 2003a, 2003b, 2005). Of those individuals with dyslexia, approximately 40% routinely perform below grade level. Moreover, at least 80% of individuals labeled as learning disabled are dyslexic (Shaywitz et al., 2008). And, while all children benefit from systematic instruction of the sublexical and lexical elements of the reading code, those who struggle with reading acquisition need intensive, targeted, and systematic instruction in the learning to read process (Shaywitz et al., 2008). Fortunately, given the magnitude of children impacted by dyslexia, the past fifteen years have been filled with a flurry of research about how to best help and teach

children who do not acquire the code with ease. In fact, dyslexia is one of the most frequently studied learning disabilities. Unfortunately, though, reading failure persists for many learners (Shaywitz & Shaywitz, 2004).

The life-long consequences of persistent reading failure attributable to dyslexia are astounding. Dysfluent readers who do not receive the necessary reading intervention often suffer from impairments in self-perception and efficacy (Ferrara, 2005). Adults with untreated learning disabilities not only suffer negative life impacts in terms of social and emotional adjustment but also are impacted economically. In fact, adults who struggle with untreated reading disorders are often are unemployed, underemployed, or prevented from job advancement due to low literacy rates (Gerber, 2012).

Dyslexia, a spectrum condition, with multiple variable underlying configurations of core sublexical deficits and varying degrees of lexical and supralexical outcomes, is complicated to treat (Peterson & Pennington, 2012). While there is a considerable amount of research literature examining intervention programs designed to treat the sublexical core deficit of phonological awareness (PA) and related lexical difficulty in single word decoding, there is substantially less literature examining programs designed to treat sublexical RAN or attentional difficulties and related lexical difficulties in fluency. As such, there are numbers of children, specifically those with RAN-type deficiencies, who do not respond well to currently available evidence-based interventions (Shaywitz et al., 2008). Further investigation, such as the current study, should be implemented to ascertain what works and what does not work for those who do not respond to traditional dyslexia treatment.

Assumptions

The present study assumed those involved in the study, including children receiving treatment, parents of children in treatment, and reading specialists providing treatment would be fully committed to the goals of the study. For children, the researcher assumed scores on pre and postassessment measures represented an effortful performance when tested and effort to attend and learn was also made during treatment. For parents, the researcher assumed regular child attendance was a priority and parental support was extended to children, the researcher, and the reading specialists providing treatment. For educators providing treatment, the researcher assumed treatment was implemented with fidelity, educator attendance was a priority, and a best effort was made by educators who worked with the students.

The author also assumed all involved, specifically the researcher and the treating educators, would follow the Health Information Portability and Accountability Act (HIPAA) (1996) privacy rule by keeping all diagnoses and information shared about treated students and families as confidential. As such, all involved in administering treatment were previously trained in HIPAA requirements, and HIPAA provisions were reviewed with families and educators prior to assessment and treatment.

Limitations

A referred population presents difficulties with the degree of randomness of design. As such, the researcher attempted to ensure the call for participants was widely available through various outlets and in various forms of media (print, online etc.). Beyond inability to directly control participation, this study was also limited because human participants always present with multiple intervening uncontrollable factors (Denton, Fletcher, Anthony, & Francis, 2006). Because of the aforementioned factors, the researcher anticipated regular attendance might be an

issue and developed a treatment protocol which is as direct, intensive, and engaging as possible. Further extraneous variables such as reading attitude, reading motivation, or factors in the home-life of the participants were not controlled.

Also at issue was the multimodal nature of the instruments used and intervention implemented. All skills tested and conceptualized as dependent variables (RAN, VA, and rate) can be potentially further divided into smaller component skills and factors. As such, the condition of task impurity when assessing is always at issue (van der Sluis, de Jong, & van der Leij, 2007). Similarly, a multicomponent treatment, although indicated as best practice by the literature (e. g. Al Otaiba & Fuchs, 2006; Gustafson, Fälth, Svensson, Tjus, & Heimann, 2011; Kirby et al., 2010; Norton & Wolf, 2012; Wolf & Bowers, 2000), can prove problematic as multiple skill areas are trained, thus making it difficult to ascertain what portion of the intervention might be affecting or improving specific tested dependent variables.

Results of this study are limited, as findings may only be generalized to other similar populations of individuals with speeded naming (RAN) difficulties. Although dyslexia is one of the more prevalent neurodevelopmental difficulties (Bishop, 2010), with prevalence rates ranging from 5-17% (Bishop, 2010; Shaywitz et al., 2008; Shaywitz & Shaywitz, 2003a, 2003b, 2005), those single deficit (RAN only) dyslexia or double deficit (RAN + PA) dyslexia only represent a subset of the total dyslexic population. Furthermore, results from treatments in the present study cannot be generalized to individuals with other sorts of disabilities.

While there is robust evidence of treatment efficacy of those with sublexical difficulties in RAN and lexical difficulties in fluency (e.g. Morris et al., 2010; Wolf et al., 2009; Wolf, Miller, & Donnelly, 2000), most previous treatments have not directly treated underlying sublexical difficulties in RAN. Accordingly, there is a lack of exact replicable model for best

practice in RAN treatment (Bakker, 2006; Kirby et al., 2010). Moreover, prior treatment studies aimed at underlying RAN improvement have found mixed results, with approximately fifty percent of studies finding positive results and fifty percent finding no effect for treatment (Kirby et al., 2010).

Delimitations

Due to logistical constraints placed upon the study by designing intervention necessitating a one-on-one instructional model, a somewhat small sample size was necessitated. This smaller sample size led the researcher to limit the number of variables investigated. Specifically, variables examined were limited to two independent grouping variables, three dependent outcome variables and one covariate. One important variable not included was reading comprehension, which is the goal of reading in general (Fountas & Pinnell, 2009). Reading comprehension would have been a logical variable to include as it has been found to be correlated to RAN skill (Arnell, Klein, Joanisse, Busseri, & Tannock, 2009).

The issue of testing and retesting in a short period was also a delimitation in the present study. Traditional dictates of psychometric testing call for an extended period between tests to deal with the phenomenon of practice effects, a phenomenon in which the participant actually improves or scores higher on subsequent rounds of testing due to test familiarity rather than treatment effects (McArthur, 2007). While the GORT-IV has an A form and B form to limit practice effects for reading rate, the CTOPP (RAN subtest) and the NEPSY-II (inhibition subtest) only have one form which was necessarily reused with the same participants within a short period (prior to and after an intensive four week treatment). Fortunately, the RAN portion of the CTOPP is comprised of items not easily recalled (random sequences of letters and numbers) and, as there is no feedback given for correctness, practice effects are greatly reduced (Wagner,

Torgeson, & Rashotte, 1999). Moreover, recent meta-analytic data shows only 17% of dyslexic individuals tested with the RAN subtest of the CTOPP had improvement in scores as a result of practice effects (McArthur, 2007). The NEPSY-II inhibition subtest is also comprised of items not easily recalled (black and white circles, squares and arrows in random order), yet test-retest coefficients in the NEPSY-II manual are at the low end of the acceptable range (Korkman, Kirk, & Kemp, 2007; Henson, 2001). As such, interpretation of positive outcomes based on metrics from both the CTOPP and NEPSY-II should be conducted with appropriate caution due to potential practice effects (McArthur, 2007).

Finally, intensive intervention aligned with the school's core reading instruction typically provides better outcomes by diminishing confusion on the part of the child (Hill, King, Lemons, & Partanen, 2012). A delimitation exists, then, because the present study occurred in a clinical setting not associated with a particular school. As such, participants potentially received different instruction about the same concepts in school as compared to the treatment site. As participants were drawn from various school settings, alignment of the intervention in this study with intervention or general instruction in various school settings was not feasible.

Definition of Terms

ADHD as defined by the American Psychiatric Association in the DSM-IV (2000) is broken into two discrete subtypes inattention (ADHD-I) or hyperactivity-impulsive (ADHD-HI) and a combined type (ADHD-C). The DSM-IV reads as follows:

"[ADHD is a] Persistent pattern of inattention and/or hyperactivity-impulsivity that is more frequently displayed and is more severe than is typically observed in individuals at comparable level of development."

A. Individual must meet criteria for either (1) or (2):

(1) Six (or more) of the following symptoms of *inattention* have persisted for at least six months to a degree that is maladaptive and inconsistent with developmental level:

Inattention

(a) often fails to give close attention to details or makes careless mistakes in schoolwork, work or other activities

(b) often has difficulty sustaining attention in tasks or play activity

(c) often does not seem to listen when spoken to directly

(d) often does not follow through on instructions and fails to finish schoolwork, chores or duties in the workplace (not due to oppositional behavior or failure to understand instructions)

(e) often has difficulty organizing tasks and activities

(f) often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (such as schoolwork or homework)

(g) often looses things necessary for tasks or activities (e.g., toys, school assignments, pencils, books or tools)

(h) is often easily distracted by extraneous stimuli

(i) is often forgetful in daily activities

(2) Six (or more) of the following symptoms of *hyperactivity-impulsivity* have persisted for at least six months to a degree that is maladaptive and inconsistent with developmental level:

Hyperactivity

(a) often fidgets with hands or feet or squirms in seat

(b) often leaves seat in classroom or in other situations in which remaining seated is expected

(c) often runs about or climbs excessively in situations in which it is inappropriate (in

adolescents or adults, may be limited to subjective feelings of restlessness)

(d) often has difficulty playing or engaging in leisure activities quietly

(e) is often "on the go" or often acts as if "driven by a motor"

(f) often talks excessively

Impulsivity

(g) often blurts out answers before questions have been completed

(h) often has difficulty awaiting turn

(i) often interrupts or intrudes on others (e.g., butts into conversations or games) Some

hyperactive-impulsive or inattentive symptoms must have been present before age 7 years.

    A. Some impairment from the symptoms is present in at least two settings (e.g., at school

       [or work] and at home).

    B. There must be clear evidence of interference with developmentally appropriate social,

       academic or occupational functioning.

    C. The disturbance does not occur exclusively during the course of a Pervasive

       Developmental Disorder, Schizophrenia, or other Psychotic Disorders and is not

       better accounted for by another mental disorder (e.g., Mood Disorder, Anxiety

       Disorder, Dissociative Disorder, or a Personality Disorder).

Decoding (phonics) is the process by which individuals break down words into discrete

phonemes in order to blend the phonemes together and read the word (Adams, 1990).

Dyslexia is defined by the Texas Education Code (1995), Section. 38.003 (d) as follows: dyslexia means a disorder of constitutional origin manifested by a difficulty in learning to read, write, or spell, despite conventional instruction, adequate intelligence, socio-cultural and educational opportunity. The International Dyslexia Association's definition of dyslexia is as follows: "Dyslexia is a specific learning disability that is neurological in origin. It is characterized by difficulties 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 the growth of vocabulary and background knowledge." (Lyon, Shaywitz, & Shaywitz, 2003).

Developmental Dyslexia is the term given to dyslexia which occurs in childhood. This terminology is most commonly used in the psychological literature in order to distinguish this form of dyslexia from acquired dyslexia which is a reading disability that occurs later in life due to traumatic brain injury, stroke, or dementia (American Psychiatric Association, 2000).

Discrete or Alternate Naming refers to the ability to quickly name highly familiar visual stimuli, such as letters or numbers, presented individually in isolation. Typically this type of naming is thought to be less robustly correlated with reading than serial RAN (Kirby et al., 2010).

Double Deficit Model of Dyslexia is a bivariate model of dyslexia causation in which dyslexia is not only caused by phonological deficit but can also be caused by a singular deficit in RAN or a combination of phonological and RAN deficiencies (Wolf & Bowers, 1999, 2000).

Encoding (spelling) is the opposite of decoding. To encode one must hear the phoneme and then write the sound as represented by a grapheme. (Adams, 1990).

Fluency is defined as the ability to read text quickly, accurately and with appropriate expression (Kuhn & Stahl, 2004). Fluency instruction typically occurs with materials at the individual's independent reading level (Rasinski, Homan, & Biggs, 2009).

General Processing Speed or *Processing Speed* is the speed at which cognitive processes occur and is an indication of how quickly and completely a learner can process information. Processing speed is typically a construct measured within a full scale battery of cognitive ability or FSIQ (Hudson, Pullen, Lane, & Torgeson, 2009)**. S**ome researchers assert RAN is simply a manifestation of general processing speed. Although a logical interpretation, no specific mechanism within RAN has been identified as the source of processing speed difficulties (Cain, Bryant, & Oakhill, 2004).

Grapheme is the written representation or symbol of a sound. In English, graphemes are represented by one or more the letters of the alphabet (Adams, 1990).

Lexical Skills are word level reading skills including decoding and encoding of words (Bowers et al., 2010).

Orthographic Processing is the method by which frequent or familiar words (often called sight or high frequency words) are quickly recognized. Orthographic processing occurs when groups of letters or words are processed as single units rather than as a chain of grapheme-phoneme correspondences (Kirby et al., 2010). Some researchers hypothesize RAN taps orthographic processing because both processes involve a seemingly arbitrary relationship between objects and their names (Bowers, Sunseth, & Golden, 1999).

Phoneme is the smallest unit of spoken language; a single speech sound (Adams, 1990).

Phonological Processing or Phonological Awareness (PA) refers to a subset of skills involving the ability to manipulate auditory speech sounds (phonemes), syllables and words by blending, segmenting, and deleting. Deficient phonological processing is most likely to cause outward reading difficulties (Shaywitz, 2003).

Rapid Naming, Speeded Naming, Naming Speed, Rapid Automatic Naming or Rapid Automatized Naming (RAN), are all interchangeable terms which refer to the ability to name quickly a group of highly familiar visual stimuli such as digits or letters, typically presented in continuous fashion (Wolf & Bowers, 1999). RAN assessment measures the speed and accuracy of naming an array of familiar stimuli presented on a single page (Denkla & Rudel, 1976). RAN is a complex process, even though it looks quite simple during assessment. In order to rapidly name a set of random letters or numbers or object, one must sustain attention over time, control eye movement, fixate on consecutive stimuli, and coordinate eye movement with cognitive and articulatory processes involved in naming each item (Wolf & Bowers, 1999). Also, the individual must cognitively suppress previous and upcoming responses, so current utterance of the correct target occurs (Arnell et al., 2009).

Reading Accuracy or *Accuracy* refers to how the individual reads in terms of error production or lack thereof. Errors are commonly called miscues. An acceptable rate for instructional level reading is 90-94% accuracy while an acceptable rate for independent level reading is 95-100% (Fountas & Pinnell, 2009).

Reading Comprehension is the ability to understand what is read or to make meaning from print. Reading comprehension is the goal of reading (Allington, 2009).

Reading Disorder or Reading Disability can be defined as a difficulty in reading not caused by a global deficiency or cognitive disability. A reading disorder or disability is a

difficulty in either component lexical skills of reading (decoding, rate, and accuracy) or in reading comprehension. Since 2000, the American Psychiatric Association has defined reading a disorder in the DSM-IV as:

A. Reading achievement as measured by individually- administered standardized tests of reading accuracy or comprehension is substantially below that expected given the person's chronological age, measured intelligence, and age-appropriate education.

B. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living that require reading skills.

C. If a sensory deficit is present, the reading difficulties are in excess of those usually associated with it.

Reading Rate or Rate refers to the speed at which an individual reads. Expected reading rates are dependent on age level and text difficulty level (Rasinski et al., 2009).

Sight Word is a word immediately or automatically activated in memory, without any sounding out or blending required (Ehri, 2005).

Sublexical Skills are those reading skills below the level of a spoken word including PA and RAN (Bowers et al., 2010).

Supralexical Skills require more complex cognitive processes than lexical skills. Reading comprehension is the best example of this type of skill (Bowers et al., 2010).

Visual Attention (VA) deals with perceptual selectivity and how we automatically attend to regions of interest in our surroundings by scanning and rapidly shifting out attention or focus. Top down or voluntary VA occurs when a cue directs your attention to a target, such as when you attend to letters and words to read. Bottom up or involuntary VA occurs when something such as a bright color or flash of light grabs your attention. During normal visual perception and

attention processing, top down and bottom up processes occur simultaneously (Frintrop, Rome, & Christensen, 2010).

Working Memory (WM) refers to the ability to mentally store and manipulate information over a short period of time. (Gathercole & Alloway, 2008). Barkley (1997) proposed working memory could be defined as the simultaneous storage and processing of information. Some researchers assert impaired RAN is simply a manifestation of impaired working memory (Arnell et al., 2009; Badian, 2005).

Summary

Difficulty learning to read is a pressing social problem. Individuals who struggle with reading are more likely to struggle in school and in later occupational endeavors, despite frequently possessing adequate intelligence. Learning to read is a complex process. Understanding the reading brain is even more complicated. Clearly, researchers have made great strides into understanding how humans learn to read, how the brain processes reading, and subsequently how to treat dyslexia. Much work, though, still needs to be done in the treatment of reading problems, especially for those with RAN-type core sublexical deficits. Further investigation, as represented by the current study, is needed so all children may have the chance to become proficient and competent readers.

Organization of the Study

In Chapter II, a thorough review of the literature including evidence from correlation studies, brain imaging studies, and treatment studies informs the research design and chosen methodology of the present study. In Chapter III, treatment conditions and methodological considerations will be described. Chapter IV contains further analysis of data collected and will specifically determine variance in treatment response by comparing independent variable of

treatment and control condition, as well as, the independent variable of level of core dyslexic deficit (RAN-only single deficit or RAN + PA double deficit). Chapter IV will also investigate outcomes in terms of multivariate and univariate response to intervention and will study the contributions of the dependent variables of underlying sublexical reading deficits in RAN and VA, as well as, the related lexical reading deficit in reading rate. Finally, Chapter V will discuss findings and conclusions as applied to prior research, theory and clinical practice in the field of practice.

Chapter II

Literature Review

The purpose of the current study was to ascertain if a multicomponent reading treatment, developed specifically for those with single deficit (RAN only) and double deficit (RAN + PA) underlying dyslexic deficiencies, improved sublexical skills in RAN and VA, as well as, the lexical skill of reading rate. A thorough review of the recent empirical literature was conducted in several related areas of research. Studies reviewed include theoretical investigations into dyslexia causality, biological/medical (brain imaging) studies, cross-linguistic endeavors, correlational studies connecting the various dependent variables (RAN, VA, rate), and behavioral treatment studies. Through this comprehensive literature review, the need for the present study is illuminated.

Brain Imaging Evidence

Functional Magnetic Resonance Imaging (fMRI) is an imaging technique used to assess blood flow in a specific brain region. For reading studies, subjects are typically asked to carry out sublexical, lexical, or supralexical tasks while being imaged, so the fMRI machine can create a picture of blood flow in the reading brain. Increased blood flow to a specific region, due to activation by the reading task, yields increased oxygenated blood. The increase in oxygenation is detected by the fMRI scanner which allows for regions involved in various reading tasks to be pinpointed (Shaywitz & Shaywitz, 2007).

In general, fMRI research in the field of neuroscience shows activation of multiple regions of the human brain during reading aloud and lexical retrieval (Shaywitz & Shaywitz, 2007). Shaywitz and Shaywitz (2007), through numerous fMRI studies comparing individuals with and without dyslexia, note three specific neural areas in the left hemisphere of the brain as

underutilized by dyslexics. These areas, shown in Figure 2, include the inferior frontal gyrus (Broca's area), the parieto-temporal area, and the occipito-temporal area and are clearly related to fluent and proficient word reading in good readers (Shaywitz & Shaywitz, 2007).
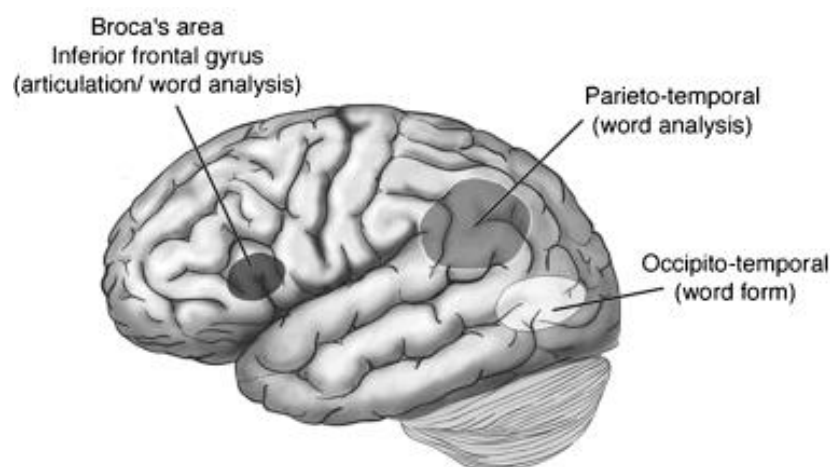
Figure 2. Left Hemisphere areas involved in fluent reading. Neural systems for reading in the brain's left hemisphere are shown. An anterior system in the region of the inferior frontal gyrus (Broca's area) is believed to serve articulation and word analysis. A system in the parieto-temporal region is believed to serve word analysis, and a second in the occipito-temporal region (termed the word-form area) is believed to be responsible for the rapid, automatic, fluent identification of words. Dyslexic readers have been found to not activate these areas as well, instead using inefficient right hemisphere regions not specified for reading.

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In the most basic sense, individuals with developmental dyslexia use right hemisphere areas of the brain to read, instead of the left hemisphere areas used by nonimpaired readers as shown in Figure 2 (Hoeft et al., 2011; Maisog, Einbinder, Flowers, Turkeltaub, & Eden, 2008; Peterson & Pennington, 2012; Richlan, 2012; Shaul, Arzouan, & Goldstein, 2012; Shaywitz & Shaywitz, 2007). Unfortunately, the right hemisphere of the brain, even when functional and unimpaired, is not structured to handle the demands of reading (Shaywitz, 2003). Fortunately though, the brain can be "lateralized" or shaped to respond in a more typical way by behavioral reading intervention (i.e. after reading treatment, fMRI activation moves from the inefficient right hemisphere structures to the efficient left hemisphere). For instance, after an intensive eight week intervention in decoding and rapid word identification, fMRI imaging showed increased

left hemisphere activation for the reading areas of the brain highlighted in Figure 2 (Simos et al., 2007).

The left occipito-temporal "word form" region, as labeled in Figure 2 (also often called the visual cortex), is particularly implicated when individuals have difficulty with alphanumeric RAN and rapid single word recognition of orthographic or visually presented words. (Peterson & Pennington, 2012; Richlan, 2012). One function of the visual cortex, then, is to form perceptual expertise for visually presented words, enabling rapid perception of familiar words (Araújo, Bramão, Faísca, Petersson, & Reis, 2012). Accordingly, imaging studies show impairment in the left visual cortex in readers who have slow, effortful reading (Richlan et al., 2010). Furthermore, damage to this area of the brain is linked to deficits in the storage, access, and processing of lexical information (Rezaie et al., 2011). In fact, the visual cortex may be responsible for at least 40% of the variance in impaired dyslexic response (Blau et al., 2010).

More specifically, an area within the left hemisphere occipito-temporal visual cortex region known as the visual word form area (VWFA), is activated when subjects engage in efficient, automatic word reading (Christodoulou, 2010; Maurer, Blau, Yoncheva, & McCandliss, 2010; Richlan, Kronbichler, & Wimmer, 2011). The VWFA is thought to be directly involved in processing of sublexical units, such as single serial letter units processed in RAN tasks (see Appendix B for RAN task example). And, the VWFA is also implicated in lexical processes such as visual whole word (sight word) recognition and fluent reading of connected text (Hasko, Bruder, Bartling, & Schulte-Körne, 2012; Schurz et al., 2010), but not in supralexical processes such as semantic knowledge activation (word meaning) (Braet, Wagemans, & Op de Beeck, 2012). As reading becomes more fluent and less effortful during typical reading acquisition (between the ages of 4-12), the VWFA increases in sensitivity to

frequent words (Ben-Shachar, Dougherty, Deutsch, & Wandell, 2011). In dyslexics, though, this specialization in the VWFA does not occur, with fMRI studies showing reduced automaticity in visual word processing, highlighting the importance of sight word recognition component in any intervention designed to help those who struggle with fluent reading (Araújo et al., 2012).

The VWFA is quite responsive to reading intervention (Proverbio, Zani, & Adorni, 2008). In fact, studies of exilliterate adults show increased response to letter strings in the VWFA as soon as reading begins (Dehaene & Cohen, 2011). Furthermore, the VWFA can theoretically be shaped for developmental dyslexics by short duration therapy as fMRI studies show differential response in the VWFA after brief training with novel words (Song, Bu, Hu, Luo, & Liu, 2010). Moreover, young prereaders who received eight weeks of brief grapheme-phoneme training (3.6 total hours), manifested changes in the VWFA, indicating plasticity in this key reading area of the brain (Dehaene & Cohen, 2011).

The Historical Single Deficit Hypothesis: RAN Subsumed under PA

Following the last five years of fMRI evidence, perception of dyslexia as a complex and multideficit type of condition has become cursorily accepted within the reading community (Peterson & Pennington, 2012). Historically and until quite recently, PA was the only deficit thought to be involved with reading difficulty (Shaywitz, 2003). PA instruction has, as such, become a staple of elementary classrooms, especially since PA was identified by the National Reading Panel as one of five key areas of reading instruction (U. S. Department of Education, 2000). Modglin and Parton (2008) add further support to the importance of instruction in PA, asserting, "focused remediation paired with phonological awareness training can assist phonological coding, therefore increasing memory storage and recall for words" (p. 3). In other

words, PA intervention has the potential to improve memory storage capacity which is required to hold sounds in mind while blending to form words.

Early theories of RAN involvement in reading suggested serial naming skill was simply subsumed underneath the phonological umbrella, asserting RAN was simply another way of measuring phonology (Ackerman & Dykman, 1993, 1996; Ackerman, Dykman, & Gardener 1990; Fletcher & Satz, 1979). Other theorists believe RAN issues maybe subsumed under a working memory construct (Arnell et al., 2009; Badian, 2005). Recent evidence has again shown support for the theory of RAN subsumed under working memory (Aguilar-Vafaie, Safarpour, Khosrojavid, & Afruz, 2012), but this theory only holds when comprehension is set as the outcome variable.

Some current researchers contend serial naming skill is simply an index of PA, a way to measure how efficiently the phonological system functions. As such, these researchers claim correlation between RAN and various reading outcomes occurs because RAN is measure of fast mapping of visual symbols to phonological codes (Vaessen, Gerretsen, & Blomert, 2009). Despite the popularity and theoretical simplicity of a single core deficit model, a large volume of correlational research demonstrates the separate and unique natures of RAN and PA. In the recent past (1990's), researchers began to thoroughly investigate the notion of two independent underlying core deficits (RAN and PA) leading to dyslexia. In addition to research about various factors related to dyslexic outcome, intervention research also began to indicate lack of responsiveness to phonologically-based treatment for some dyslexic learners, lending further support to the notion of dyslexia as a disorder with bivariate causality. (Wolf & Bowers, 1999, 2000; Wolf, Bowers, & Biddle, 2000).

The Newer Double Deficit Hypothesis: RAN as a Unique Predictor

Investigation of bivariate causality for reading struggle (RAN and PA) led to into intense research into the relationship between RAN and reading, a scholarly literature stream which has increased exponentially since Denkla and Rudel's (1976) creation of the RAN assessment task. In a small study, Cornwall (1992), found letter naming added significantly to the variance in word identification and fluency outcomes. Shortly thereafter, in another relatively small correlational study, RAN explained significant variance in reading fluency, independently of PA (Bowers, 1993). Evidence also shows RAN longitudinally predicated reading tasks involving orthographic processing such as single word identification, whereas PA was more strongly associated with tasks requiring phonological decoding of words (Manis, Doi, & Bhadha, 2000; Manis, Seidberg, & Doi, 1999).

Wolf and Bowers (2000) proposed a double deficit model in which three categories of impaired readers are noted. These included single deficit in PA only, single deficit in RAN only, and readers with a double deficit stemming from difficulties in both PA and RAN. According to Wolf and Bowers (2000), the two sublexical deficits responsible for reading difficulties were not one in the same. They believed RAN could not be subsumed under the phonological loop, as evidenced specifically by the resistance of RAN to change when phonological-based treatments were implemented for children with single RAN deficits or double (RAN + PA) deficits (Wolf & Bowers, 2000).

Many researchers followed the lead of Wolf and Bowers, conducting various studies to indicate RAN and PA are indeed separate constructs. For instance, in a recent confirmatory factor analysis, RAN and PA were found to represent separate, discrete factors (Hulslander, Olson, Willcutt, & Wadsworth, 2010). And, several studies utilizing regression analyses have

found RAN is dissociated from phonological measures, accounting for unique variance in multiple components of reading such as word identification, pseudoword decoding, and reading comprehension (de Jong & Olson, 2004; DeMann, 2011; Georgiou, Das, & Hayward, 2008; Høien-Tengesdal & Tønnessen 2011; Johnston & Kirby, 2006; Joshi & Aaron, 2000; Warmington & Hulme, 2012). Also, studies utilizing structural equation modeling conceptualize RAN and PA as separate latent variables, with unique predictive paths to reading (Pennington et al., 2012; Powell, Stainthorp, Stuart, Garwood, & Quinlan 2007). Moreover, researchers have found models with multiple predictors including, but not limited to RAN, paint a more comprehensive picture of the varied dyslexic population (Høien-Tengesdal & Tønnessen 2011; Menghini et al., 2009; Pennington et al., 2012). For example, a model including PA, RAN, and visual short term memory as separate, uncorrelated, predictors explained approximately 30% of variance of the reading skills of over 1000 children (Høien-Tengesdal & Tønnessen, 2011). According to Pennington et al. (2012), this multifactorial hybrid model of dyslexia provides the most reasonable explanation for how various underlying cognitive components, such as RAN, may drive dyslexia and produce children with varied profiles of reading difficulties within the overall dyslexia diagnostic umbrella.

Cross-Linguistic Support for RAN and the Double Deficit Hypothesis

Reading researchers have also thoroughly studied the role of RAN as a predictor and causal factor of dyslexia in languages other than English. Outcomes of these studies indicate RAN-based dyslexia is not a language or culture-specific phenomenon. Furthermore, in phonetically regular (orthographically transparent) languages, RAN is often a stronger predictor of reading deficit than PA (Ziegler et al., 2010).

Studies of RAN contribution to variance in reading outcomes, specifically reading fluency, include thorough investigations into multiple languages other than English, including Arabic (Elbeheri, Everatt, Mahfoudhi, Abu Al-Diyar, & Taibah 2011), Mandarin Chinese (Ding, Richman, Yang, & Guo, 2009; Ho, Lueng, & Chang 2011; McBride-Chang et al., 2011; Pan et al*.,* 2011; Ho, Chan, Lee, Tsang, & Luan, 2004), Korean (Pae, Sevcik, & Morris, 2010), Japanese (Kobayashi, Haynes, Macaruso, Hook, & Kato, 2005), Spanish (Davies, Cuentos, & Glez-Seijas, 2007; Escribano, 2007; Jiménez et al*.,* 2008; López-Escribano & Katzir, 2008; Ziegler et al., 2010), Italian (Facoetti, Corradi, Ruffino, Gori, & Zorzi, 2010), Portuguese (Albuquerque & Simões, 2010; Araújo, Pacheco, Faísca, Petersson, & Reis, 2010; Cardoso-Martins &Triginelli, 2010), French, (Plaza & Cohen, 2004), Dutch (Boets et al., 2010), Scandinavian/Swedish (Furnes & Samuelsson, 2010, 2011), Finnish (Lepola, Niemi, Kuikka, & Hannula, 2005; Lyytinen, Erskine, Kujala, Ojanen, & Richardson, 2009), Hebrew (Oren & Breznitz, 2005; Shany & Breznitz, 2011), Persian (Soleymani, Saeedmanesh, Dastjerdi, Mehri, & Jahani, 2009), German (Schulte-Körne et al., 2006), and Greek (Nikolopoulos, Goulandris, Hulme, & Snowling, 2006). Consistently, cross-linguistic studies demonstrate RAN is either a strong predictor, a unique predictor, or the single best predictor of current and/or later reading difficulties. Moreover, some of these studies also note individuals with double deficits in RAN and PA have the poorest outcomes on other reading measures, as compared to single deficit groups (Araújo et al*.,* 2010; Escribano, 2007; Jiménez et al., 2008). Again, dyslexic deficiency in RAN and concomitant difficulties in reading fluency is not language-specific, as dyslexia is of biological origin, occurring similarly across linguistic domains (Oren & Breznitz, 2005).

Orthographic depth: RAN evidence from transparent languages.

The strength of association between RAN and reading fluency varies across languages according to orthographic depth, with orthographic transparency (phonetic regularity) related to a higher predictive capacity of RAN tasks (Landerl & Wimmer, 2008; Ziegler et al., 2010). According to Ziegler et al. (2010), English is often designated as an "outlier" language in global research communities, due to the lack of orthographic transparency. In other words, English is an orthographically deep and complex language, full of irregular forms and various manners in which letters and sounds correspond. More specifically, vowels in English connect with multiple sounds (phonemes) and spellings (orthographic representations). The long /a/ phoneme, for instance, can be spelled eight different ways in English, some of which correspond with letter position within the word and some of which do not (Adams, 1990). Phonologically speaking, then, English reading skill is simply harder to acquire (than phonetically regular languages), thus difficulties with PA and resultant labored single word decoding are prevalent in English speakers. While deficits in phonology are less common in transparent languages, rate of acquisition of reading typically occurs much more quickly and subsequently reading difficulties, with sublexical difficulties in RAN, manifest at earlier ages as well (Ziegler et al., 2010).

Furthermore, reading disability in transparent languages has been empirically connected to RAN deficiencies. For instance, 32% of the variance in reading speed in Spanish is associated with RAN (López-Escribano & Katzir, 2008) and 14% of the variance in reading proficiency in a large cohort of Finnish first graders was predicted by RAN, after controlling for the contribution of IQ (Lepola et al., 2005). Finally, in Landerl and Wimmer's (2008) eight year longitudinal study of German 1st graders, RAN was the most stable unique predictor of reading fluency over

time (r = .64 to .77 at grades 1, 4, and 8). In comparison, PA only predicted oral fluency at grade 1 only, adding no longitudinal predictive power to the equation (Landerl & Wimmer, 2008).

Language comparison studies.

Beyond general investigation into the causal factors of dyslexia in various languages, several recent seminal works have compared sublexical predictors of dyslexia across languages. Recently, Fuernes and Samuelsson (2010, 2011) completed a large-scale, multiyear study in which they compared primary school student performance in English (n = 754) to students speaking Norwegian/Swedish (n = 249). Findings suggest RAN significantly predicted reading and spelling skills in both languages. Moreover, RAN was shown to predict reading problems better longitudinally and cross-linguistically, as PA had relatively little predictive validity for Scandinavian speakers at any time and PA lost its predictive power for English-speaking children as they increased in age (Fuernes & Samuelsson, 2010, 2011). In fact, RAN's predictive power was roughly equivalent across languages, leading the researchers to conclude RAN must deal with universal sublexical cognitive processes underlying lexical outcomes across languages (Fuernes & Samuelsson, 2010, 2011). Similar findings were also noted in another longitudinal, cross-linguistic study involving English, Spanish, Slovak, and Czech (N = 735) (Caravalos et al., 2012). And, in examining a smaller population of dyslexic Korean-English bilingual subjects (n = 50), researchers concluded proficiency in PA and/or RAN was a pathway to reading success, regardless of language proficiency (Pae et al., 2010).

Research into the role of RAN in nonalphabetic scripts reliant on whole-word picture symbols, such as Chinese and Japanese (Ho et al., 2004; Ho et al., 2011), can also be found. In investigations of seven reading difficulty subtypes in Chinese, RAN was the underlying cause of three subtypes, leading to difficulty in orthographic representation of Chinese characters for

individuals who were RAN-impaired (Ho et al., 2004). And, in examining differences in IQ and genetic variables, the predictive power of RAN deficiency for Chinese readers was stable across all levels of ability and heritability (Ho et al., 2011). In one recent study of Chinese character reading, children's RAN performance between ages five and ten increasingly predicted Mandarin character recognition ($r = .40$ to $.47$) and oral reading fluency ($r = .38$ to $.47$) (Pan et al., 2011). Furthermore, findings from a large scale study of RAN ability in Japanese children indicated RAN proficiency in terms of Kanji symbols (Japanese characters) was the single best predictor of reading rate (Kobayashi et al., 2005).

Correlational Evidence: The RAN to Reading Relationship

Correlational evidence from behavioral and neuropsychological studies of the RAN to reading relationship demonstrates the importance of RAN development for positive reading outcomes. Sublexical RAN routinely predicts higher level lexical and supralexical reading difficulties in comparative studies (Kirby et al., 2010; Wolf & Bowers, 1999). Also, in a recent study utilizing principal component analysis, RAN predicted 19.71% of the unique variance in general reading (Savage & Frederickson, 2005). And, in a multiple regression design focusing on children in grades 2-5, RAN was shown to be a strong predictor of reading comprehension, spelling, and word attack (Christo & Davis, 2008). Other current studies also show a connection between deficiencies in RAN, specifically in terms of extended pause times between items being named, and impaired decoding of high frequency sight words and orthographic processing ability (Araújo et al., 2011), slow reading rate and labored, inaccurate, phonetic decoding (Neuhaus, Foorman, Francis, & Carlson, 2001), poor reading comprehension (Li et al., 2009), and poor written expression (Berninger et al., 2006).

RAN can also be universally utilized as a predictor of future reading struggles (Bishop & League, 2006; Howe, Arnell, Klein, Joanisse, & Tannock, 2006). For instance, Fuchs et al., (2012) screened RAN letters and word identification fluency in grade 1 and were able to reliably predict reading disability status in grade 5 (Fuchs et al., 2012). Another similar study noted a modest yet significant correlation ($r = .38$) between RAN skill in Kindergarten and higher level lexical and supralexical reading skills in 3rd grade (Compton, Olson, DeFries, & Pennington, 2002). Data also indicated RAN scores from the fall of grade 1 modestly predict composite reading scores ($r = .59$) at the end of grade 2 (Compton et al., 2010). Finally, a large scale longitudinal study showed RAN assessment at age 3.5 could correctly classify 80.3% of children for later risk of dyslexia (Torppa, Poikkeus, Laakso, Eklund, & Lyytinen, 2006).

RAN difficulties may predict current and future problems because readers who are slow with RAN tasks may also be inherently slow, laborious, and dysfluent in terms of cognitive processing speed (Araújo et al., 2011; Christopher et al., 2012; Peter, Matsushita, & Raskind, 2011). The processing speed theory of RAN is backed by data from genetic, family, and twin studies. For example, in a longitudinal study of individuals with familial risk for dyslexia, parental RAN was the key indicator later dyslexia manifestation in children. Dyslexic parents with more impaired RAN were also more likely to produce children with more severe dyslexic outcomes (van Bergen, de Jong, Plakas, Maassen, & van der Leij, 2012).

RAN and processing speed are also empirically connected. For instance, in a study utilizing hierarchical multiple regression, RAN, processing speed (as measured by the WISC-IV coding subtest), and simple reaction time were all modestly correlated ($r = .22$ to $.48$) (Powell et al., 2007). In a multivariate sense, these predictors contributed significant variance to reading, yet when entry order into the regression model was manipulated, RAN was the only predictor

accounting for unique variance in every model, accounting for 17% of the unique variance in reading when entered last (Powell et al., 2007). On the other hand, a factorial analysis indicated RAN only accounted for 2% of the variance in reading after processing speed and decoding were accounted for (Savage, Pillay, & Melodina, 2008). The way in which processing speed is measured seems to matter in terms of its relationship with RAN (Powell et al., 2007). For instance, when processing speed was measured in terms of auditory memory for word order, correlations with RAN were nonsignificant ($r = .14$); yet when processing speed was measured in terms of continuous processing or simultaneous processing of visual targets, the relationship, though modest, did show significance ($r = .33$ to $.34$) (Powell et al., 2007). Indeed, processing speed is most related to RAN and other reading outcomes when measured with reading-related materials. Nevertheless, the exact nature of the relationship between RAN and processing speed is not yet fully understood (Naples, Katz, & Grigorenko, 2012).

Whatever the cause for RAN impairment, individuals who are RAN-impaired clearly struggle and are at-risk for reading difficulties (Norton & Wolf, 2012). Moreover, these individuals do not read for pleasure (Stanovich, 1988) and are often not afforded the time needed to practice reading during the school day (Kent et al., 2012). In fact, RAN deficiency may be a logical starting point for Stanovich's "Matthew Effect", in which good readers engage in frequent reading and become increasingly proficient while poor readers, especially those with RAN difficulties, avoid reading and become increasingly deficient (Ackerman, Holloway, Youngdahl, & Dykman, 2001; Stanovich, 1988). Unfortunately, unless children acquire RAN skills, they will continue to fall behind in reading (National Early Literacy Panel & National Center for Family Literacy, 2008). Thus, individuals with RAN deficiencies are in need of early

identification and preventative treatment (Boscardin, Muthén, Francis, & Baker, 2008; National Early Literacy Panel & National Center for Family Literacy, 2008)

Correlational evidence connecting RAN to reading rate of text.

Beyond connections to reading in general, sublexical RAN difficulties are associated with specific lexical difficulties in reading rate (Wolf & Bowers, 1999, 2000). The RAN task requires the reader to quickly and automatically retrieve sublexical units (letters/phonemes), just as reading fluently, with adequate speed, requires the reader to quickly and automatically retrieve lexical units (words). Early theorists believed RAN and rate were related due to the shared serial nature of the tasks (LaBerge & Samuels, 1974). This belief was underscored by the lack of correlation between measures of alternate nonserial discrete naming and reading fluency of connected text. (de Jong, 2011; Perfetti, Finger, & Hogaboam, 1978; Stanovich, 1981; Stanovich, Freeman, & Cunningham, 1983).

Further support for the connection between serial RAN and reading rate comes from the existence of a strong body of recent correlational research demonstrating the statistical relationship between these two constructs. Recent evidence shows a strong relationship between RAN and reading rate (r = .85 to .90), with RAN contributing unique variance to fluency above contributions of processing speed and PA (Georgiou, Papadopoulos, Fella, & Parilla, 2012). Furthermore, in a recent longitudinal study (n = 95), grade 2 RAN was the strongest predictor of grade 3 reading fluency (r = .61). (Georgiou, Manolitsis, Nurmi, & Parilla, 2010). Another well-controlled study of impaired readers (n = 67) also found alphanumeric RAN predicted reading rate (r = .53) (Savage & Frederickson, 2005). And there was a modest (r = .41) correlation between RAN and fluency found in recent research involving nonreading disabled adults,

suggesting RAN is related to fluency development in nonimpaired readers, as well as, those with dyslexia (Arnell et al., 2009).

      Correlational evidence connecting RAN to word reading fluency.

      Beyond the association with fluent decoding of connected text, proficient RAN is also predictive of automatic single word recognition (Cutting & Denkla, 2001; Howe et al., 2006; van den Bos, Zijlstra, & van de Broeck, 2003). Recently, a longitudinal regression study showed RAN accounted for 27-30% of the variance in word reading outcomes in students grades 2-6 ($n = 68$) assessed at three time periods (Georgiou et al., 2011). And, in a large scale SEM study investigating differences in reading acquisition between dyslexic and nondyslexic learners ($N = 483$), alphanumeric RAN was found to be significantly related to word reading ($p < .01$). In this same study, authors concluded experienced, fluent readers were those individuals able to efficiently, automatically, and rapidly process alphanumeric stimuli (Christopher et al., 2012). Finally, in another recent large scale study RAN was found to strongly predict single word decoding ($r = .75$) (McGrath et al., 2011).

      In investigations of what type of single words RAN ability most influenced, studies have shown connections with exception words and sight words. For instance, RAN has been found to be specifically related to exception word (irregularly formed, nonphonetic words) naming latency ($r = .558$), with poor RAN and poor word naming both reflective perhaps of impaired visual serial processing and reduced lexical access (Wile & Borowsky, 2004). Furthermore, alphanumeric RAN was found by van den Bos et al. (2003) to be a better predictor of monosyllabic, small "sight words" ($r = .52$ to .66) as compared to multisyllabic decodable word units ($r = .28$ to .46). Researchers in this particular study theorized a stronger relationship existed between RAN and small monosyllabic sight words because small sight words must be processed

singularly as a unit, much like visual recognition of single letter units measured in the RAN task, whereas multisyllabic words necessitate syllabic parsing. Moreover, these researchers found as readers became more adept at reading and as sight words become more unitized (processed as a single unit), RAN became a stronger predictor of word reading ($r = .52$ at age 8; $r = .66$ at age 10, $r = .64$ at age 12). (van den Bos et al., 2003). These findings were replicated in a more current study with children in grades 1-6 ($N = 1,423$), indicating the weight of RAN contribution to word reading increases with age. In fact, by grade 5, RAN was the dominant contributor to word reading as compared to PA (Vaessen & Blomert, 2010).

ADHD: A Third Deficit?

According to a large ($N = 5178$) birth cohort study tracking individuals born between 1976 and 1982, the incidence of reading difficulties in children with ADHD is significantly higher (51% for boys, 46.7% for girls), than those without ADHD (14.5% for boys, 7.7% for girls), putting children diagnosed with ADHD, and especially girls with ADHD, significantly more at risk for dyslexia than the general population (Yoshimashu et al., 2010). While ADHD and dyslexia are comorbid, these two genetic, heritable conditions are indeed separate entities. While there are currently at least six candidate genes identified in developmental dyslexia, only one, ADRA2A, is also implicated in ADHD (Stevenson et al., 2005). Furthermore, in two recent large scale twin studies ($N = 6000$ to 7000), researchers found high yet separate rates of heritability for both conditions (ADHD = 70%; RD = 45-65%) with the predictive nature of genetic contributions stable over time (Greven, Harlaar, Dale, & Plomin, 2011; Greven, Rijsdijk, Asherson, & Plomin, 2012). This bidirectional overlap between dyslexia and ADHD was not accounted for by IQ or other inherited cognitive ability factors (Cheung et al., 2012; Paloyelis, Rijsdijk, Wood, Asherson, & Kuntsi, 2010).

Although clearly separate conditions, dyslexia and ADHD do have shared underlying factors contributing to comorbidity (van de Voorde, Roeyers, Verté, & Wiersema, 2010). Multiple, complex relationships between the various predictors and outcomes of dyslexia and ADHD exist within the research (Arnett et al., 2012). For instance, in one recent study utilizing exploratory factor analysis, twelve different factors derived from various timed tasks, including RAN, visual matching, and visual coding loaded onto two principal components (verbal output and motor output) to predict dyslexic and ADHD outcomes (Shanahan et al., 2006). Moreover, measures of sustained attention, task focus, and RAN predicted unique and significant variance in the outcome of reading fluency with multiple bidirectional predictive paths between variables (Georgiou et al., 2010; 2011).

Beyond a predictive relationship with dyslexia, RAN is theoretically associated with many bottom-up (subconscious) attention processes including response inhibition, set shifting between stimuli, and accessing long term store (Wolf, 1999). In a cohort of children with ADHD and age-matched controls, RAN tasks significantly predicted comprehension and fluency, with RAN pause time accounting for 20% of the unique variance in fluency and 14% of the unique variance in comprehension (Li et al., 2009). Pham (2010) discovered RAN directly mediated the relationship between inattentiveness and reading fluency difficulty. Even in dyslexic individuals whose attention symptoms do not reach the level of severity required for a formal medical diagnosis of ADHD, inattentive outcomes such as poor sustained attention, slowed reaction time, and reduced inhibitory control are often present (Marzocchi, Ornaghi, & Barboglio, 2009).

In a recent study of comorbid dyslexic/ADHD individuals, RAN predicted 26% of the variance in fluency, and alphabetic RAN was the strongest significant predictor of fluency ($r =$ .60). When the influence of RAN was controlled, the relationship between dyslexia and ADHD

was not evident; suggesting underlying RAN deficiencies may even mediate the comorbidity between the two conditions (Pham, Fine, & Semrud-Clikeman, 2011). Although other similar models indicate processing speed as the shared cognitive deficit mediating the relationship between dyslexia and ADHD, researchers suggest the influences of RAN and processing speed are quite hard to separate due to multicollinearity (McGrath et al., 2011).

Recent genetic research shows a stronger correlation between dyslexia and ADHD-I (inattentive subtype type) ($r = -.25$ to $-.31$) than dyslexia and ADHD-H (hyperactive subtype) ($r = -.15$ to $-.19$) (Greven, et al., 2011, 2012; Hart, Massetti, Fabiano, Pariseau, & Pelham, 2011; Pennington, Willcutt, & Rhee, 2005). Moreover, in a recent large study ($N = 1506$) of elementary age children in the US and Australia, authors discovered RAN scores predicted ADHD-I symptom severity (Arnett et al., 2012). Theoretically, the relationship between RAN and attention measures may occur more frequently in those with ADHD-I (inattentive type) than those with ADHD-H (hyperactive type) because adequate RAN performance requires just what inattentive individuals lack: good output speed, efficient shifting of attention between stimuli, and the ability to control for interference from an array of similar visual targets (Goth-Owens, Martinez-Torteya, Martel, & Nigg, 2010).

For struggling readers with comorbid dyslexia and ADHD, reading success remains more elusive than for those impaired with a singular condition. Individuals with comorbid dyslexia and ADHD have poorer academic outcomes than those with either disorder alone (Germanò, Gagliano, & Curatolo, 2010). And, comorbid individuals have more profound impairment in executive functions such as processing speed and working memory (Katz, Brown, Roth, & Beers, 2011). Unfortunately, comorbidity of dyslexia and ADHD is additive, conferring additional difficulties in processing speed and reaction time (Willcutt, Pennington, Olson,

Chhabildas, & Hulslander, 2005). Moreover, individuals with comorbid ADHD and dyslexia, as compared to those with singular ADHD or dyslexia, also have higher concomitant rates of Oppositional Defiant Disorder, Anxiety, Depression, Conduct Disorder, Bipolar Disorder, and other learning disabilities (Classi, Le, Ward, & Johnston, 2011).

Connecting RAN to VA.

While understanding the nature of the comorbidity between reading disorders and ADHD as discussed above is necessary, further understanding of the specific relationship between VA and impaired RAN is also warranted (Pham et al., 2011; Shaywitz et al., 2008). While classic dyslexia research posits a singular auditory-linguistic underlying cause for dyslexia, some research now shows involvement of a visual factor. Indeed, many researchers now agree both visual and auditory systems are logically necessary in order to read (McCandliss, 2012). The visual system involved in reading extends far beyond the sensory experience of using the eyes to process visual information (simple visual processing); rather, the visual system involved in the reading process deals with how the brain responds to and processes orthographic (letter-type) stimuli (Handler & Fierson, 2011; Hawelka, Gagl, & Wimmer, 2010). In fact, visual processing centers in the brain respond more accurately and quickly to real words or patterns of nonsense words mimicking typical real patterns (Mariol, Jacques, Schelstraete, & Rossion, 2008). Thus, orthographic processing deficits in terms of encoding sounds into visual symbols and RAN deficits in terms of rapidly reading visual symbols may be cognitively related (Bowers, 1993; Gabrieli & Norton, 2012). Moreover, VA and RAN are also clinically related as 50% of studied dyslexics have poor performance when tested with visual or orthographic processing tasks (Georgiou et al., 2011).

VA involvement in developmental dyslexia also exists in the brain imaging evidence. For instance, in one fMRI study by Yoncheva, Zevin, Maurer & McCandliss (2010), participant top down attentional orienting upon language impacted the response of the Visual Word Form Area, indicating conscious integration of phonological and orthographic processes necessary for fluent reading. Moreover, comparative fMRI research demonstrates attentional involvement in coordination of the brain's reading network, with specific involvement of VA processes in terms of visual word reading (Pugh et al., 2012).

In recent correlational research, VA deficits, specifically when measured in terms of inhibition tasks (Barkley, 1997), adequately predict RAN and subsequent reading difficulties (Berninger et al., 2006; Dhar, Been, Minderaa, & Althaus, 2010; Wang, Tasi, & Yang, 2012). For instance, in a sizable recent study of familial dyslexia ($n = 122$ dyslexic children, $n = 200$ dyslexic parents), affected individuals struggled with decoding rate, RAN, automaticity tasks, and inhibition tasks (Berninger et al., 2006). And, in another similar large scale correlational study, nonphonological abilities (specifically attention and visuo-spatial abilities) accounted for 23% of the unique variance in word reading (Wright, Conlon, & Dyck, 2012).

Measures of processing speed involving VA are also problematic for dyslexic participants. For instance, Wright, Conlon, and Dyck (2012) discovered large numbers of dyslexics struggle with tasks of serial visual search which require deployment of visuo-spatial attention in order to locate a target within an array of visually similar distracters. Processing speed tasks of coding (serial visual scan and visual memory) and symbol (speed of visual scan) are also impaired in dyslexic readers (Thomson, 2003). Other measures involving VA, such as the visuo-spatial components of tests of processing speed, also predict reading abilities, accounting for approximately 25-31% of unique variance in irregular word decoding (Abu-

hamour, Urso, & Mather 2012; Facoetti, Corradi et al., 2010; Jacobsen et al., 2011; Stenneken et al., 2011). Visual matching and task switching measures, in particular, appear to have a strong relationship to reading outcomes (Abu-hamour et al., 2012), specifically presenting a moderate correlational relationship to reading fluency ($r = .45$) (Hudson et al., 2009) and nonsense word reading ($r = .43$) (Facoetti, Corradi, et al., 2010).

VA deficit due to sluggish attentional shift.

The deficit in VA seen in many dyslexic readers, as measured by poor performance on tasks of inhibition, may be caused by sluggish visual attentional shifting mechanisms within the inhibitory process (Berninger & Richards, 2010; Lallier et al., 2010; Savill & Thierry, 2012). The sluggish VA shift hypothesis suggests dyslexics perform poorly on tasks requiring visual shifting due to difficulty facilitating attentional disengagement of a current target and subsequent reengagement with the upcoming target (Collis, Kohnen, & Kinoshita, 2012; de Boer-Schellekens &Vroomen, 2012; Hawelka et al., 2010; Lallier et al., 2009; van der Sluis et al., 2007). In fact, a recent study found dyslexics, as compared to age-matched controls, were 27% slower on tasks requiring rapid visual shifting between targets (Stoet, Markey, & López, 2007). The sluggish shift is most likely noted in dyslexics because reading requires, "accurate and rapid selection of sublexical orthographic units by attentional letter string parsing" (Ruffino et al., 2010, p. 3793). Efficient VA orienting and subsequent shifting is logically needed when reading because we must rapidly orient and shift VA to read letters, words, and sentences (Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012).

Although tasks of attention shifting and RAN are significantly and clinically related ($d = .54$ to .93), the nature of the relationship has yet to be fully determined (van der Sluis et al., 2007); as several well controlled studies note evidence is lacking in terms of directionality and

causality (Peterson & Pennington, 2012; Pham et al., 2011; Shaywitz et al., 2008). To this end, a few small scale studies, conducted mainly in transparent orthographies (Spanish and Italian), have found sluggish visuospatial attention as a causally implicated underlying factor in dyslexia, resulting in poor serial tracking and decoding of words and in impaired mapping of phonemes to graphemes (Facoetti, Corradi et al., 2010; Geiger et al., 2008; Rodríguez Pérez, González Castro, Álvarez, Álvarez, & Fernández-Cueli, 2012).

VA deficit due to timing and retrieval deficit.

VA tasks may also present difficulty for dyslexics due to general timing and retrieval deficiencies. Wolf, Bowers, and Biddle (2000) asserted RAN deficiencies represent a complex domain general timing deficit occurring in terms of choice making and integration of the multiple subprocesses underlying reading. To this end, dyslexic participants in two experimental studies struggled with auditory discrimination tasks, specifically in terms of detecting subtle changes in frequency and intensity, when sounds were presented in rapid fashion (Facoetti, Trussardi et al., 2010; Goswami, Fosker, Huss, Mead, & Szűcs, 2011). Similarly, Coalla &Vega (2012) showed dyslexic participants struggled globally with timing and retrieval tasks, performing poorly in auditory phonological discrimination tasks in addition to visual orthographic discrimination tasks (Coalla & Vega, 2012).

The data thus far indicate mapping of phonemes to graphemes, as required for fluent oral reading, may be mediated by a timing mechanism operating within the VA system (Huetting, Mishra, & Olivers, 2012). For instance, Hawelka et al., (2010) revealed lengthened visual fixation times (eye gaze) on letter and nonletter stimuli for dyslexic readers when compared to nondyslexic same age peers. And, related comparative research discovered slower overall

processing times in visual modalities when comparing dyslexic and nonimpaired age matched

controls (Jones, Branigan, Hatzidaki, & Obregón, 2010).

The timing deficit seen in dyslexics may occur due to slow retrieval of auditory

phonemes from long term store, with subsequent slow mapping of stored phonemes to specific

visual graphemes (Facoetti et al., 2003; Horowitz-Kraus & Breznitz, 2011a, 2011b; King, Wood,

& Faulkner, 2007; Valdois, Lassus-Sangosse, & Lobier, 2012). In fact, Snellings, van der Leij,

Blok, & de Jong (2010) found speed of phoneme retrieval and mapping to spoken language were

delayed in dyslexics, not because of a general slower processing, but because of difficulty

differentiating between similar phonemes, leading to impaired automatic access of phonetic

representations. Furthermore, in a study of 23 dyslexic readers and 42 age matched controls,

participants with dyslexia were significantly slower ($p < .0001$) on tasks involving reading of

visual print (mapping auditory phonemes to visual graphemes) as compared to tasks

necessitating simple auditory lexical decision (Marinelli, Angelelli, Di Filippo, & Zoccolotti,

2011). Although this timing/retrieval issue may be directly related to RAN tasks, controlled

studies of relationship strength and causality have not yet been conducted (Conlon, Wright,

Norris, & Chekaluk, 2011; Tannock, Martinussen, & Frijters, 2000).

Connecting RAN to Poor Treatment Outcomes

Beyond the robust connection between speeded naming and reading difficulty, there is

much research evidence suggesting RAN deficiency may somehow convey treatment resistance.

In a review of the intervention literature, Al Otaiba and Fuchs (2002) found individuals with

RAN deficiencies could be classified as resistant to treatment in 6 out of 7 studies with RAN

measures. Moreover, in a recent study comparing various regression models for predicting

responsiveness to intervention, RAN was a significant predictor in all models (Fletcher et al.,

2011). Brain imaging (fMRI) studies of individuals who not respond to traditional phonology-based treatment also show those with RAN-type dyslexia may be particularly at risk for poor treatment response. While these nonresponders may demonstrate appropriate posttreatment fMRI activation of the left hemisphere superior temporal regions responsible for phonology, they often continue to manifest fMRI and behavioral markers of poor single word decoding (Odegard, Ring, Smith, Biggan, & Black, 2008; Shaywitz & Shaywitz, 2003a, 2004; Simos et al., 2007). Treatment nonresponders also show significantly less activation in the left inferior parietal area, a cerebral region thought to link phonological representations to orthographic word forms (Simos et al., 2007; Odegard et al., 2008).

Outcomes related to RAN, specifically reading fluency, are also notably hard to treat. RAN deficient individuals treated with a traditional phonologically-based program often continue to lack fluency as compared to age-level peers. While phonological and decoding ability are often found to be adequate posttreatment, reading rate often remains inadequate (Shaywitz et al., 2008). For instance, 70% of formally diagnosed and treated dyslexic university students maintain a slow reading rate posttreatment (Deacon, Cook, & Parrila, 2012). And dyslexic adults, who were not responsive to treatment as children, carry sublexical RAN impairment into adulthood (Birch & Chase, 2004).

RAN may be synonymous with treatment resistance because individuals with RAN-only or double deficit (RAN + PA) dyslexia have never received targeted intervention. Often, dyslexia treatments designed to remediate PA deficits lack a focus on reading speed, a necessary focus for automatization of RAN and subsequent development of reading fluency (van der Leij & van Daal, 1999). PA-focused treatments also often lack needed instruction in orthographic analysis and repeated exposure to print (Wolf et al., 2009). Accordingly, nonresponders to traditional

phonological treatment (i.e. those with RAN-type difficulties) need intense multimodal treatment in letter-sound correspondence with auditory and visual stimuli (Odegard et al., 2008). Moreover, further treatment studies for individuals with nonresponsive RAN-type and double deficit dyslexia are called for (Al Otaiba & Fuchs, 2006; Kirby et al., 2010; Nancollis, Lawrie, & Dodd, 2005).

Poor reading achievement outcomes related to RAN deficiency may also be due to inadequate or delayed identification of individuals with RAN-based difficulties (O'Brien, Wolf, & Lovett, 2012). Even though the predictive power of RAN is well established, measures of RAN are not typically included in early reading screening batteries for young children (Boscardin et al., 2008). Moreover, readers with single RAN deficits often fall within the average range in disability screening tasks related to PA (O'Brien et al., 2012). As RAN is a strong important predictor of reading impairment, it is imperative RAN be considered in dyslexia identification batteries and reading intervention programs (Frijters et al., 2011).

Treatment Recommendations for RAN-Impaired Individuals

Unfortunately, only a few prior studies have specifically focused on treating RAN and related outcomes. Moreover, no large scale experimental studies have sought answers to this end. Norton and Wolf (2012) suggest this hole in the treatment literature exists because researchers in the field know RAN is untreatable. They further assert direct and explicit training of RAN (much like how the sublexical skill of PA is now successfully treated) is not possible because RAN taps a basic index of immutable processing speed. In many research circles and in various academic disciplines, underlying cognitive skills such as RAN are often deemed untreatable until groundbreaking treatment studies are undertaken and resulting empirical findings show promise. For example, the "untreatable" position has recently been all but

overturned by notable research in terms of the underlying cognitive ability of working memory. A strong and growing body of literature on the benefits of behavioral working memory treatment has garnered growing attention due to evidence of significant effects for computer-based working memory training programming generalizing to multiple academic outcomes, including improved academic achievement (Gray et al., 2012; Holmes, Gathercole, & Dunning, 2009; Klingberg, 2006; McNab et al., 2009; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009). Failure, then, to investigate treatment for RAN due to notions of treatment futility is not a cogent argument; especially as individuals significantly affected by RAN-type dyslexia are in need of treatment options.

Direct treatment of RAN.

Although no large scale studies on the efficacy of direct and explicit RAN treatment exist, five small to medium size behavioral studies have directly treated RAN deficiencies. Two of these studies treated RAN in isolation. Most recently, in 2004, a dissertation with a multiple baseline, single subject design reported positive clinically significant treatment results for RAN-impaired struggling readers ($n = 4$) with administration of a 16 day intervention consisting of repeated reading of letter sounds from RAN array protocols (see Appendix A). Participants in this study not only significantly improved RAN with direct treatment but also maintained gains when retested two weeks postintervention (Hughes, 2004). And, in an experimental study, a group of first graders ($n = 39$) were randomly assigned to letter naming or a control condition. Participants practiced drilling on letter names 12-15 minutes daily for twelve days. At posttesting, the treatment group had higher scores in RAN and fluency as compared to the control. Unfortunately, these gains were not maintained at follow up testing seven weeks later, perhaps due to the short nature of the treatment. (Fugate, 1997).

Three studies investigated more comprehensive multicomponent treatments (direct treatment of RAN in conjunction with other treatments). Two experimental studies ($N = 120$) investigated the effects of a curriculum called *Stepping Stones*, designed to specifically target letter knowledge, PA, RAN, and sentence comprehension in students aged 4-6. The RAN component of the program consisted of explicit instruction in naming of letters, colors, numbers, and pictures distributed in arrays much like the original Denkla and Rudel (1976) RAN task (see Appendix A). Students in the study, who were at risk for reading and behavior problems, were exposed to 10-20 minutes of daily programmed intervention with the *Stepping Stones* program. Upon posttesting, both studies found positive effects for RAN improvement with moderate to large effect sizes (Nelson, Benner, & Gonzalez, 2005; Nelson, Stage, Epstein, & Pierce, 2005). Moreover, The What Works Clearinghouse qualified both of Nelson's studies as meeting evidence for RAN improvement, noting the one-on-one treatment design was most effective for those with more severe reading and attention difficulties (U.S. Department of Education, 2007). Most recently, Conrad and Levy (2011) investigated treatment response for first and second grade students ($n = 44$), 31 of whom had double deficits in PA and RAN. These participants were randomly placed in one of three training conditions: orthographic training followed by RAN training, RAN training followed by orthographic training, or a control math training condition. The RAN portion of the condition involved six days of training, in which students completed five RAN trials per day. RAN trials involved rapidly naming letters in three arrays presented on a computer screen, resulting in practice of fifteen RAN arrays per day. Orthographic training included direct instruction in letter-sound correspondence in order to decode and encode frequent phonetic patterns. The researchers discovered RAN improvements, but only for those who received the orthographic treatment first (Conrad & Levy, 2011).

Direct treatment of VA.

Clinicians in many fields have attempted, with some success, to behaviorally treat the underlying executive skills manifesting in general attention deficits for some time. For instance, meta-analytic research in the field of traumatic brain injury and stroke recovery has indicated successful use of attention process training as a part of rehabilitation to improve auditory and visual attention abilities (Barker-Collo et al., 2009; Cicerone et al., 2011). One team of researchers has even shown attention can be trained in infants with tasks developed to induce visual and auditory distraction and training designed to sustain attention to specific components (Wass, Porayska-Pomsta, & Johnson, 2011). In school age children general attention training transfers to improved word reading efficiency and improved rate (Chenault, Thomson, Abbot, & Berninger, 2006; Hayward, Das, & Janzen, 2007). Conversely, treatment of reading outcomes also enhances sublexical attention processes such as visual perception of letters (Szwed, Ventura, Querido, Cohen, & Dehaene, 2011). While treatment of related sublexical difficulties associated with RAN-type dyslexia are called for, and while limited research has indicated VA improvement with reading intervention, direct treatment for VA as part of a multicomponent reading treatment is still a somewhat novel concept.

Individuals with attentional deficits also benefit from direct training in visual scanning and higher level visual processing to treat VA. In fact, by providing individualized training with visual scanning tasks, once used solely in adult rehabilitation therapy, children improved in selective attention and attentional shifting (Tang & Posner, 2009; Tucha et al., 2011). Another effective treatment, aimed specifically at treating VA deficits in dyslexics, involved a six week intervention consisting of visual serial search among distracters, building mental representations of orthographic sequences, and visual exploration. This study showed positive changes in

behavioral and fMRI data postintervention. (Peyrin et al., 2012). Finally, in 2011, O'Brien,

Wolf, Miller, Lovett, and Morris conducted a repeated measures study in which ($n = 45$)

struggling readers were provided with a multicomponent treatment analyzed for effectiveness

using a visual scanning task. Visual arrays for this task included those with standard letters, as

well as a more novel orthogonal visual search task with flipped, transcribed, and visually

confusable letters. Outcomes of this treatment included a decrease in time needed for search in

traditional arrays ($p < .001$), a decrease in letter confusion and reversals in confusable arrays ($p = $

.02), and an increase in rate and accuracy of identification of sublexical letter clusters. Yet, when

analyzing the data in a multiple regression pattern to ascertain existence of any unique

contribution for these visual search tasks, low beta weights were found, possibly indicating a

lack of unique contribution of the treatment to visual search outcomes. At the same time, a

modest correlation coefficient was noted between rapid naming of letters and the visual search

task ($r = -.466$) (O'Brien et al., 2011).

Other treatments of VA have concentrated on improvement of speed and automaticity of

letter and whole word recognition. One promising recent study discovered treatment of

sublexical VA skills, through rapid presentation of visual stimuli (letter, letter strings, words,

short sentences) by a computer program called *Flash Word*, resulted in reading speed gains

(Lorusso, Facoetti, Paganoni, Pezzani, & Molteni, 2006). And, a prior small study ($n = 24$) using

the same *Flash Word* training program found more impressive gains in reading rate and accuracy

when making comparisons to gains garnered by traditional reading intervention with a speech

language pathologist (Facoetti, Lorusso, Cattaneo, Galli, & Molteni, 2005).

Finally, a study by Solan, Shelley-Tremblay, Ficarra, Silverman, & Larson (2003)

investigated a VA program called *PAVE (perceptual accuracy and visual efficiency,)* a combined

treatment of visual scanning and flashed letters and numbers. Middle school struggling readers who participated in the experimental *PAVE* treatment improved significantly in reading comprehension ($d = 1.17$) as compared to controls. *Reading Plus,* a multicomponent reading intervention program, now includes *PAVE* as a portion of the treatment regime (Rasinski, Samuels, Hiebert, Petscher, & Feller, 2011).

  Direct treatment of reading rate.

  According to Wolf and Katzir-Cohen (2001), "the unsettling conclusion is that reading fluency involves every process and subskill involved in reading…fluency is influenced by the rapid rates of processing all the components of reading" (p. 220). And, although fluency is an important and complex component of skilled reading, it is often neglected in classroom instruction (Shaywitz et al., 2008). Fluency instruction most importantly must focus on the development of the reader's ability to read sufficiently, such that comprehension can ensue (Wolf & Katzir-Cohen, 2001). Fluent readers are those readers who no longer have to concentrate on decoding and figuring out of words, rather these readers are able to read seamlessly, without effort. Fluency instruction with the aim of creating automaticity, then, is needed to assist all developing and struggling readers, particularly those who are RAN-deficient.

  Instruction in fluency necessitates repeated exposures to appropriately leveled print (National Institute of Child Health and Human Development, 2000; Rasinski et al., 2009). To this end, guided repeated reading to improve reading rate is the best empirically supported intervention (Shaywitz et al., 2008). Several research reviews, meta-analyses, and large scale studies have investigated the aggregate findings of studies of repeated reading intervention. In 1989, in an initial narrative review of ten repeated reading studies with experimental or experimental designs, Dowhower found repeated reading produced gains in rate, accuracy,

prosody, and comprehension for good and poor readers; yet no methodological or statistical analysis was conducted to investigate the statistical, clinical, or practical significance of these findings. A decade later, another qualitative narrative review of ten studies of repeated reading showed similar outcomes (Meyer & Felton, 1999). Shortly thereafter, the National Reading Panel analyzed fifty experimental and experimental studies on repeated reading and also found positive outcomes in terms of improved reading rate (NICHD, 2000). In 2002, Chard, Vaughn, and Tyler completed a thorough meta-analysis of 104 studies of repeated reading treatment, indicating repeated reading intervention with multiple features (adult modeling, graphing rate, controlled amount of text, and text difficulty based on learner reading level) produced significant gains in fluency (rate and accuracy) with a large mean effect size of $d = .71$. Most recently, a multilevel hierarchical linear modeling study reviewed 44 single subject studies ($N = 290$) of at-risk readers in grades 1-11, confirming adult guided repeated reading with individualized student goal setting for fluency and student graphing in terms of error percentage, words per minute, and accuracy percentage was most effective in increasing and maintaining fluency gains longitudinally (Morgan, Sideridis, & Hua 2012). In predicting future outcomes from reading fluency instruction, a large longitudinal study ($N = 12,536$) found fluency instruction in grade 1 made the strongest contribution to reading comprehension in grade 3 (Kim, Petscher, Schatschneider, & Foorman, 2010). Finally, a recent twelve week experimental forty hour repeated reading treatment called *RAFT* (reading and fluency training) designed to specifically remediate reading rate in struggling readers ($n = 112$) compared response of treatment and control groups and found significant effects for comprehension, rate, and spelling directly after treatment completion and also a year later (Wolff, 2012).

Other meta-analytic studies indicate repeated reading may not be the most effective intervention for reading fluency issues. In 2009, a review of the evidence for repeated reading for learning disabled students was conducted. This review examined five experimental and six single subject designs for methodological quality in terms of experimental control, reliability, validity and replicability. Study authors indicated further research into the effectiveness of repeated reading for learning disabled students was needed, because several reviewed studies failed to meet standards of methodological rigor in several categories (Chard, Ketterlin-Geller, Doabler, & Apichatabutra, 2009). In 2012, O'Keeffe, Slocum, Burlingame, Snyder, and Bundock reviewed repeated reading treatment studies and echoed similar sentiments, asserting repeated reading does not have enough rigorous research support to be classified as an empirical treatment. As such, while repeated reading has more evidence than any other intervention for fluency, there is a call for further evidence as to the effectiveness of repeated reading as a treatment.

Multicomponent treatments.

Multicomponent treatment options for dyslexia are considered best practice due to the multivariate nature of reading disorders (Al Otaiba & Fuchs, 2006; Gustafson et al., 2011; Kirby et al., 2010; Norton & Wolf, 2012; Wolf & Bowers, 2000). According to a recent review of the reading treatment literature, practitioners need comprehensive treatments to address multiple outcomes of reading difficulty (Al Otaiba & Fuchs, 2006). Furthermore, according to Shaywitz, Morris, and Shaywitz (2008), "At this point, determining which instructional programs work best is not necessarily important, but rather determining what program works best for what kind of dyslexic student with what kind of characteristics in what kind of implementation [should be the goal of treating clinicians when selecting treatments]" (p. 466). As long as treatment includes

interventions to meet the specific presenting areas of reading difficulty, there is no formulaic or singular correct way to treat those with RAN-based dyslexia and subsequent outcomes (Morris et al., 2010; Torgeson, Wagner, Rashotte, Herron, & Lindamood, 2010). What is important in terms of this study and in clinical practice in general, then, is to tailor reading intervention treatment to the needs of the individual child (Fiorello, Hale, & Snyder, 2006; Hale & Fiorello, 2010).

One well-researched and versatile multicomponent program, *RAVE-O* (retrieval, automaticity, vocabulary, elaboration, and orthography) was created by Dr. Maryanne Wolf to specifically treat the lexical and supralexical difficulties children with RAN-type dyslexia face. *RAVE-O* has undergone several empirical investigations over the past decade. In 2000, Wolf, Miller, and Donnelly treated children with single word decoding and sight word recognition difficulties with the *RAVE-O* intervention, or a control treatment called phonological analysis and blending for a five month period. Children received an average of seventy intervention sessions of approximately thirty minutes each. Those in the *RAVE-O* condition manifested significant gains in word attack, word identification, rate, accuracy, and comprehension as compared to those in the control condition (Wolf, Miller, & Donnelly, 2000). Wolf et al., (2009) later replicated these results in a five year longitudinal study, as well as, a smaller scale study in which *RAVE-O* was also found to be effective in shorter, more intensive half day long intervention occurring during a four week long summer school program. While *RAVE-O* is effective, it is not more effective than other similar programs, again highlighting the existence of multiple paths to effective reading intervention. For instance, Morris et al. (2010) discovered *RAVE-O* and another similarly well designed intervention conveyed no differences for a large cohort ($N = 279$) of children with learning difficulties. In fact, children receiving either

intervention improved equally in terms of fluency, comprehension, and vocabulary immediately after treatment and continued growth at one year follow up testing (Morris et al., 2010).

Similarly to *RAVE-O*, other multicomponent programs have successfully treated RAN, without direct RAN intervention. In one treatment of a small group of children ($n = 11$), a program called *Seeing Stars*, involving visualization of letters, words and clusters, finger tracing of words, letters clusters, and letters, coupled with nonsense word study resulted in significant increases in RAN ($p = .003$) with a mean pretreatment standard score of 75 and a posttreatment standard score of 85. *Seeing Stars* also showed postintervention increases in word attack, real word decoding, reading comprehension, and PA (Krafnick, Flowers, Napoliello, & Eden, 2011). In another brief multicomponent intervention, children ($n = 44$) treated in PA and alphabetic skills during thirty minute sessions (average of nine hours total treatment time) showed increases in speeded naming of pictures. While these increases in naming were not significant in terms of treatment effect, there was a significant dosage effect, with each session of intervention resulting in subsequent gains in naming outcomes (Bailet, Repper, Piasta, & Murphy, 2009).

Conversely, other successful multicomponent treatments have directly treated RAN in addition to related sublexical and lexical variables. One such program targeting letter naming, PA, decoding, and sentence processing with a computer-based intervention demonstrated participant improvement in all areas of treatment after a two month intervention (Helland, Tjus, Hovden, Ofte, & Heimann, 2011). Another multicomponent program directly treated RAN deficiencies with rapid naming of syllables and words, as well as, repeated reading of connected text. This treatment, after approximately twenty hours of intervention, resulted in significant effects on letter RAN (Kairalouma, Ahonen, Aro, & Holopainen, 2007).

Finally, a recent multicomponent program designed to treat fluency in secondary students also shows promise. This program, called *Reading Plus*, now includes computer-based component *PAVE* to treat VA, as well as other computer-based interventions for reading rate, vocabulary, and comprehension (Rasinski et al., 2011). In a 2004 pilot study of *Reading Plus*, adult college students scored better in reading comprehension following treatment, but no statistically significant effects were noted (Tran, Yu, Okumura, & Laukkanen, 2004). However, in an analysis of 16,143 students in twenty-three schools, many of whom were impoverished and/or learning disabled, students participating in *Reading Plus*, as compared to long-standing reading intervention programs *Read 180* and *Accelerated Reader*, made significant gains in VA, rate, comprehension, and vocabulary, with small to moderate effect sizes ($d = 0.03$ to 0.34) (Rasinski et al., 2011).

The reading process is more complex than following a simple, linear, lock-step process. Reading intervention must take into account all areas of sublexical and lexical difficulty potentially contributing to difficulties in supralexical outcomes (i.e. reading comprehension). Those implementing reading intervention must have awareness of the student's sublexical (RAN, VA) and lexical (rate) difficulties to appropriately structure treatment to meet the student's individual learning profile (Hale & Fiorello, 2010; Meisinger et al., 2010).

Summary

In Chapter II, a thorough review of the literature including evidence from brain imaging studies, cross-linguistic studies, correlation studies, and treatment studies pertaining to the dependent or outcome variables (RAN, VA, rate) and independent or grouping variables (level of deficit, treatment condition) was conducted to inform the research design and chosen methodology explored in Chapter III. Chapter IV contains further analysis of data collected and

specifically presents variance in treatment response by comparing the independent variable of treatment and control condition, as well as, the independent variable of level of core dyslexic deficit (single deficit of RAN-only or double deficit of RAN + PA). Also, Chapter IV investigates findings in terms of multivariate and univariate response to intervention and includes the dependent variables of sublexical reading deficits in RAN and VA, as well as, the related lexical reading deficit in reading rate. Finally, Chapter V discusses findings and results as applied to prior research, theory and clinical practice in the field of practice.

Chapter III

Method

The purpose of this study was to ascertain if a multicomponent reading treatment, developed specifically for those with single deficit (RAN only) and double deficit (RAN + PA) underlying dyslexic deficiencies, improved sublexical skills in RAN and VA, as well as, the lexical skill of reading rate. To this end four null hypotheses were developed.

Null Hypotheses

H_o1: There will be no difference between treatment and control groups (IV 1) on overall treatment response.

H_o2: There will be no difference between treatment and control groups (IV 1) on all dependent variables (RAN, VA, rate).

H_o3: There will be no difference in treatment response between single and double deficit groups (IV 2) on overall treatment response.

H_o4: There will be no difference in treatment response between single and double deficit groups (IV 2) on all dependent variables (RAN, VA, rate).

Research Design

This treatment or intervention-type study utilized a quantitative, experimental design to explore differences between and within groups in order to ascertain causality. Experimental designs with control conditions are the most effective way to discover if treatments or interventions work and for whom (Field, 2009). Indication of causality was sought in this study as the purpose was to determine if the particular multicomponent treatment administered caused improvement in RAN, rate, and VA in children with two levels of reading difficulty (single

deficit RAN-only dyslexia and double deficit RAN + PA dyslexia) after controlling for cognitive ability (FSIQ).

A-Priori Power Analysis

In order to determine the necessary approximate sample size for the study, an a-priori power analysis was conducted utilizing power analysis software, G-Power 3.1. G-Power 3.1 is a general stand alone power analysis program, providing support for many statistical tests and also serving to calculate effect size. Use of G-power in particular and a-prior power analysis in general functions to ensure reliable discrimination between H_o and H_a is made (Faul, Erdfelder, Lang, & Buchner, 2007). Moreover, a-priori power analysis is important because an insufficiently powered study may garner nonsignificant results leading to a type II error. In other words, the researcher may fail to reject the null hypothesis when a rejection would have occurred, had the study been sufficiently powered with an adequate sample size (Faul et al., 2007).

In computing the power needed for the main analysis in the present study, G-power 3.1 computed the sample size as a function of the required power level $(1 - \beta)$ where $\beta = .2$ (Cohen, 1988; Faul et al., 2007). It was determined a total sample size of approximately $n = 28$ was necessary at to attain power of .8, where $\alpha = .05$ and with the effect size of $d = .40$ (considered a large effect size when comparing groups) (Cohen, 1988). Due to larger than expected qualification rates (30.77% of tested children qualified), the researcher was able to obtain an initial total sample size of $n = 52$, thus resulting in a sufficiently powered study.

Variables Examined

Variables examined included two independent or grouping variables, three dependent or outcome variables, and one covariate. Variables are listed in Table 1.

Table 1

Variables Examined

Independent Variables	Dependent Variables	Covariate
Deficit (Single or Double)	Rapid Naming (RAN)	Full Scale IQ (FSIQ)
Group (Treatment or Control)	Visual Attention (VA)	
	Reading Rate (rate)	

Independent variables.

Two independent variables (IVs) were examined, each with two levels. Random assignment of participants by level for both IVs is shown in table 2. The first IV compared outcomes for treatment and control conditions; while the second IV compared participant response by classifying participants into sublexical deficit categories of single deficit or double deficit. Participants were assigned to either single or double condition based on outcome of initial screening and pretreatment assessment with the RAN and PA subtests of the Comprehensive Test of Phonological Processing (CTOPP). Individuals who scored below average (at or below $T = 90$, 25th percentile) on either alphanumeric RAN subtest were assigned to the single deficit (RAN-only) group. Participants who scored below average (at or below $T = 90$, 25th percentile) on one of both of the alphanumeric RAN subtests as well as the PA subtest were assigned to double deficit (RAN + PA) group.

Table 2

Independent Variables Examined by Level of Deficit

Deficit Type	Treatment	Control (delayed treatment)	Total IV2
Double	$n = 8$	$n = 8$	$n = 15$ [a]
Single	$n = 15$	$n = 10$	$n = 24$ [a]
Total IV1	$n = 23$	$n = 18$	

Note. IV1 compared treatment and control participants; IV 2 compared single and double deficit participants

[a] 1 double deficit and 1 single deficit participant dropped out during delayed treatment; for purposes of analyzing data for IV 2 (single versus double deficit participants) as applied to H_o2 and H_o4 $n - 1$ represents the actual total used.

Dependent variables.

Three dependent or outcome variables (DVs) were examined, including two sublexical variables: RAN and VA, and one lexical variable: reading rate. Each DV was measured prior to and after treatment in order to ascertain growth. Clearly, the DV of RAN (as measured by the CTOPP) was necessary for inclusion in the study sample due to study design. Reading rate (as measured by the Gray Oral Reading Test - IV) was selected as an outcome variable because prior literature suggested students with a RAN deficit also have poor outcomes in rate (see Chapter II). Finally VA as measured by inhibition (NEPSY - II) was included to determine if treatment effects also helped to improve underlying VA deficits (see chapter II).

Covariates.

According to Stevens (2009), it is particularly important in the social sciences, where groups are typically small and in which effect sizes are also typically small to medium at best, to include covariates (COVs). By controlling for covariance, error variance is reduced, and power is improved and thus causality assertions are strengthened (Stevens, 2009; Tabachnick & Fidell, 2007). Perhaps more importantly, use of a COV, "in experimental work…serves as a noise reducing device where variance associated with the covariate is removed from error variance." (Tabachnick & Fidell, 2007, p. 245). Hence a COV of full scale intellectual quotient (FSIQ) was

included in the design of this study in order to adjust DVs (RAN, VA, rate) for differences in FSIQ, in effect lessening the influence of varying FSIQs on treatment outcomes for different individuals. The COV number was limited to the single most important covariate, FSIQ, due to a relatively small sample and group size in accordance with Huitema's (1980) recommendations and formula.

For the current study, FSIQ was chosen as the COV as cognitive ability is typically correlated with academic achievement in general (Stevens, 2009). Beyond academic achievement in general, there is much research correlating FSIQ and general reading ability development. Impaired FSIQ is generally thought to correlate with reading difficulties across the board, resulting in the notion of a "garden variety" poor reader (Bower-Crane, Snowling, Duff, & Hulme, 2011; Kirby et al., 2010; Stanovich, 1988). In typical readers, IQ is dynamically linked to reading over time (Ferrer, Shaywitz, Holahan, Marchione, & Shaywitz, 2010), contributing specific to variance to reading outcomes (Compton et al., 2002). Conversely, those with dyslexia have an uncoupling of FSIQ and reading ability (Boniffaci & Snowling, 2008; Lyon et al., 2003). Moreover, in both compensated and persistently poor dyslexic readers, the dissociation of FSIQ and reading ability tends to widen over time (Ferrer et al., 2010). Covarying for FSIQ controls for any differential treatment response potentially emanating from varied cognitive ability, while simultaneously providing a better sense of individual participant's profile of ability and disability (Stevens, 2009; Tabachnick & Fidell, 2007).

Population/Participants

The population studied for the present study was pulled from a large urban area of over 700,000 residents. Participants were directly recruited by the research team via a large, professional, marketing and advertising campaign directly targeting 8,760 families with children

ages 7-12. This multimedia campaign included direct mailing to 1,800 families in close proximity to the clinical location, and direct marketing with advertising materials to 6,960 families obtained from 56 referral sources such as private clinical practices (speech-language pathologists, occupational therapists, pediatricians, neuropsychologists, and pediatric psychiatrists), local private schools, and local public schools. This intensive marketing campaign was carried out by the research team and lasted for two months. See Appendix B for a sample call for participants.

Children younger than age 7 were excluded from the initial screening as the proposed treatment requires some knowledge of letter sounds (Adams, 1990; Shaywitz, 2003). Children older than age 12 were excluded as well, as the proposed treatment was not designed for adolescents. Also, children served in school-based programs for individuals with profound disabilities (i.e. individuals who were nonverbal or unable to communicate) were excluded from the initial screening, again because the minimum requirement for treatment is knowledge of letter names and sounds. Finally, those children who did not fit the definition of dyslexia due to severely impaired FSIQ (at or below $T = 75$; at or below 5th percentile) were included for treatment but not for statistical analysis of the data (Bonifacci & Snowling, 2008; Lyon et al., 2003).

Screening appointments were scheduled for $N = 247$ clinic-referred children ages 7-12 with parent reported difficulties in reading, specifically in terms of reading rate (representing a 2.8% response rate to the call for participants). Of this initial pool, 37 children (14.99%) did not show up or cancelled the initial screening appointment; 134 children (54.25%) did not qualify for study inclusion due to no RAN deficit; and 76 children (30.77%) qualified for inclusion in the study. Of the 76 who qualified, 24 participants (31.58%) dropped out of the study after screening

or pretesting and never received treatment of any kind. The remaining 52 participants (68.42%) were offered the intervention in terms of the DVs under study, and were randomly assigned to the treatment group or the control group (delayed treatment).

During the initial treatment session, 2 participants stopped attending midsession and did not receive posttesting. And, after treatment, data was removed for participants ($n = 9$) whom manifested significantly impaired FSIQ (at or below $T = 75$; at or below 5th percentile), leaving 41 data sets for analysis purposes in terms of IV 1 (comparing treatment and control groups). Finally, 2 participants also dropped out of the control delayed treatment, leaving 39 data sets for analysis in terms of IV 2 (comparing single and double deficit groups).

To better understand participants in this study, descriptive statistics were analyzed in terms of age, grade level, gender, ethnicity, and school type. Participant ($n = 41$) median age was 9.5 ($SD = 1.37$). Participant grade levels were reported as grade level completed before summer and ranged from 1st to 7th. More specifically the study included 5 1st graders, 11 2nd graders, 7 3rd graders, 8 4th graders, 8 5th graders, 1 6th grader and 1 7th grader. In terms of gender, 15 (36.6%) participants were male and 26 (63.4%) were female. In terms of ethnicity, 19 participants were Hispanic (46.3%), 8 were African American (19.5%), 12 were Caucasian, nonHispanic (29.3%), 1 was Middle Eastern (2.5%) and 1 was Asian (2.5%). In terms of school type, 22 (53.7%) participants attended public schools (including public charter schools), 13 (31.7%) attended private schools (including private preparatory schools, Catholic schools, and other Christian schools) and 6 (14.6%) were homeschooled.

Instrumentation

      Reynolds Intellectual Achievement Scale (RIAS).

      The Reynolds Intellectual Achievement Scale (RIAS) is a norm-referenced, commercially-produced, brief measure of cognitive ability. The RIAS includes three scales measuring verbal ability, nonverbal ability, and working memory for individuals age 4.0 to adult. The RIAS also provides a composite FSIQ score, taking into account the influence of verbal and nonverbal ability. For the present study, the composite FSIQ score for each participant was measured as a standard *T* score (equivalent to percentile scores) and used for the covariate. As FSIQ is relatively stable over time, this instrument was only administered before treatment began (Reynolds & Kamphaus, 2003).

      RIAS normative procedures.

      The RIAS was normed on a sample of 2,438 ethnically and gender diverse participants located in 41 states. This data collection lasted from 1999 until 2002. Examiners collecting normative data were experienced practitioners or graduates students in school or clinical psychology. In norming of the RIAS, t-scores were used ($M = 10$, $SD = 3$) to provide the most flexible range of conversion to other standardized sores. RIAS index or *T* scores, based on these individual t-scores, are commonly referred to as standard scores in the field of psychometrics. *T* scores have a population mean of 100 and a population standard deviation of 15. For purposes of this study, the *T* scores were used for analysis (Reynolds & Kamphaus, 2003).

      RIAS reliability.

      To measure internal consistency for the RIAS subtests, the test authors utilized Cronbach's alpha (Reynolds & Kamphaus, 2003). A measure of internal consistency such as Cronbach's alpha assesses the degree to which similar items jointly measure the same construct

(Henson, 2001). According to Nunnally and Bernstein (1994), a psychometric, norm-referenced measure such as the RIAS should attain a reliability coefficient of $\alpha = .80$ to produce minimally reliable scores. Coefficients of $\alpha = .90$ or above are considered to be the most desirable. When originally computed by the authors of the RIAS, Cronbach's alpha coefficients were $\alpha = .84$ or higher for every age group, indicating a reliable level of internal consistency (Reynolds & Kamphaus, 2003). After assessment of the sample for this study, a Cronbach's alpha coefficient of $\alpha = .97$ was computed for FSIQ scores, indicating a desirably high level of internal consistency for the RIAS (Nunnally & Bernstein, 1994). Furthermore, this high degree of internal consistency also indicates low measurement error in the covariate, a necessary assumption of MANCOVA (Jamieson, 2004).

RIAS validity.

The authors of the RIAS analyzed construct validity through a multistep process. RIAS items were originally written by the authors in 1998. All items were reviewed by several staff members working in conjunction with the authors and the publisher of the test kit, many of whom had doctoral level credentials. Items were reviewed initially for detection of ambiguities of wording or visuals, objectivity in scoring, potential cultural bias, and consistency with item-writing principles in the field of measurement. Next, perceived fit to assigned scale was evaluated using an EFA and a CFA after which 507 items remained distributed between the three factors (verbal, nonverbal, working memory). The instrument was then field tested nationally in fall of 1998 and spring of 1999 with a sample of 203 participants. At this juncture, items with poor discrimination indexes or statistics resulting in gross disparities were removed. This process resulted in a reduced pool of 369 items included on the standardized version. Further measures were implemented, specifically a measure to detect differential item functioning, which

determines if an item is substantially harder for one group than another. The presence of DIF

may indicate a bias and as such items with DIF must be augmented or deleted. Any item showing

a statistically significant correlation for DIF ($p < .01$) when comparing age, ethnic, and gender

groups was reviewed for effect size. If the item had an effect size indicating a strong enough DIF

to create bias, the item was eliminated (Reynolds & Kamphaus, 2003).

Comprehensive Test of Phonological Processing (CTOPP).

The Comprehensive Test of Phonological Processing (CTOPP) is regarded as an

indispensible tool in the identification of dyslexia. Like the RIAS, the CTOPP is a nationally-

normed, standardized assessment tool. The CTOPP can be used with individuals age 5.0 to age

24.0. There are two protocol versions of the CTOPP, one for age 5-6 and one for age 7-24.The

test is comprised of three main scales: PA, phonological memory, and RAN. Each of these three

scales produced a composite score when scores from internal subscales are combined. There are

also alternate measures to provide further information in terms of phonological processing

(Wagner et al., 1999). For purposes of the current study, only the main PA and RAN composites

on the age 7-24 form were used. As such, each student aged 7-12 was administered the two

subtests within the PA factor, elision and blending words, prior to intervention and the two

subtests within the RAN factor, rapid digit naming and rapid letter naming (RAN) prior to and

after treatment.

CTOPP normative procedures.

The CTOPP was normed on a sample of 1,656 persons in 30 states. Individuals in the

sample were tested during the fall of 1997 and spring of 1998. Examiners for the norming

process were all speech language pathologists or psychologists. The sample, much like the RIAS,

was comprised of individuals of all ethnicities, genders, and testable ages. Norms for the CTOPP

subtest are reported as t-scores or standard scores having a mean of 10 and a standard deviation

of 3. Composite scores are reported as *T* scores based on a normal population distribution with a

mean score of 100 and a standard deviation of 15. Conversions for percentiles and age and grade

equivalents are also provided. (Wagner et al., 1999). For purposes of the present study *T* scores

were used for statistical analysis.

CTOPP reliability.

The internal consistency or reliability of the CTOPP subtests and composites, with the

exception of the RAN subtests, was measured using Cronbach's alpha. Reliability for the PA

composite for the normative sample was α = .90 for ages 7-24 (Wagner et al., 1999) which

represents a high degree of internal consistency (Henson, 2001; Nunnally & Bernstein, 1994).

Similarly, with the sample in the present study, reliability of α = .90 was indicated for the PA

factor. For measurement of internal consistency for the RAN factor, the test authors utilized an

alternate measure of internal consistency (Wagner et al., 1999) because Cronbach's alpha and

other split-half coefficients are not appropriate for speeded tests as alphas tend to be inflated

(Onwuegbuzie & Daniel, 2002; Osburn, 2000). As two RAN subscales are given at each test

session, the correlation between the two RAN forms can be used as a reliability index to estimate

content sampling error (Anastasi & Urbina, 1997). Using this alternate form of reliability

measure, the RAN composite for the normative sample had a reliability correlation coefficient of

r = .92 for ages 7-12 (Wagner et al., 1999). For the present study, a bivariate correlation was also

computed comparing RAN letters to RAN numbers at each testing session to assess internal

consistency. Correlations were found significant (p = .01) for the three testing sessions in which

RAN was administered (r = .85; r = .87; r = .65 respectively). Finally, test-retest correlations

were reported by the authors as an alternate measure of reliability. Reported test-retest

correlations ($r = .74$ to $.97$) indicate adequate reliability over multiple administrations for the normative sample (Wagner et al., 1999). For the current study, test-retest correlations were computed ($r = .70$ to $.76$) indicating little change in RAN scores over time (i.e. treatment resistance). Also interscorer reliability was also reported as strong ($r = .95$ to $.99$). As the CTOPP is nonsemantic in nature and difficult for a participant to recall, reuse of the one form for pre and posttesting is considered acceptable (Wagner et al., 1999).

CTOPP validity.

According to Wagner et al. (1999), valid inferences can be made from tests if the test measures what it purports to measure. As test validity is a somewhat relative concept and can actually differ according to how the test is being utilized, test authors are thus encouraged to measure validity in a variety of ways. Provision of at least three measures of validity per test tool is the standard norm provided by instrument authors. The measures used to ascertain validity for the CTOPP included content validity, criterion-related validity, and construct validity (Wagner et al., 1999).

Content validity is the process of systematically examining the content of the test to ensure test items are representative of the domains being measured (Anastasi & Urbina, 1997). Content validity is provided for the CTOPP as authors offer a discussion of the rationale for item selection, as well as engage in conventional item analysis and differential item functioning (DIF) analysis in order to show freedom from bias in terms of the test's items. By using item discrimination and difficulty statistics, items which did not fit within the parameters of the item response theory for the CTOPP were deleted. Differential functional analysis or DIF was also computed using logistic regression. Again, as was the case with the RIAS, DIF was successfully

used to detect and delete items which may present different response probabilities for different groups of individuals (Wagner et al., 1999).

Criterion validity was measured by correlating the CTOPP with other tests measuring the same constructs as well as tests measuring related constructs. Correlations reported were either concurrent or predictive, depending on the amount of time between administration of the criterion test and the test being validated (CTOPP). For this type of validity, the CTOPP was correlated with the Woodcock Reading Mastery Test-Revised (WRMT-R) and the Test of Word Reading Efficiency (TOWRE). Moderate to strong correlations between these criterion measures (WRMT-R and TOWRE) and the CTOPP support the criterion-validity of the CTOPP (Wagner et al., 1999).

Construct validity tells how well the test measures a particular construct (Anastasi & Urbina, 1997). Construct validity for the CTOPP was measured using CFA. CFA is different from EFA as it does not allow items to load on any other factors other than the factor the item represents. Moreover, CFA tests how well the theoretical model the instrument is built upon is confirmed by the test data. In previous research, there was only a moderate correlation between PA and RAN (suggestive of factor difference), while PA and phonological memory were strongly correlated. Finally, this theoretical model was confirmed by the Comparative Fit Index as the model scored a .99 (maximum value is 1.00) (Wagner et al., 1999).

Gray Oral Reading Test, 4th Edition (GORT-IV).

The Gray Oral Reading Test, 4th Edition (GORT-IV) is a norm-referenced assessment, originally created by Dr. William Gray in 1963. The GORT-IV measures reading rate, reading accuracy and oral reading comprehension and consists of equivalent A and B forms and can be given to individuals aged 6.0 to 18.0 (Wiederholt & Bryant, 2001). While all factors (rate,

accuracy, comprehension) were administered in this present study to prevent inaccuracies in analysis, only scores from rate in the data analysis. For purposes of $H_{\circ}1$ (discerning differences between treatment and control), form A was used in pretesting and form B was used in posttesting. For purposes of $H_{\circ}3$ (discerning differential treatment response between single and double deficit groups), participants in the delayed treatment (control) group were pretested with form B and posttested with form A, necessitating a reuse of form A for the second posttesting session.

GORT-IV normative procedures.

The GORT-IV was normed on a sample of 1,677 students, grades 1-12 in 28 states between the fall of 1999 and the fall of 2000. All demographic populations such as age, gender, income, ethnicity, residential areas, and geographic area were evenly represented. Linear equating procedures were used to correct for any differences in difficulty between A and B forms of the test so examiners can use these forms interchangeably (Kolen & Brennan, 1995). Scores for the GORT-IV are presented as individual t-scores ($M = 10$, $SD = 3$). Score conversion into standardized T scores ($\mu = 100$, $\sigma = 15$), percentiles, age, and grade equivalents is also provided in the manual (Wiederholt & Bryant, 2001). GORT-IV T scores were used in statistical analysis for the present study.

GORT-IV reliability.

GORT-IV internal consistency was calculated by the test authors for each of 13 age intervals for forms A and B. The average Cronbach's alpha coefficients for all subtests and composites in the test manual (rate, accuracy, comprehension) are acceptable as they all meet or exceed $\alpha = .90$ (Henson, 2001; Nunnally & Bernstein, 1994; Weiderholt & Bryant, 2001). For purposes of the present study internal consistency reliability coefficients for rate were calculated

at each testing session, resulting in acceptable metrics as well (Henson, 2001; Nunnally & Bernstein, 1994; Weiderholt & Bryant, 2001). For pretesting, GORT-IV rate on form A attained an internal consistency coefficient of α = .85. For posttesting (round 1) to ascertain differences between treatment and control groups, GORT-IV rate on form B attained an internal consistency coefficient of α = .86.   Finally, for posttesting (round 2) to ascertain differences between single and double deficit groups, GORT-IV rate on form A attained an internal consistency coefficient of α = .83.   The GORT-IV authors overcame the confounding issue of computing split-half reliability for timed measures by converting words per minute attained to raw scores in the format of scaled data (1-5) (Onwuegbuzie & Daniel, 2002; Osburn, 2000).

Also, the reliability of the GORT-IV was tested in a secondary manner involving correlation between form A and form B at the various age levels. After running this correlation, the authors show the means and standard deviations are similar on both forms at every age interval and the correlation coefficient between the two forms was r =.71, again pointing to a high degree of internal consistency (Anastasi & Urbina, 1997; Weiderholt & Bryant, 2001). The correlation coefficient between form A and form B was also computed for the present study (r = .87) and was found to be significant (p = .000).

Finally, time sampling or giving the test multiple times to individuals across a short amount of time (2 weeks in this instance) was employed as an alternate measure of reliability. Two test-retest correlations reported were all at or above r = .78, indicating the GORT-IV has acceptable test-retest reliability. For purposes of this study, as Form A was used twice for participants in the control group, a test-retest correlation was also computed and was not significant (r = -.329, p = .213), indicating undesirable variability in rate scores (more impaired rate scores) after treatment. Finally, interscorer reliability was tested through a sample of

research staff scoring sessions and the interscorer correlation found was strong (r = .94 to .99). (Wiederholt & Bryant, 2001).

GORT-IV validity.

As with the CTOPP, the GORT-IV was validated using content, criterion, and construct validity. Content validity was controlled for by implementation of careful procedures such as ensuring stories were high interest, logically constructed, and grade level appropriate in terms of vocabulary. Furthermore, the GORT-IV stories were assessed using the Flesch-Kinkaid Readability Formula to ensure appropriate ordering of stories from easy to difficult in terms of reading level. Finally item-analysis was employed to ensure content validity, and whole and partial correlations were employed, as well as, differential item functioning (DIF) to compare group performance on items in order to control for bias in terms of race, gender, age, etc. Of the nine items in which the DIF was significant (p = .001), none had moderate or large effect sizes as measured by R^2, so the authors retained the items while concluding the test was nonbiased in regard to gender, race, and ethnicity (Wiederholt & Bryant, 2001).

In terms of criterion validity, the GORT-IV correlated in a predictive manner with the Gray Diagnostic Reading Test (GDRT-II), the Gray Silent Reading Test-2 (GSRT-II), the Test of Word Reading Efficiency (TOWRE), the Woodcock Reading Master Test-revised (WRMT-R) and the Wide Range Achievement Test (WRAT). Moreover, the GORT-IV fluency composite correlated modestly to the CTOPP RAN (r = .49) suggesting a relationship between reading fluency and RAN ability (Wiederholt & Bryant, 2001).

In terms of construct validity, there is an assumption all subtests measure aspects of oral reading and should be significantly intercorrelated. As such, all correlations between subtests

were significant ($p = .01$). And, all correlations showed a moderate to high degree of relationship; indicating construct validity was met (Wiederholt & Bryant, 2001).

NEPSY-II.

The NEPSY-II is a comprehensive norm-referenced neuropsychological battery suitable for children ages 3 to 16. This test was normed in 2003 on 1,200 children and adolescents, evenly distributed into age bands and also evenly stratified by race, ethnicity, and geography. This battery has six theoretical domains of cognitive functioning including attention and executive function, language, memory, sensorimotor, social perception and visuo-spatial perception. Within these six domains, thirty-two individual subtests are available for administration (Korkman et al., 2007).

Three NEPSY-II subtests (switching, inhibition, and naming) make up the inhibition subset of the attention and executive function domain and can be administered to individuals age 5-16 in approximately 10 minutes (Korkman et al., 2007). Low scores (below 16th percentile, below *T* score of 85) on the inhibition subtests are suggestive of slow processing speed, difficulty with cognitive flexibility and shifting set, difficulty with inhibiting unnecessary visual stimuli, and difficulty controlling or inhibiting incorrect responses (Brooks, Sherman, & Strauss, 2010). For purposes of the present study, only the inhibition subtest from the inhibition subset of the attention and executive function domain of the NEPSY-II was administered to ascertain if individual subjects manifested sluggish visual attentional shift and retrieval difficulties due to primary deficits in inhibition or impulse control.

Accordingly, the inhibition subtest has strong roots in the classic 1935 Stroop task in which the subject must rapidly give the opposite of an automatic response (Korkman et al., 2007, p. 31) In the classic Stroop task, color words such as red and blue are printed in the opposite

color and the subject is asked to suppress reading of the word (automatic prepotent response) in favor of naming the color of the word. In terms of the NEPSY-II, the inhibition task is designed as a nonlexical Stroop task as it does not include any reading of words (i.e. the participant must say, "up" when the arrow points down). On the inhibition subtest, the subject receives a combined score reflecting the contribution of errors (accuracy) and time (rate of responding) (Korkman et al., 2007).

NEPSY- II reliability.

Reliability in terms of internal consistency measures across all age groups in the NEPSY-II normative sample was adequate to very high. For individuals ages 7-12, 93% of subtests have internal consistency coefficients of .80 or greater (inhibition $r = .80$), indicating adequate reliability (Henson, 2001; Korkman et al., 2007; Nunnally & Bernstein, 1994). For purposes of the current study, alternate internal consistency metrics were computed for the inhibition subtest due to the measure's timed nature (Anastasi & Urbina, 1997). In comparing alternate forms of the inhibition subtest (shapes versus arrows) given to all participants in this study ($r = .343$ for pretesting; $r = .643$ for posttesting after the initial treatment session; $r = .399$ for the posttesting after the delayed treatment session), it appears outcomes for this sample may not be as internally consistent as expected when compared to the normative sample ($r = .80$). As such, interpretations of the NEPSY-II inhibition subtest should be made cautiously (Henson, 2001).

Test-retest reliability for the normative sample was also was adequate for the normative data, with all scores for utilized subtests in all relevant age bands at .70 or higher, with the exception of the inhibition (.66 at ages 9-10 only) allowing for researchers to readminister with only a twenty-one day interval following original administration (Korkman et al., 2007). Test-retest correlations were also computed for this study and outcomes were modest yet significant

between pretesting and posttest 1 ($r = .411$, $p = .008$) and not significant between posttest 1 and

posttest 2 $(r = -.293$, $p = .272)$. Lower metrics for test-retest in the present sample, as compared

to the normative data, indicate positive changes in VA due to treatment effects. Finally, practice

effects were also minor for the inhibition task when normed (Korkman et al., 2007) and as such

this task may be used more than once as was the case with the present study.

NEPSY-II validity.

The NESPY-II manual provides evidence for concurrent and clinical validity. Concurrent

validity specifically for the inhibition subtests was also found when comparing inhibition

outcomes to WISC-IV processing speed outcomes. Clinical measures of validity were measured

in terms of clinical group performance effect size (Cohen's d) when administering the test with a

sample of children with ADHD ($n = 55$) and reading disorder ($n = 36$). Overall metrics for

inhibition subtests indicate effect sizes ($d = .42$ to $.46$) adequate for identification of cognitive

problems in terms of attention in those with ADHD and reading disorders (Korkman et al.,

2007). No factor analysis was included for creation of the overall test domains, indicating while

the theoretical domains are based on prior literature, they are not currently derived from any

psychometric, statistical grouping method. Overall though, the NEPSY-II is considered the most

thorough, sound, and well-developed comprehensive neuropsychological battery available

(Brooks et al*., 2010*).

Data Collection Procedures

Data was collected during the spring of 2013 in a tiered fashion by the researcher and a

team of research assistants with credentials in test administration (individuals had at least a

master's level course in reading or special education assessment). After the University

Institutional Review Board reviewed and qualified the study as safe for all participants,

permission was obtained from parents for testing and treatment. Then, all interested children were screened for inclusion with the RAN subtests from the CTOPP. Those scoring at or below the 25th percentile ($T = 90$) on either alphanumeric RAN subtest were invited to participate in the study. All qualifying participants were then scheduled to be pretested for the remaining DVs of rate (with the GORT-IV), VA (with the inhibition subtest of the NEPSY-II), the covariate of FSIQ (using the RIAS), and PA (with the CTOPP) which served to collate participants into single or double deficit levels (IV 2).

After pretesting, participants were randomly divided into immediate treatment and control (delayed treatment) conditions (IV1). The immediate treatment group then received four weeks of intervention immediately following pretesting. All participants were then posttested on all DVs (RAN, VA, rate) following the initial 4 week treatment (posttest 1). Those in the control condition were then offered a chance to receive an identical delayed intervention and were posttested again on all DVs after the four weeks of delayed treatment (posttest 2). By scheduling in this staggered manner, all participants in need of treatment had equal access and a repeated measures experimental design was still feasible.

Treatment

Treatment fidelity.

To ensure implementation fidelity for this study, assignment of carefully interviewed selected clinical intervention personnel occurred as a part of study design, resulting in creation of a small intervention or research team, consisting of trained, certified educators with specializations in reading. The researcher directly trained the research team in administration of the individual one-on-one treatment with an explicit, structured, written treatment format (see Appendix C). The researcher also regularly observed implementation of treatment to ensure all

instructional components were correctly and consistently implemented (Hill et al., 2012; Lange & Thompson, 2006; Morris et al., 2010; Nye, Konstantopoulos & Hedges, 2004).

Treatment group size.

For purposes of the present study, treatment was offered to each participant in a one-on-one direct instruction arrangement. In a large meta-analysis of reading interventions (42 samples, $N = 1539$), one-on-one designs had an effect size of $d = .41$ when compared to controls, with those students in one-one-one conditions performing 2/5 of a population standard deviation higher than comparison conditions (Elbaum, Vaughn, Hughes, & Moody, 2010). Moreover, for children who fail to respond to classroom-based intervention, Denton (2012) found one-on-one intervention, in a quiet location outside of the classroom setting to be most effective. Denton (2012) also noted one-on-one treatment designs consistently garnered higher effect sizes as compared to small group or whole class designs, indicating higher levels of clinical significance for one-on-one designs. Conversely, while whole class sublexical reading intervention is effective in the short term, gains are not maintained over time as compared to individualized condition (Henning, McIntosh, Arnott, & Dodd 2010; O'Connor, Arnott, McIntosh, & Dodd, 2009). Similar research shows one-on-one work between teacher and learner is even more effective than one teacher with a small group (Alexander & Slinger-Constant, 2004; McMaster, Fuchs, Fuchs, & Compton, 2005; Peterson & Pennington, 2012). Finally, in comparing treatment response rates to a brief sublexical intervention, 50% of the struggling readers in a one-on-one condition were classified as nonresponders whereas 81% of those in a group condition failed to respond, again indicating better response to intervention in one-on-one conditions (McMaster et al., 2005).

Treatment dosage and duration.

While there is limited study of dosage effects in intervention research, those in the field generally assert more impaired individuals need a higher or more intensive dosage of treatment (Denton, 2012; Ramey & Ramey, 2005). According to the What Works Clearinghouse, those most impacted struggling readers need treatment at least three times a week, for twenty to forty minutes per session (Gersten et al., 2008). Other studies highlight the importance of intervention frequency over intervention duration (length), showing no significant difference when comparing duration of treatment, if the overall amount of time in treatment (dosage) is held constant (Denton et al., 2011; Elbaum et al., 2010). For instance, there was no difference in treatment response when comparing those receiving sixteen weeks of a thirty minute one-on-one intervention at biweekly frequency and those receiving the same intervention for 8 weeks, four times a week (Denton et al., 2011). Furthermore, individuals with dyslexia have been shown to be more responsive to treatment if the dosage or frequency of the intervention is increased (Alexander & Slinger-Constant, 2004).

Readers who do not respond to classroom instruction and/or school-based intervention need higher and more intense intervention dosages (Denton & Al Otaiba, 2011). As such, this short duration one-on-one intervention was offered during summer break for four weeks, at a high dosage of four days per week (16 days) for thirty minutes (8 hours total). Total treatment attendance time for the initial treatment group was in reality slightly less than the full treatment offered ($M = 7.25$ hours, $SD = .658$; $M = 14.70$ days, $SD = 1.52$). Total treatment attendance time for the delayed treatment group was also slightly less ($M = 6.85$ hours, $SD = 1.69$; $M = 13.31$ days, $SD = 3.59$). While a longer duration treatment would likely produce more robust results, feasibility of this option was limited due to the relatively small size of the clinical location, as

well as, the school schedule of the involved participants (i.e. pretesting, posttesting and 4 week

intervention was offered for two identical treatment sessions during the summer which lasts

approximately 10 weeks).

Multicomponent treatment description.

As noted in Chapter II, treatments for RAN-type dyslexia are often not sufficient when

RAN is treated in isolation. Instead, multicomponent intervention designs fashioned to treat

underlying causal factors and related outcomes are more effective (Kirby et al., 2010; Morris et

al., 2010; Wolf & Bowers, 2000; Ziegler et al., 2008). As such, an explicit and systematic

multicomponent treatment was designed for this study to meet the deficits represented by the

DVs of RAN, VA, and reading rate (see Appendix C for treatment scope and sequence). Explicit

instruction indicates treatment was direct and followed a prewritten lesson sequence with clear

objectives taught through modeling, guided practice with corrective feedback, independent

practice, monitoring for understanding, and reteaching. Systematic teaching involved following

of a clear developmental trajectory within an increasingly difficult sequence a daily lesson cycle,

and a reasonable pace based on the learner's needs (Denton & Al Otaiba, 2011).

RAN component.

Timed RAN protocols (see Appendix A) were developed by the researcher specifically

for this study and were implemented daily (approximately 5 minutes). Special care was given not

to replicate protocols used in the assessment of RAN. RAN protocols were initially developed to

contain five letters, repeated 10 times each, and distributed in 5 rows of ten letters each (Denkla

& Rudel, 1976). Protocols with letter clusters were added based on cluster frequency as noted in

Adam's research of phonograms (1990). Seventeen RAN protocols, ordered in increasing

difficulty, were utilized (Denton & Al Otaiba, 2011). Furthermore, as fMRI and treatment study

outcomes show visual word or letter exposure is not sufficient for improvement of RAN, training in phoneme to grapheme correspondence was necessary to activate the Visual Word Form Area (Dehaene & Cohen, 2011). As such, RAN protocols were practiced in two ways during each session: rapid naming of letter names (for single letter protocols) and rapid naming of letter or cluster sounds (for single letter and letter clusters) (Nelson, Benner, & Gonzalez, 2005; Nelson, Stage et al., 2005).

VA component.

The VA portion of the treatment occurred daily through two applications delivered via an Ipad (10 minutes) (see Appendix C). A visual search exercise, in which the participant silently scans from left to right while tapping single and double letter targets within an array of distracters, was implemented daily. Array difficulty increased, in terms of distracter similarity and number of targets, as student proficiency increased (Franceschini et al., 2012; Peyrin et al., 2012; Rasinski et al., 2011; Solan et al., 2003; Wright et al., 2012). Also, high frequency sight words were drilled via a flash reader Ipad application. Speed of word presentation gradually increased as student proficiency increased (Lorusso et al., 2006; Rasinski et al., 2011).

Reading rate component

Repeated reading of high interest text occurred daily (15 minutes) to target reading rate (see Appendix C). This short term, intensive course of repeated reading aimed to improve reading rate by providing a model of what fluent reading feels like while simultaneously breaking dysfluent reading habits developed as a consequence of reading above-level text in whole group classroom settings (Allington, 2006). Preleveled short texts (without pictures) were matched to each participant's independent reading level computed from GORT-IV grade level scores (Fountas & Pinnell, 2009). Daily repeated reading followed a specific sequence: teacher

modeling prior to reading, initial oral reading, participant graphing of reading rate, direct and

explicit correction of initial miscued words, participant practice of miscued words in isolation,

and rereading (Chard et al., 2002; Morgan et al., 2012). Over the course of four weeks (sixteen

days), participants read approximately sixteen passages.

Data Analysis

Data scoring and coding.

Data was coded and entered into SPSS 21.0 for all variables. Coding in the form of

standard *T* scores ($\mu = 100$ and $\sigma = 15$), gathered from norm-referenced testing protocols (RIAS,

CTOPP, GORT-IV, NEPSY-II), was used for all DVs (RAN, VA, rate) and the covariate (FSIQ).

Independent variables were coded, sorted, and entered by level (treatment or control; single or

double deficit). Treatment and control groups (IV 1) were created by random assignment while

single and double deficit groups (IV 2) were created by pretesting each participant with the PA

subtests from the CTOPP to ascertain if there was a single deficit (low RAN only) or a double

deficit (low RAN + low PA).

Main analyses: Repeated measures MANCOVA and repeated measures MANOVA.

The first analysis used in the present study was a 2 x 3 x 2 within-within-between

repeated measures multiple analysis of covariance (MANCOVA), employed with two time

periods, three DVs (RAN, VA, rate), and two groups (treatment versus control, IV 1, H_o1)

(Tabachnick & Fidell, 2007, p. 312). Also a covariate, FSIQ, was included in the initial analysis

in order to determine what the outcomes of various dependent variables would be if FSIQ was

held constant (Thompson, 2002). Repeated measures MANCOVA, often called a doubly

multivariate design, is an appropriate statistical design for this experimental study because it tests

differences between groups (IVs) in terms of DVs measured on three different instruments, while

controlling for a covariate at more than one point in time (Tabachnick & Fidell, 2007, p. 339).

Benefits to using repeated measures MANCOVA include avoiding issues of sphericity present in

singly multivariate designs and avoiding usage of difference scores which often produce

unreliable outcomes (Tabachnick & Fidell, 2007, p. 312).

This second analysis, originally conceptualized as a repeated measures MANCOVA,

compared the response of two different groups formed by comparing single deficit (low RAN

only) participants and double deficit (low RAN + low PA) participants in terms of the same three

DVs (RAN, VA, rate) tested directly prior to and after intervention. When testing for

independence of covariate and treatment effect for single and double deficit groups (IV 2),

significance was found, $F(1, 38) = 6.631$, $p = .014$. More specifically, the mean covariate FSIQ

score differed significantly between single deficit ($M = 94.76$, $SD = 9.207$) and double deficit ($M = 87.60$, $SD = 7.169$) groups. As such, the covariate was removed from the analysis, resulting in

use of a MANOVA, rather than a MANCOVA (Field, 2009, p 397-398; Stevens, 2009).

Although much research holds FSIQ is dissociated from dyslexic deficit (as measured by

the DVs), regardless of the deficit type (Bonifacci & Snowling, 2008; Lyon et al., 2003), there is

some contradictory evidence indicating FSIQ may share variance with impaired sublexical and

lexical outcomes, thus limiting its function as a predictor and covariate (Stage, Abbot, Jenkins, &

Berninger, 2003). Moreover, some research asserts FSIQ cannot account for comorbidities and

outcomes in samples with comorbid reading disorder and ADHD, noting multivariate familial

models account for 53-72% of variance (Cheung et al., 2012), while only a small portion of

variance can be attributed to FSIQ (Paloyelis et al., 2010). Therefore, as the covariate of FSIQ

did not explain variance separate from the experimental case, use of a 2 x 3 x 2 within-within-

between repeated measured MANOVA for IV 2 (H_o3) was a more appropriate statistical technique (Field, 2009, pp. 397-398; Stevens, 2009).

Repeated measures MANCOVA and MANOVA have several assumptions to test, some before (interval level data, independence of observation, multivariate normality, linearity, and independence of covariate and treatment effect), and some after (homoscedasticity, homogeneity of regression slopes) the main analysis. As all scores in this study are "scored scores" from norm-referenced assessment tools, the level of data assumption was automatically met. And independence of observation was also met as participants must be administered all assessment measures in a one-on-one setting. Multivariate normality and linearity were also ensured prior to the main analyses. For MANCOVA only, independence of covariate and treatment effect was analyzed and met. After both analyses, testing for homoscedasticity (homogeneity of variance-covariance matrices) was analyzed (as groups were of unequal size) and met. Finally, for MANCOVA only, homogeneity of regression slopes was examined to ensure the interaction between the outcome and covariate was generally equivalent across groups (Field, 2009; Tabachnick & Fidell, 2007).

Follow up analysis: Descriptive Discriminant Analysis (DISCRIM).

After the main analyses were conducted, descriptive discriminant analysis (DISCRIM) was employed in SPSS 21.0 to further understand individual contributions of the dependent variables as explored in H_o2 and H_o4. DISCRIM is conceptually and mathematically equivalent to multiple regression, except DISCRIM predicts to a categorical criterion (groups) rather than a continuous criterion (Betz, 1987). More specifically, DISCRIM is used to break down the MANCOVA/MANOVA into additive portions which are uncorrelated linear combinations of the original variables. The linear equation serving as the basis of DISCRIM, a discriminant function,

is written as follows: $D = b_1X_1 + b_2X_2 + ...b_pX_p + a$. Where the D is the categorical variable

to be predicted, the bs are the unstandardized beta weights applied to the variables X, and the a is

the constant (reflecting the intercept of the regression line) (Betz, 1987). In the case of the

present study, in which standardized scores are used, the following formula for the standardized

discriminant score the ith was needed to accurately represent standardized beta weights (structure

coefficients): $D_i = b_1X_{1i} + b_2X_{2i} + b_3X_{3i} +...b_pX_{pi,}$ (Betz, 1987).

Use of DISCRIM to follow multivariate analyses, as compared to calculating multiple

individual ANOVAS, is advantageous as DISCRIM overcomes the issue of multicollinearity

among dependent variables, while controlling the experiment-wise error rate or risk of Type 1

error (Betz, 1987; Borgen & Seling, 1978). Moreover, analysis using DISCRIM is particularly

useful when multiple variables and groups are involved in a study, as the analysis can

parsimoniously and clearly depict in which dimensions or discriminant functions the groups

differ, while also showing the contribution of individual DVs (Borgen & Seling, 1978; Stevens,

2009). To generalize DISCRIM results, approximately $n = 20$ participants or scores per variable

are needed (Stevens, 2009).

Effect size calculations.

Finally, effect sizes demonstrating group differences were calculated to provide more

concrete and specific evidence of practical, clinical effects than provided by null hypothesis

significance testing in isolation (American Psychological Association, 2006; Cohen, 1994;

Ferguson, 2009). Multivariate effect size was measured to further understand overall treatment

effectiveness by comparing levels within independent variables (treatment versus control; single

deficit versus double deficit). The multivariate effect size metric most appropriate to this

situation is Mahalanobis Distance (D^2), as two groups were measured on multiple dependent

variables (Sapp, Obiakar, Gregas, & Schulze, 2007). The formula used for D^2 is as follows: $D^2 =$

$[(n_1 + n_2)/(n_1 * n_2)] \, T^2$ where n_1 and n_2 represent treatment and control group or single and

double deficit group participant numbers (Sapp et al., 2007). In order to find T^2, where N

represents the total number of participants and k represents the number of groups, the following

formula can be used with output from SPSS 21.0: $T^2 = $ Hotelling's trace*$(N - k)$ (Sapp et al.,

2007).

Univariate effect size metrics for individual dependent variables were also calculated

using Cohen's d (Cohen, 1988). Cohen's d is simply a measure of the difference between two

means. When comparing experimental and control group means, if the assumption of

homogeneity of variance is met, the SDs of the two groups are considered to be estimates of the

same population SD. Since estimates based on larger numbers are more accurate, researchers are

advised to use the pooled standard deviation or standard error ($S)$ of both groups (Volker, 2006).

The equation used for d in this instance becomes:

$$\left[d = \frac{\bar{X}_1 - \bar{X}_2}{S_{pooled}} \right]$$

Where S $_{pooled}$ can be calculated using the formula:

$$S_{pooled} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

Summary

Chapter 3 provided an overview of the design of the current experimental treatment study

aimed at ascertaining the effectiveness of a multicomponent treatment for individuals with single

and double deficit RAN-type dyslexia. Dependent outcome variables included RAN, VA, and

reading rate. Independent grouping variables served to gauge differential treatment response by

randomly dividing the sample into a treatment and a control condition and by categorizing

participants into single (RAN only) and double deficit (RAN + PA) groups. Demographic

information and the rationale behind treatment selection also were provided. An extensive

review of the instruments used for data collection including specific evidence of instrument

reliability and validity was given. Also, procedures for data collection and data analysis were

discussed. Finally, specific statistical analysis selection and rationale for analysis were reported.

Chapter IV contains further analysis of data collected and specifically determines multivariate

variance in treatment response by comparing the independent variable of treatment and control

condition, as well as, the independent variable of level of core dyslexic deficit (single deficit of

RAN only or double deficit of RAN + PA). Also, Chapter IV investigates findings in terms of

univariate response to intervention by analyzing the sublexical DVs of RAN and VA, as well as,

the related lexical DV of reading rate. Finally, Chapter V discusses findings and results as

applied to prior research, theory, and clinical practice in the field of practice.

CHAPTER IV

Data Analysis

The purpose of this study was to ascertain if a multicomponent reading treatment, developed specifically for those with single deficit (RAN only) and double deficit (RAN + PA) underlying dyslexic deficiencies, improved sublexical skills in RAN and VA, as well as, the lexical skill of reading rate. After reviewing descriptive statistics and meeting pre and postanalysis assumptions, inferential statistics were analyzed using the main analyses, a repeated measures MANCOVA to test difference between treatment and control outcomes (IV1, H_o1) and a repeated measures MANOVA to test the difference between single and double deficit outcomes (IV 2, H_o3). Results indicated there was not a significant difference between treatment and control groups when statistically combining the results of all variables, thus the researcher failed to reject H_o1. Results did indicate significant differences between single and double deficit groups, hence H_o3 was rejected.

After running each main analysis, DISCRIM was implemented to further understand the univariate contribution of each dependent variable (RAN, VA, rate) in terms of variance in the independent variables. Each DV was analyzed in terms of its contribution to differences between treatment and control groups (IV 1, H_o2) and in differences between single and double deficit groups (IV 2, H_o4). In terms of differentiating between treatment and control groups (H_o2), a combined discriminant function of all DVs only accounted for 22.5% of the variance between groups; but in terms of differentiating between single and double deficit group treatment response (H_o4), a combined discriminant function of all DVs accounted for 38% of the variance between groups. Further analysis of DVs further explained directionality of the relationship between each DV and associated groups (IV levels).

Descriptive Statistics

  Initial analysis included computation of descriptive statistics in terms of mean scores and standard deviations. Descriptive data were analyzed for each of the DVs and the COV by level of IV as shown in Table 3.

Table 3

Descriptive Statistics by Level

COV & DVs	Treatment Group (IV 1) $n = 23$		Control Group (IV 1) $n = 18$		Single Deficit (IV 2) $n = 24$		Double Deficit (IV 2) $n = 15$	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
FSIQ[a]	93.74	9.24	89.83	8.69	95.21	9.63	87.60	7.19
RAN Pretest	84.48	9.34	84.12	8.40	87.88	5.77	78.60	11.22
RAN Posttest	81.91	14.14	85.88	9.99	87.33	12.15	79.33	10.55
VA Pretest	86.96	16.97	93.24	21.06	89.17	18.98	93.00	15.56
VA Posttest	95.65	18.60	95.00	17.50	100.42	17.63	95.00	16.80
Rate Pretest	80.43	9.76	89.24	13.20	86.46	10.27	75.67	8.84
Rate Posttest	76.78	12.57	84.18	12.03	84.29	12.51	76.00	11.05

Note. Pretest and posttest for IV 1(treatment versus control) refer to testing of DVs (RAN, VA, rate) before and after the initial treatment session. Pretest and posttest for IV 2 (single or double deficit) refer to pre and posttesting scores collected prior to and directly after treatment and represent a combination of scores collected before and after treatment session, as well as, the delayed treatment session received by controls. For all norm-referenced tools used to produce *T* scores above, tests $\mu = 100$ and $\sigma = 15$. [a]FSIQ = full scale intelligence quotient.

Assumptions Tested Prior to the Main Analyses

  Multivariate normality (H_o1 & H_o3).

  Multivariate normality is assumed within significance tests for MANCOVA and MANOVA. For this condition to be met, the sampling distributions of the DVs in each cell and all linear combinations of the DVs must be normally distributed (Tabachnick & Fidell, 2007, p.251). As an estimate of multivariate normality, multivariate indicators of skewness and

kurtosis were assessed. None of the DVs showed extreme skewness and while the RAN subtests

were slightly leptokurtic, multivariate designs show robustness to nonnormality with overall $N =$

40 ($n = 10$ per group), as was the case with the present study (Tabachnick & Fidell, 2007, p.

279). Specific data for multivariate normality are presented in table 4.

Table 4

Multivariate Normality

Dependent Variable	Skewness	Kurtosis
RAN Pretest	-1.29	1.87
VA Pretest	0.07	-.804
Rate Pretest	0.25	-.522
RAN Posttest 1	0.65	2.571
VA Posttest 1	0.26	-.940
Rate Posttest 1	0.56	-.269
RAN Posttest 2	0.72	2.896
VA Posttest 2	0.18	-.471
Rate Posttest 2	-1.41	-1.101
FSIQ	.20	-1.03

*Note. S*kewness values between -3 and 3 are considered acceptable for social science research (Zar, 2010); Posttest 1 refers to posttesting conducted after treatment group to analyze IV 1 (treatment versus control); Posttest 2 refers to posttesting occurring after control group received delayed treatment to analyze IV 2(single or double deficit).

Linearity (H_o1 & H_o3).

MANCOVA and MANOVA both assume a linear relationship between all pairs of DVs

and all DV-covariate pairs. Given the instruments used and variables used, there was little

reason to suspect a curvilinear relationship. Nevertheless, bivariate scatter plots were reviewed

and relationships between pairs of DVs, as well as DV-covariate pairs, were linear. Thus the

assumption of linearity was met (Tabachnick & Fidell, 2007, p.110).

Independence of covariate and treatment effect (H_o1).

Prior to running the main analysis for H_o1, the assumption of independence between the

covariate (FSIQ) and the treatment effect was tested. If there is overlap between the covariate, in

this case the RIAS FSIQ score, and the independent variables, then using the covariate in the

analysis will not correctly control for differences. The desired outcome, in order to proceed with the main analysis of MANCOVA, is nonsignificance. If significance is found, the researcher must utilize a different more appropriate statistical procedure, as significant interaction between the covariate and treatment effect indicates shared variance, resulting in spurious treatment effects and misinterpretation of the MANCOVA. (Field, 2009; Stevens, 2009). For IV 1 (treatment versus control), the interaction between the covariate and the treatment effect was not significant, $F(1, 38) = 1.846$, $p = .182$. Nonsignificance in this case indicates the mean FSIQ was roughly the same between groups with FSIQ; thus FSIQ contributed unique variance to the solution and use its use as a covariate for H_o1 was an appropriate way to partial out variance not accounted for by the treatment effect (Field, 2009, p. 397).

Main Analyses Results

RM MANCOVA comparing treatment and control groups (H_o1).

A repeated measures MANCOVA was run in SPSS 21.0 to test the multivariate null hypothesis of no difference in outcomes between treatment and control groups (H_o1), when measured on the dependent variables of RAN, VA, and rate, while covarying for FSIQ. Multivariate results from this analysis, as seen in Table 5, indicated the covariate of FSIQ significantly and clinically impacted participant performance on a combination of tested DVs of RAN, VA, and rate ($p = .010$, $D^2 = 1.35$) as predicted by prior research (e.g. Compton et al., 2002; Ferrer et al., 2010; Stevens, 2009). Although the significant impact of the covariate of FSIQ was removed, the overall posttest results of the treatment group were not significantly different than those of the control ($p = .082$). Although the null was not rejected for H_o1, a medium multivariate size effect ($D^2 = .81$; 1- Wilk's $\Lambda = .172$) was found, indicating the

treatment was moderately clinically (practically) significant and responsible for approximately

17% of the variance between groups after treatment (Stevens, 2009).

Univariate results presented in Table 6 showed in terms of individual DVs, RAN and VA

exerted a large effect on the model (RAN d = .43; VA d = .45), while rate exerted a more modest

effect (d = .16). Moreover, each DV (RAN, VA, rate) behaved in a different manner according

to mean score differences. RAN mean scores were relatively stable for the control group over

time; the moderate effect size thus occurred not due to treatment effects, but due to a decrease in

treatment group RAN scores after the intervention, resulting in a larger difference after

treatment. Rate mean scores showed comparable behavior in both groups, decreasing over time,

with or without the presence intervention. VA differences posttreatment, though, were due to a

fairly substantial mean VA score increase (approximately 3/5 of the population standard

deviation) for the treated group, as compared to a very small increase (less than 2/15 of the

population standard deviation) for the control group, indicating potential treatment effects in

terms of VA.

Table 5

Repeated Measures MANCOVA: Multivariate Analysis of Treatment and Control Groups

Effect	Wilk's Λ	F	df_M	df_R	P	D^2
COV	.272	4.367	3.0	35.0	.010	1.35
TC	.828	2.422	3.0	35.0	.082	0.81

Note. COV = covariate of FSIQ; TC = treatment versus control (IV1); according to D^2 benchmarks, 0.025 = small effect, 0.5 = medium effect, > 1 = large effect (Stevens, 2009).

Table 6
Repeated Measures MANCOVA: Univariate Analysis of Treatment and Control Groups

DV	*F*	df_M	df_R	*p*	Cohen's *d*
RAN	1.658	1	37	.206	0.43
VA	1.790	1	37	.189	0.45
Rate	.220	1	37	.642	0.16

Note. According to Cohen's d benchmarks, 0.01= small effect, 0.09 = medium effect and > 0.25 = large effect (Cohen, 1988).

RM MANOVA comparing single and double deficit groups (H_o3).

A repeated measures MANOVA was run in SPSS 21.0 to test the multivariate null hypotheses of no difference in outcomes between single and double deficit groups (H_o3) when measured on the DVs of RAN, VA, and rate. Interpretation of the repeated measures MANOVA, F (3, 35) = 4.437, p = .01, indicated a statistically significant difference between single and double deficit groups terms of treatment outcomes. Moreover, review of effect size estimates (D^2 = 1.52, 1 - Λ=.28) indicate a large clinical effect, with the overall MANOVA accounting for 28% of the variance between groups (Stevens, 2009). As such, the null for H_o3 was rejected.

In analyzing univariate results comparing treatment response in single and double deficit groups, as shown in Table 7, no statistically significant univariate differences were noted, indicating the multivariate combination of DVs is a better model for predicting group outcome differences than individual, isolated DVs. In further examining nonsignificant univariate results, VA and rate served to differentiate clinically between single and double deficit groups due to a medium effect size (VA p =. 077, d = .41; rate p = .498, d = .30). VA, the only variable approaching statistical significance, saw mean score increases after treatment that were most pronounced for the single deficit group (approximately 2/3 of the population standard deviation), while the double deficit group only modestly improved (2/15 of the population standard deviation). Although rate exerted an effect nearly as large as VA, this outcome reflected mean

score differences between single and double deficit groups present prior to and after intervention, rather than a treatment related effect. Finally, RAN was not clinically involved in the overall model (rate $p = .953$, $d = .14$) due to a negligible small effect (Cohen, 1988). To better understand individual DV differences between single and double deficit groups, mean score changes seen in Table 3 can be further examined.

Table 7
Repeated Measures MANOVA: Univariate Analysis of Single and Double Deficit Groups

Effect	F	df_M	df_R	P	Cohen's d
RAN	.004	1	37	.953	.14
VA	3.303	1	37	.077	.41
Rate	.468	1	37	.498	.30

Note. According to Cohen's d benchmarks, .01 = small effect, .09 = medium effect and > .25 = large effect (Cohen, 1988).

Assumptions Tested after the Main Analyses

Homogeneity of variance-covariance matrices (H_o1 & H_o3).

Often in treatment studies such as the present study, groups are not of equal size. Due to sampling availability and noncompleting individuals, groups attained for the IV 1 of treatment versus control were not of equal size (treatment $n = 23$, control $n = 18$), nor were groups for IV 2 of single versus double deficit (single deficit $n = 24$, double deficit $n = 15$). In the case of different group sizes, equality across groups between the observed covariance matrices of the dependent variables must be tested (Field, 2009). This procedure can be accomplished by examining Box's test in SPSS 21.0. As seen in Table 8, Box's test for both multivariate null hypotheses was not significant, indicating homogeneity across group behavior on DVs, despite differences in group size.

Table 8
Box's Test for Equality of Covariance Matrices

IV	Box's M	F	df1	df2	p
1 (TC)	21.243	.832	21	4364.326	.682
2 (SD)	24.610	.946	21	3254.185	.530

Note. TC = treatment versus control (H$_o$1), SD = single versus double (H$_o$3)

Homogeneity of regression slopes (H$_o$1).

Finally, homogeneity of regression slopes was tested by examining the relationship

between the outcome and the covariate for H$_o$1 (treatment versus control). In order to test this

assumption, another repeated measures MANCOVA was run in SPSS 21.0 and customized to

show interaction effects. As shown in Table 9, interaction effects were not significant; indicating

the assumption of homogeneity of regression slopes was met.

Table 9

Repeated Measures MANCOVA, Customized Model for Homogeneity of Regression Slopes

Variance	Interaction Effect	Wilk's Λ	F	df_M	df_R	P
Between subjects	FSIQ*TC	.974	.308	3	34	.819
Within Subjects	FSIQ*Pretest/Posttest*TC	.896	1.310	3	34	.278

Note. TC = treatment versus control groups; FSIQ = full scale intelligence quotient, the covariate.

Follow Up Analysis: Descriptive Discriminant Analysis (DISCRIM)

DISCRIM comparing treatment and control groups (H$_o$2).

In terms of H$_o$2, DISCRIM was employed to ascertain if random assignment to groups

produced enough difference in the predictors (RAN, VA, rate) so groups could be further

analyzed on the basis on those predictors (Tabachnick & Fidell, 2007, p.381). Forty-one cases (*n*

= 23 treatment, *n* = 18 control) were analyzed in SPSS 21.0. Missing data was not at issue and

the assumptions of linearity, normality, and multicollinearity were met. Homogeneity of

variance-covariance matrices was also met with a nonsignificant Box's test (*p* = .278).

With only two groups (treatment versus control), a single discriminant function was produced. As shown in Table 10, there was not enough difference among predictors such that the discriminant function of all variables (RAN, VA, rate) was able to significantly classify cases into group membership ($x^2 = 8.890$, $p = .181$). This was an expected outcome as the MANCOVA between treatment and control groups was also not significant (see Table 5). In terms of the degree of relationship between group membership and the set of predictors, effect size in terms of variance accounted for by the discriminant function is found by squaring the canonical correlation (.474), thus indicating the proportion of variance shared between groups and predictors (Tabachnick & Fidell, 2007, p.380). Therefore, the overall effect size of the discriminant function ($R^2 = .225$) indicated the discriminant function accounted for 22.5% of the total relationship between predictors and treatment and control groups.

Table 10

Discriminant Analysis Results for Predictors (RAN, VA, Rate) on Treatment and Control Groups

Discriminant function	Percent variance	Canonical correlation	Significance of discriminant	
			x^2	p
1	100%	.474	8.890	.180

Much like multiple regression, DISCRIM is also used to test each of the DVs contribution to the discriminant function after adjustment for all other DVs (Tabachnick & Fidell, 2007, p. 273). Loadings (correlations) between the predictors and the discriminant function show how various predictors influenced group membership in treatment and control groups as seen in Table 11. Loadings (ranging from -1 to 1; -1 = perfect negative relationship; 1 = perfect positive relationship; 0 = no relationship) show the strength and direction of the linear relationship between the variable and the discriminant function predicting membership in treatment and control groups (Tabachnick & Fidell, 2007).

In further analyzing predictor loadings (β) and standardized predictor loadings (structure coefficients, r_s^2) in Table 11, rate at both pre and posttest most strongly differentiated between treatment and control group categorization. Specifically, treatment group participants started with an initially lower mean rate score and both groups subsequently decreased in rate scores over time. RAN and VA loadings also decreased over time for both groups, indicating that RAN and VA were also less predictive of group membership after treatment. Interestingly, while VA pretest indicated a positive relationship, VA posttest indicated a reversal in directionality, showing a negative predictive relationship.

Table 11

Discriminant Structure Matrix for Treatment and Control Groups

Predictor	Structure Coefficients (r_s^2)	Discriminant Function 1, (β)
Rate Pretest	.732	1.585
Rate Posttest	.517	-.654
VA Pretest	.315	.506
RAN Pretest	.298	-.274
RAN Posttest	-.038	-.039
VA Posttest	-.034	-.586

DISCRIM comparing single and double deficit groups (H_o4).

DISCRIM was also employed to ascertain if the DVs (RAN, VA, rate) predicted membership in single and double deficit groups (H_o4) (Tabachnick & Fidell, 2007, p.381). Thirty-nine cases ($n = 24$ single deficit, $n = 15$ double deficit) were analyzed in SPSS 21.0. Missing data were not at issue and the assumptions of linearity, normality, and multicollinearity were met. Homogeneity of variance-covariance matrices was also met with a nonsignificant Box's test ($p = .530$).

With only two groups (single deficit and double deficit), a single discriminant function was produced. As shown in Table 12, there was enough difference among predictors such that

the discriminant function of all variables (RAN, VA, rate) significantly classified cases into

group membership ($x^2 = 16.108$, $p = .013$). This was an expected outcome as the overall

MANOVA between single and double deficit groups was also significant. The overall effect size

(variance accounted for) of the discriminant function was $R^2 = .38$, indicating the discriminant

function accounted for 38% of the total relationship between predictors and groups (Tabachnick

& Fidell, 2007, p.380).

Table 12

Discriminant Analysis Results for Predictors (RAN, VA, Rate) on Single and Double Deficit

Groups

Discriminant function	Percent variance	Canonical correlation	Significance of discriminant	
			x^2	P
1	100%	.614	16.108	.013

Loadings (correlations) between the predictors (DVs) and the discriminant function for

single and double deficit groups, computed in order of relational strength for standardized

loadings (structure coefficients, r_s^2) are presented in Table 13 (Tabachnick & Fidell, 2007). In

analyzing contributions, RAN and rate pretest scores strongly differentiated between single and

double deficit groups. After treatment, loadings for RAN and rate were weaker, but still

predictive of group membership. VA loadings at all points in time were negligible, suggesting no

differential property for VA in terms determining level of deficit (single or double deficit).

Table 13
Discriminant Structure Matrix for Single and Double Deficit Groups (H_o4)

Variable	Structure Coefficients(r_s^2)	Discriminant Function 1 (β)
RAN Pretest	.720	.742
Rate Pretest	.710	.822
Rate Posttest	.444	-.355
RAN Posttest	.443	-.342
VA Posttest	.201	.054
VA Pretest	-.138	-.193

Summary

Although there were no statistically significant multivariate gains for individuals receiving treatment in this study, clinically significant multivariate effects were found suggesting the treatment was beneficial in practice (H_o1). In terms of individual dependent variables, VA improvements most strongly impacted differences between treatment and control groups, suggesting an important role for VA's involvement in reading disorders and potentiality for behavioral treatment of VA in those with reading impairment (H_o2). Moreover, the current theoretical assertion of a double deficit (RAN + PA) conveying a more profound dyslexic profile (H_o3) was supported, with RAN and rate specifically conveying a more impaired profile for double deficit participants (H_o4).

This chapter contained analysis of data collected and described variance in treatment response by comparing the independent variable of treatment and control condition (IV 1), as well as, the independent variable of level of core dyslexic deficit (IV 2). Also, this chapter investigated findings in terms of multivariate and univariate response to intervention in terms of the dependent variables of sublexical reading deficits in RAN and VA, as well as, the related lexical reading deficit in reading rate. In conclusion, Chapter V will discuss findings and results as applied to prior research, theory, and clinical practice.

CHAPTER V

Findings

The purpose of this study was to ascertain if a multicomponent reading treatment, developed specifically for those with single deficit (RAN only) and double deficit (RAN + PA) underlying dyslexic deficiencies, improved sublexical skills in RAN and VA, as well as, the lexical skill of reading rate. After a brief review of the research problem, null hypotheses, and study design, major findings for each null hypothesis are presented. Findings are organized by null hypothesis, with multivariate findings (H_o1, H_o3) followed by univariate (H_o2, H_o4) and covariate findings. Based on analysis of these findings, implications for practice and suggestions for future research are delineated.

Problem Overview

Research on treatments for nonphonological (RAN-type) single and double deficit dyslexia, as investigated in this study, is limited in scope (Kirby et al., 2010; Wolf & Bowers, 2000). Moreover, individuals with RAN-type dyslexia are often not well served by existing treatment regimens, leading to sustainment of sublexical deficits in RAN and related lexical difficulties in reading rate (Al Otaiba & Fuchs, 2002, 2006; Shaywitz et al., 2008; Torgeson et al., 1994). Creation of a multicomponent treatment for RAN-based dyslexia and testing of this treatment with experimental conditions was one necessary step to uncover to best assist students with RAN-type single and double deficit dyslexia. Investigation into if and how treatment can improve the sublexical process of RAN and related sublexical process of VA, as well as the lexical outcome of reading rate, was essential in terms of assisting many dyslexic learners who are currently not receiving adequate treatment.

Null Hypotheses

H_o1: There will be no difference between treatment and control groups (IV 1) on overall treatment response.

H_o2: There will be no difference between treatment and control groups (IV 1) on all dependent variables (RAN, VA, rate).

H_o3: There will be no difference in treatment response between single and double deficit groups (IV 2) on overall treatment response.

H_o4: There will be no difference in treatment response between single and double deficit groups (IV 2) on all dependent variables (RAN, VA, rate).

Review of Study Design

This treatment or intervention-type study utilized a quantitative, experimental design to explore differences between and within groups in order to ascertain causality. Experimental designs with control conditions are the most effective way to ascertain if treatments or interventions work and for whom (Field, 2009). Indication of causality was sought in this study as the purpose of the study was to determine if a particular multicomponent treatment can cause improvement in RAN, rate, and VA in children with reading various two levels of reading difficulty (single deficit RAN-only dyslexia and double deficit RAN + PA dyslexia) after controlling for cognitive ability (FSIQ).

Major Findings

Ho1: Multivariate outcomes comparing treatment and control groups.

Although no significance was found ($p = .082$) when comparing treatment and control groups (H_o1), the DISCRIM analysis between DVs accounted for 22.5% of the variance between groups and a medium multivariate effect size ($D^2 = .81$) was indicated. As there are very few

treatment studies in the field of double deficit dyslexia and RAN deficits in general, there is no consensus as to what constitutes an adequate effect. Thus finding of a modest effect of the treatment in the present study is promising, as most small treatment studies in the learning disabilities field rarely have larger effect sizes (according to Stevens, 2009). In addition, statistical significance (yes or no type) measures are inadequate in fully indicating the practical or clinical significance of findings (as represented by effect size metrics) that may positively inform practice (according to Ferguson, 2009; Ives, 2003; Onwuegbuzie, Levin, & Leech 2003; Sapp et al., 2007). As such, it appears the treatment was successful in practice, conveying beneficial effects to recipients at the time of posttesting.

As previous research shows interventions are often more effective for younger participants (e.g. Braet et al., 2012; Denton et al., 2011; Holt, 2008), all participants age 10.0 or older were deleted (resulting in $n = 14$ for treatment and $n = 9$ for control groups; mdn age = 8.6, $SD = .81$); and the repeated measures MANCOVA for the present study (H_o1) was rerun and reanalyzed. While this smaller sample ($N = 23$) led to somewhat reduced statistical power and should be interpreted with caution, all assumptions of repeated MANCOVA were met and a statistically significant main effect was found, $F (3, 18) = 3.457$, $p = .038$, indicating treatment success. Moreover, there was a large practical multivariate effect size ($D^2 = 2.17$; $1 - \Lambda = .37$); and the treatment was responsible for 37% of the variance in group outcomes. There was also a significant effect for the covariate of FSIQ, $F (3, 18) = 3.701$, $p = .031$, demonstrating use of FSIQ as a covariate correctly controlled for IQ differences among participants. As such, it appears the relatively short treatment in the present study was more effective for younger children, in line with prior research showing better response to intervention for younger children (e. g., Braet et al., 2012; Denton et al., 2011; Holt, 2008).

H$_o$3: Multivariate outcomes comparing single and double deficit groups.

In contrast to nonsignificant outcomes for treatment and control conditions, comparison of single and double deficit groups showed a statistically and clinically significant multivariate difference in terms of a treatment effect ($p = .01$, $D^2 = 1.52$). In particular, double deficit participants were not responsive to any portion of the treatment; a finding which resonates with previously noted double deficit treatment resistance (e.g. Al Otaiba & Fuchs, 2002, 2006; Fletcher et al., 2011; Torgeson et al., 1994). Moreover, findings of double deficit treatment resistance in the present study coincide with fMRI imaging research showing lack of posttreatment lateralization across various involved cerebral regions (e.g. Odegard et al., 2008; Shaywitz & Shaywitz, 2003a, 2004; Simos et al., 2007).

Overall group differences as measured by the DISCRIM analysis in the present study coincided with significant MANOVA outcomes. DISCRIM results strongly suggested the existence of two separate profiles of sublexical deficiency, one for those with single (RAN-only) deficits and another for those with double (RAN + PA) deficits. In fact, the combination of RAN, VA, and rate in the DISCRIM accounted for a significant portion of the variance between single and double deficit groups (38%), providing support for Wolf and Bower's (1999, 2000) double deficit theory of dyslexia.

H$_o$2 & H$_o$4: Univariate outcomes.

RAN outcomes comparing treatment and control groups.

RAN mean scores for treatment and control groups were flat over time and lack of significance was found for univariate RAN outcomes ($p = .206$), suggesting the treatment was not effective in terms of RAN improvement. Recent evidence shows good RAN is the best indicator of treatment responsiveness (e.g. Gustafson et al., 2011); and outcomes in the present

study in terms of nonsignificant univariate RAN results lend support to use of poor RAN as an index of treatment resistance (Boscardin et al., 2008; Conrad & Levy, 2011; Fletcher et al., 2011; McBridge-Chang et al., 2011; van Bergen et al., 2012). Flat RAN outcomes in the present study also are supported by similar lack of RAN improvement noted in meta-analytic reviews (e.g., Kirby et al., 2010; Tran, Sanchez, Arrellano, & Swanson, 2011) and in recent imaging research showing that 73.3% of treatment nonresponders have RAN impairments (e.g., Berninger & Richards, 2010). Finally, present RAN findings coincide with evidence of RAN impairment as a deficit typically sustained into adulthood (e.g., Birch & Chase, 2004; Göbel & Snowling, 2010).

In Kirby et al.'s (2010) comprehensive review of the RAN literature, only five studies (prior to this one) successfully treated RAN using arrays similar to tested RAN tasks. While prior direct RAN treatment studies were similar in dosage, duration, and treatment group size (one-on-one or small group) to the present study, prior studies differed in terms of participant age (all participants in successful studies were in grades K-1 and between ages 5-7) (e.g., Conrad & Levy, 2011; Fugate, 1997; Hughes, 2004; Nelson, Benner, & Gonzalez, 2005, Nelson, Stage et al., 2005). As such, univariate data was also analyzed from the secondary repeated measures MANCOVA comparing RAN treatment and control outcomes for younger participants ($n = 23$, mdn age = 8.6, $SD = .81$). However, the univariate effect for RAN for younger participants was statistically insignificant, $F(1, 20) = .028$, $p = .868$, indicating lack of RAN treatment response for younger participants as well.

RAN outcomes comparing single and double deficit groups.

Although RAN score improvement pre and posttreatment did not occur for any group (treatment or control, single or double deficit), RAN pretreatment scores did classify individuals with single or double deficit profiles ($r = .720$ in the DISCRIM analysis). Moreover, significant

bivariate correlations from the present study indicate RAN scores were directly connected to rate outcomes (r = .446) prior to treatment. These data are corroborated by prior research indicating sublexical RAN is a good indicator of related lexical reading difficulties, as suggested by the theoretical double deficit model (Wolf, 1991; Wolf & Bowers, 1999, 2000; Wolf, Bowers, & Biddle, 2000. As such, RAN's utility as a screening device, indentifying severity of reading disability, also is confirmed by findings from the present study (e.g. Berninger et al., 2006; Bishop & League, 2006; Compton et al., 2002, 2010; Fuchs et al., 2012; Howe et al., 2006; Torpa et al., 2006).

VA outcomes comparing treatment and control groups.

Although change in VA was not statistically significant (p = .189), a moderate effect size (d = .45) was found, indicating practical or clinical significance for VA improvement in treated individuals. Gains seen in VA for those receiving treatment (nearly 3/5 a population standard deviation between pre and posttest), as compared to little change for control participants, are corroborated by this moderate effect size finding. Therefore, VA, as measured by the nonword Stroop task on the NEPSY-II subtest of inhibition, likely improved due to treatment provided in the present study.

Conservative interpretation of improved VA is warranted as the relationship between VA and the other reading variables (RAN and rate) found in the present study, much like results found by Savage et al., (2008), is at best tenuous. Unlike strong and significant correlational data between task focus and reading outcomes found by Georgiou, Manolitsis, Nurmi, & Parilla (2010), VA in the present study was not found to strongly discriminate between treatment and control groups at pretest (r = .315) or posttest (r = -.034) as seen in Table 11. Furthermore, bivariate correlations between VA and RAN (r = .187 to .475) and VA and rate (r = .336 to .477)

for treatment and control groups ranged from insignificant to moderately significant, indicating

VA may only be somewhat related to RAN and rate. As such, improvements in VA may not

transfer to other reading variables.

VA outcomes comparing single and double deficit groups.

Unlike RAN and rate scores, VA scores did not strongly differentiate between single and

double deficit groups either prior to treatment ($r = -.138$) or after treatment ($r = .201$), as seen in

the DISCRIM analysis in Table 13. VA loadings, while not as predictive of group membership at

either time point, can be comparatively analyzed to better understand VA behavior. Interestingly

the direction of the relationship between loadings changed from negative prior to treatment, to

positive after treatment. This change of direction is indicative of the fact that the double deficit

group actually attained slightly higher initial mean VA scores (population standard deviation

difference of 4/15), but these initially positive findings were eclipsed by the single deficit

group's vast improvement in VA between pre and posttest sessions (population standard

deviation difference of 11/15), as compared to only a slight growth in the double deficit group

(population standard deviation increase of 2/15).

The cause for more pronounced improvement in VA scores for single deficit participants

is not fully understood but logically seems related to better FSIQ scores possessed by single

deficit participants (single deficit $M = 95.21$, $SD = 9.632$; double deficit $M = 87.60$, $SD = 7.169$).

In fact, recent correlational research has connected sublexical reading skill and cognitive ability,

indicating that those individuals better processing speed may be able to automatize sublexical

skills, such as VA, more efficiently (Naples et al., 2012; McGrath et al., 2011; Peter et al., 2011;

Powell et al., 2007; Shanahan et al., 2006). Caution must be taken in interpretation of why

improvement occurred more substantially in single deficit participants, though, as prior research

also shows contrasting evidence with no differential outcomes in response to linguistic and nonlinguistic stimuli (Lachmann & van Leeuwen, 2007)

Rate outcomes comparing treatment and control groups.

Similar to RAN outcomes, rate scores also failed to improve in response to treatment. In fact, as shown in Table 3, mean rate scores slightly decreased for all participants. In the DISCRIM analysis shown in Table 11, rate served to most differentiate between treatment and control groups prior to treatment ($r = .732$), but was less able to group participants after treatment ($r = .517$). This differentiation, though, was not resultant from treatment effects but was caused by slight mean differences present between treatment and control groups at both points in time. Rate treatment resistance, as seen in the present study, has been found elsewhere in the developmental reading treatment literature (Shaywitz et al., 2008). Moreover findings from the adult dyslexia literature indicate rate is often uncompensated for treated dyslexic adults, even when other areas of reading function have normalized (Deacon et al., 2012; Horowitz-Kraus & Breznitz, 2011a). In terms of the analysis for the younger participants (*mdn* age = 8.6), rate deficits were also still present $F (1, 38) = 29.346$, $p = .277$, suggesting no differential response for rate in terms of age.

Prior studies (e.g. Arnell et al., 2009; Georgiou et al., 2010, 2012; Kirby et al., 2010; Wolf & Bowers, 1999, 2000) have also found a strong relationship between poor rate treatment response and low RAN scores. Due to the lack of treatment response of both RAN and rate in all studied groups, strong correlations between both DVs at all points in time, and similar profiling properties in terms of assigning degree of deficit, the relationship between these DVs may be reciprocal. It is likely, then, that poor outcomes in rate are reinforced by poor outcomes in RAN and vice versa. The reciprocity found between RAN and rate in the present study is also found in

the research literature. For instance, a sizeable treatment study ($n = 75$) found RAN impairment also mediates treatment response in terms of rate (Tijms, 2011). More specifically, in a study examining the most impaired readers in terms of rate and accuracy, RAN more strongly predicted rate ($r = .53$) as compared to correlations with accuracy ($r = .37$) or comprehension ($r = .37$), suggesting rate treatment resistance is expected and related to poor RAN, as asserted by Savage and Fredrickson (2005).

Rate outcomes comparing single and double deficit groups.

Although rate score improvement did not occur for any group (treatment or control, single or double deficit), differences in rate pretreatment scores served to group individuals either as those with single or double deficits ($r = .710$). This finding supports prior discovery of more pronounced lexical impairments in those with a double sublexical deficits (RAN + PA) (O'Brien et al., 2012), as participants were more significantly impacted with rate difficulties. The connection between double deficit profile and more impaired rate outcomes as seen in the present study is not a novel finding (e.g. Araújo et al., 2010; Escribano, 2007; Jiménez et al., 2008).

Modestly significant bivariate correlations from this study show rate outcomes were directly connected to RAN scores ($r = .446$) prior to treatment for all participants (as seen in Hulslander et al., 2010; Pennington et al., 2012; Powell et al., 2007). In looking closely at single deficit (RAN only) participants, poor rate and poor RAN correlation provides support for the theory of RAN and PA as separate sublexical causal elements (Wolf & Bowers, 1999, 2000). If RAN were simply subsumed under PA, as theorized by Vaessen et al. (2009), then RAN-only single deficit individuals (those without PA deficits) with concomitant visible dyslexic outcomes

in rate should not exist. On the contrary, 56% of those treated in this study had singular RAN deficits with concomitant poor lexical outcomes in reading rate.

Covariate outcomes.

The covariate of FSIQ's influence on participant treatment response in comparing treatment and control groups was not significant $F(1, 38) = 1.846$, $p = .182$, indicating independence of covariate and treatment effects. By controlling for FSIQ and removing the significant unique variance presented by FSIQ ($p = .01$), multivariate and univariate treatment effects better represented participant treatment response (Stevens, 2009; Tabachnick & Fidell, 2007). On the other hand, FSIQ was not useful as a covariate in the analysis comparing single and double deficit groups as FSIQ was significantly lower in double deficit participants, indicating a positive relationship between FSIQ and level of impairment $F(1, 38) = 6.631$, $p = .014$. This finding replicates other correlational research that shows a directional association between FSIQ and level of impairment (Bower-Crane et al., 2011; Kirby et al., 2010; Stage et al., 2003; Stanovich, 1988).

Conclusions

A double deficit conveys more profound impairment.

Many studies (e.g., Araújo et al., 2010; Escribano, 2007; Gilbert, Compton, & Kearns, 2011; Høien-Tengesdal & Tønnessen, 2011; Jiménez et al., 2008; Norton & Wolf, 2012; O'Brien et al., 2012; Powell et al., 2007), in accordance with the present study, suggest double deficit sublexical impairment (RAN + PA) leads to more severe lexical outcomes. More specifically, in the present study, individuals with double deficits experienced and maintained more profound sublexical RAN and related lexical difficulties in rate across time. For instance, as displayed in Table 3, double deficit mean scores for RAN and rate, both prior to and after treatment, were

approximately 2/3 of the population standard deviation ($\sigma = 15$) lower than single deficit mean scores. Moreover, while single deficit mean RAN and rate scores were in the low average range of functioning (clustering around -1σ, 16th percentile), double deficit mean RAN and rate scores were impaired (> -1σ, between the 5th and 9th percentile) suggesting an multiplicative effect for the RAN + PA double deficit profile (in line with prior findings from Greenwood, Tapia, Abbot, & Walton, 2003).

A critical period for RAN.

Unless treatment occurs at the right age, RAN skills may be hard to improve. According to recent multilevel modeling research by Holt (2008), reading growth significantly decelerates across the age span from kindergarten to third grade; thus there may be a point at which intervention for RAN is too late. A critical period theory for sublexical RAN development coincides with data suggesting older elementary and adolescent readers are much less responsive to intervention (Corrin, Somers, Kemple, Nelson, & Sepanik, 2008; James-Burdumy et al., 2009; Kemple et al., 2008), as well as findings that dyslexic adults, even those who have received PA-based dyslexia treatments, tend to retain poor RAN skills (Birch & Chase, 2004; Swanson, 2012).

Results from the present study imply univariate RAN results were intractable for all age groups. In contrast, only one similar treatment study can be found in which participants ($n = 11$) with median age of 9.1 significantly improved RAN posttreatment (Krafnick et al., 2011). Results from Krafnick et al. (2011), though, should be analyzed with caution given the small sample size and lack of control group, which could have led to underpowered conclusions. On the other hand, sufficiently powered studies that reported statistically and or clinically significant RAN improvement were only those studies that treated very young children (i.e. ages 5-7) (e.g.,

Bailet et al., 2009; Conrad & Levy, 2011; Fugate, 1997; Hughes, 2004; Kairalouma et al., 2007;

Nelson, Benner, & Gonzalez, 2005; Nelson, Stage et al., 2005). As such, RAN treatment may

only be successful during an early "critical period" of brain plasticity (between ages 5-7). This

concept of a critical period for RAN improvement is also supported by the What Works

Clearinghouse which, based on both Nelson et al., 2005 studies, found strong evidence of RAN

treatment efficacy, but only for beginning readers (USDOE, 2007).

Short-term behavioral treatment of VA works.

One important, exciting new understanding emerged from the present study – VA, which

ranged impaired to low average for all participants prior to treatment ($M = 89.63$, $SD = 18.82$),

normalized with the brief behavioral multicomponent reading treatment provided by the present

study. While there is substantial imaging evidence connecting reading impairment to lack of

visual specialization in the dyslexic brain (Araújo et al., 2012), there is a deficit in the existence

of behavioral treatment studies and guidelines for clinical treatment of VA in the reading

disordered population. Only a small of body treatment research focuses specifically on

behaviorally treating VA in dyslexic participants (e.g. Facoetti et al., 2005; Lorusso et al., 2006,

Peyrin et al., 2012; Solan et al., 2003; Tang & Posner, 2009; Tucha et al., 2011), with only one

known study (Rasinski et al., 2011) including VA treatment as part of a comprehensive reading

intervention as seen in the present study. As such, the current study supplies needed data to the

lacking treatment literature, showing that behavioral training of VA as part of a multicomponent

reading treatment, is possible and potentially beneficial.

As multiple components were involved in treatment, and as prior studies have not utilized

the same combination of treatment components, it is difficult to pinpoint whether or not a

particular aspect of treatment was responsible for VA improvement. For instance, previous

research notes treatment success (mainly in adult rehabilitation patients) using visual scanning exercises with letters, similar to the Ipad application (*Visual Attention Therapy*) used herein (Cicerone et al., 2011; Peyrin et al., 2012; Tucha et al., 2011). VA improvements have also resulted from training developmental dyslexic participants with flash software (similar to the Ipad flash reader application used for sight word learning in the present study) to facilitate automatic whole word recognition (e. g. Facoetti et al., 2005; Lorusso et al., 2006; Solan et al., 2003). Finally, while the only study using both visual scanning and flash type exercises (Rasinski et al., 2011) did find improvements in reading variables across the board, the authors did not include VA as an outcome measure. So, treatment success in the present study may emanate from the visual scanning exercise, or the flash reading sight word exercise, or the combined use of both VA treatments or the use of all treatment components (visual scanning, flash word, RAN arrays, repeated reading). Whatever the case, the treatment in the present study likely contributed to discernible improvements in VA, perhaps by targeting necessary skill improvement in automaticity of retrieval of letters or words from long term store while facilitating the self-monitoring, sustained attention, and attention to detail necessary to improve upon the tested NEPSY-II Stroop task of nonlinguistic VA.

While the literature on behavioral treatment of VA is sparse and many study are limited in scope, medical treatment of domain-general attention difficulties is well studied (Molina et al., 2008). Findings from large, multiyear, stimulant medication trials show inhibition skills and attention-mediated academic tasks often normalize when children with ADHD are provided stimulant medication as compared to placebos. In simple terms, the stimulant medication, through means of dopamine stimulation, allows for the necessary inhibition of and reallocation of attention to whatever arduous learning task the child is asked to attempt (Molina et al., 2008).

Stimulants can also improve reading, even in those without ADHD, suggesting inhibition skills are necessary precorrelates to improve reading skills (Kastner, Tingstrom, & Edwards, 2000; Sumner et al., 2009; Tannock et al., 2000; Wigal et al., 2012). As medical treatment of attention provides transfer to reading, behavioral treatment of attention, as seen in the present study, may also convey the same benefits, perhaps when longer duration treatment is provided.

Beyond responding to treatment, VA improvements in the present study also transferred to novel assessment tasks (i.e. treatment components did not include practice on Stroop-type tasks tested by the NEPSY-II). This transfer, occurring between the multicomponent reading treatment and improved performance on the nonlexical Stroop task of inhibition on the NEPSY-II, is particularly promising as Stroop task performance is typically impaired in dyslexic children (e.g., Protopapas, Archonti, & Skaloumbakas, 2007; Reiter, Tucha, & Lange, 2005). At the same time, only one prior study has demonstrated a similar transfer of reading training to improvements in detection of complex nonlexical visual targets (e.g. Szwed et al., 2011). As attention improvements in the present study were not linguistically specific and transferred to a novel nonlinguistic assessment of inhibition, the multicomponent reading intervention perhaps resulted in more global normalization of inhibitory abilities of the participants.

What remains to be seen is if this brief treatment effect in inhibition would, with longer and more intensive treatment, transfer back to underlying improvements in linguistic domains such as RAN and rate. For instance, one recent experimental study found that low level visual training improved speed of lexical decision for treated children with ADHD ($p = .03$) (Chouake, Levy, Javitt, & Lavidor, 2012). And, a comprehensive program called Attention Process Training (APT), often used in counseling contexts, shows not only improvements in measures of inhibition or VA, as seen in the present study, but also in terms of transfer to written expression,

accuracy, and letter naming fluency (Chenault et al., 2006). Finally, many of the VA-based treatments utilizing flash reader software and visual scanning training saw improvements in other reading domains including rate and accuracy (e.g. Facoetti et al., 2005; Lorusso et al., 2006) and reading comprehension (Rasinski et al., 2011; Solan et al., 2003).

Rate improvements take time.

In the present study, reading rate remained intractable for younger and older participants and for those with single and double deficits, regardless of treatment provision. Therefore, although treatment was more generally effective for younger and less impaired (single deficit in RAN) children, brief treatment may not be sufficient to improve reading rate in any situation. In further examining other similar, successful multicomponent treatment studies for those with RAN-type single and double deficit dyslexia, rate improvements did occur but treatments were much longer in duration (i.e. approximately 30 hours or more as shown in Morris et al., 2010; Torgeson et al., 2010; Vadasy & Sanders, 2008; Vadasy, Sanders, & Peyton, 2005; Wolf, Miller, & Donnelly, 2000; Wolf et al., 2009). As the present study was similarly comprehensive and intensive in nature to other longer treatments, the limited treatment time may simply be insufficient for purposes of improving rate.

Implications for Practice

Early identification and intervention.

The present study, in addition to previous research (e.g. Berninger et al., 2006; Bishop & League, 2006; Compton et al., 2002, 2010; Fuchs et al., 2012; Howe et al., 2006; Torpa et al., 2006), reveals poor RAN predicts impaired rate, especially for those who are most impaired, thus providing an easy and empirical way to screen and identify potential children at-risk for reading disorders. Moreover, RAN is an important correlate of early reading development (Boscardin et

al., 2008; Catts, Nielsen, Bridges, Liu, & Bontempo, 2013; National Early Literacy Panel &
National Center for Family Literacy, 2008). In fact, the predictive power of RAN can be
harnessed to identify children at risk for reading disorders as early as age 3.5 (e.g. Torppa et al.,
2006), potentially facilitating prevention of reading disorders before reading even begins.
Unfortunately, current research indicates that even though RAN is understood to be a good early
predictor of reading disorder, most children are not screened accordingly (Boscardin et al., 2008;
Frijters et al., 2011). Practitioners are encouraged then, to include RAN as a part of a standard
early screening battery for young children.

Beyond early identification, educators are also encouraged to treat reading problems
early. The present study, as supported by previous research (e.g. Braet et al. 2012; Denton et al.,
2011; Holt, 2008), clearly indicates reading intervention for older children may necessitate a
longer and more intensive course than early preventative instruction. Simply comparing
treatment response between the original MANCOVA with a median age of 9.5 $(p = .082, D^2 =
.81)$ and the MANCOVA analysis with a median age of 8.6 $(p = .038, D^2 = 2.17)$, confirms the
reading intervention in the present study was more beneficial for younger participants. At this
finding, parents and educators should screen for underlying sublexical difficulties in all children
upon school entry and educators should subsequently and vigorously treat children who do not
meet expectations for grade level reading standards.

In terms of school-based preventative instruction, preventing fluency problems at ages 5-
7 is more effective than fluency remediation (Edmonds et al., 2009). Prevention is even
successful for younger students in whole class settings, as long as programming is begun upon
school entry (e.g. Greenwood et al., 2003). As closing the gap in fluency for older struggling
readers requires extensive remedial instruction (Peterson & Pennington, 2012), outcomes in the

present study support prevention as more efficacious than remediation, as treatment effectiveness was statistically and clinically significant only for younger participants. Practicing educators, then, should act proactively; specifically for those children with RAN difficulties by providing preventative fluency treatment such as the multicomponent treatment used herein (see Appendix C).

Repeated reading reconsidered.

In line with prior findings from O'Keefe et al. (2012), Chard et al. (2009), and Scammacca et al. (2007), lack of rate improvement in the present study calls into question the status of repeated reading as best practice for fluency intervention. Interestingly, similar multicomponent studies in which repeated reading was found effective were at least 30 hours in duration, as compared to the 8 hours provided in the present study (e.g. O'Brien et al., 2011; Morris et al., 2010; Wolf, Bowers, & Biddle, 2000; Wolf et al., 2009; Wolff, 2012). While two meta-analyses of fluency interventions (e.g. Chard et al., 2002; NICHD, 2000) pinpointed repeated reading as the most effective intervention for fluency, a meta-analysis by O'Keefe et al. (2012) indicates a dearth of rigorous empirical evidence in studies of repeated reading. Moreover, according to Chard et al. (2009), studies have not investigated repeated reading specifically for those with dyslexia. Meta-analytic data also shows repeated reading for older elementary students, like those in the present study, may not transfer to improved reading rate (e.g., Scammacca et al., 2007). Thus, while repeated reading is typically the most commonly advocated intervention for treatment of rate (according to O'Keefe et al., 2012); educators should know repeated reading may not be effective for all students.

Another intervention, wide reading, may be more beneficial than repeated reading for short duration fluency treatment, especially for older elementary students (Kuhn et al., 2006).

Other data shows older students benefit most when wide reading is utilized in addition to repeated reading (Rasinski et al., 2011). Furthermore, how fluency is measured may influence whether repeated reading or wide reading produces more significant effects. For instance, Rashotte and Torgeson (1985) discovered repeated reading only produces measurable gains when there is a high degree of vocabulary overlap between treatment reading passages and tested reading passages. As such, wide reading may be more effective when treatment reading passages and tested reading passages are disparate, as was the case with the present study (e.g., Homan, Kelsius, & Hite, 1993). Clinicians, then, should utilize intervention in wide reading, especially for struggling readers in grade 2 and above, in addition to traditional intervention in repeated reading. It may be for students presenting with fluency problems, a combination of repeated and wide reading techniques represents the best chance at attaining sustained improvement in reading rate.

Individualized targeted intervention.

As a result of the present study, practitioners are also encouraged to design intervention based upon the type and severity of underlying reading deficiency in each child. While there is an appeal to universal designations and universal programming, the multifactorial nature of dyslexia, as supported by the differences in deficit profiles seen in the present study, calls for intervention programming to take into account the unique deficit profile of each child (Fiorello et al., 2006; Pennington et al., 2012; Mengheni et al., 2009; Shaywitz et al., 2008). Moreover, practitioners should be thoughtful and deliberate when designing treatment for those with multiple underlying deficits (RAN, PA, VA etc.). As evidenced by the lack of double deficit treatment response in the present and other studies (Al Otaiba & Fuchs, 2002; Fletcher et al., 2011), those with more pronounced deficits will necessitate longer treatment time, especially if

diagnosis occurs past the early elementary years. In particular, those with RAN deficits will need RAN treatment as early as possible (before age 7), to prevent entrenchment of RAN difficulties as seen by participants in the present study. Finally, clinicians should consider inclusion of VA treatments seen in the current study as part of the treatment regimen for those with RAN-type difficulties, as VA treatment may convey improvements in limited inhibitory resources, allowing struggling readers to better sustain and manage attention resources needed for the reading process.

Specific educator preparation.

Although the State Board for Educator Certification recently adopted Texas Administrative Code (TAC) Chapter 228.35, which states, "An education preparation program…must require, as part of the curriculum for a bachelor's degree that is a prerequisite for educator certification, that a candidate receive instruction in detection and education of students with dyslexia" (SB, 2011), the majority of research evidence illuminates a deficit in teacher knowledge about dyslexia identification and/or treatment (Washburn, Joshi, & Binks-Cantrell, 2011). Based on outcomes from the present study, all educators may benefit from specific training to understand noticeable indicators of those learners with single and double deficit dyslexia profiles. Even more importantly, early childhood educators (PK-2) may need training in screening for and recognition of deficits in RAN, as prevention can then occur prior to development of reading difficulties.

In terms of general classroom instruction, all educators may benefit from understanding the importance of providing high-quality, varied, and diverse reading instruction. While classroom teachers should not be responsible for clinical assessment and treatment of those with pronounced reading impairment, learning how to identify markers for single and double deficit

dyslexia presented herein, might facilitate proper and timelier referral to reading specialists and special educators for assessment and treatment. Specifically, class-wide screening for RAN, VA, and rate difficulties is warranted, although direct treatment of RAN and VA may not be appropriate in a classroom setting. Classroom-based fluency instruction is already included as part of a balanced reading curriculum and has been since the National Reading Panel issued findings about quality reading programs over a decade ago (NICHD, 2000). As such, findings from the present study, in accordance with outcomes from the National Reading Panel, support continued teacher training in fluency instruction.

Reading specialists and special educators who work with small groups of children in public settings or with individual children in private and/or university-based clinical settings should have more specific training in assessment and treatment of less studied underlying sublexical causes of reading difficulty (RAN, VA). Moreover, these individuals should receive thorough training in designing specific treatment depending on type and level of sublexical deficit (Fiorello et al., 2006; Hale & Fiorello, 2010). Therefore, traditional preparation in terms of proprietary dyslexia curriculum is discouraged, while training in identification and individualized targeted treatment of various reading-related difficulties, including but not limited to difficulties in RAN and VA, is encouraged.

Recommendations for Future Research

Treatment dosage and duration.

Treatment dosage in terms of measuring increasing daily performance on intervention components related to the DVs of RAN, VA, and rate was not measured or analyzed for the present study. Unfortunately study of dosage effects is an area of limited investigation (Denton, 2012); thus specific dosage needed for optimal response to intervention is yet undetermined by

research (Gersten et al., 2008). Interestingly, one similar study, Bailet et al., (2009) found increases in RAN were not significant in terms of treatment effect although daily gains for RAN manifested in terms of a dosage effect. Replication of the present study with individual student growth curve modeling for dosage effects (as suggested by Holt, 2008), could be warranted as similar gains to Bailet et al., (2009) may be present in the data. Moreover, by measuring dosage effects in reading intervention, future researchers may be able to answer the practical question as to how much reading intervention is necessary for gains to be made and sustained by struggling readers.

Future reading intervention research is also called for in terms of longer treatment duration, specifically for those with RAN-based single and double deficits. Elbaum et al.'s 2010 meta-analysis of one-on-one reading intervention studies ($N = 29$), indicated more intense intervention in terms of duration was reliably associated with larger effect sizes. And, behavioral reading intervention studies demonstrate treatment promotes changes in outward reading behavior very slowly in less skilled readers (i.e. those with multiple sublexical deficits), also calling for an intervention of longer duration (e.g., Ehri & Wilce, 1983; Ehri, 2005). In fact, according to Amtmann, Abbot, and Berninger (2008), treatment for the most impaired children must often span across multiple school years to consolidate learning and make significant reading progress. Finally, specific evidence supports longer duration treatments are necessary for RAN-impaired individuals (e.g. Morris et al., 2010; Wolf et al., 2009; Wolf, Miller, & Donnelly, 2000). Further studies, then, might simply replicate and extend the intervention period used in the present study, specifically to ascertain if a lengthened intervention might facilitate transfer of VA gains to reading rate and/or other lexical and supralexical skills.

Multiple measures of reading fluency.

Fluency as a construct is as multifaceted and complex as RAN (Wolf & Katzir-Cohen, 2001). As such, while reading rate did not improve, the treatment provided in the current study may have impacted other unmeasured elements of fluency. Potentially impacted elements of reading fluency not measured in the current study include: reading accuracy, orthographic knowledge, sight word vocabulary, single word decoding fluency, and multiple cue efficiency (Hudson et al., 2009). In comparing struggling readers treated in other context, some studies suggest those with the greatest degree of impairment may only improve in terms of word reading in isolation (i.e. Clements-Stephens et al., 2012; Hudson, Isakson, Richman, Lane, & Arriaza-Allen, 2011). And treatments similar to the intervention in the present study may improve reading accuracy instead of reading rate (Lorusso, Facoetti, & Bakker, 2011). Future research, then, should use a similar treatment protocol but should include more comprehensive and diverse measures of fluency including instruments that discern reading rate of words in isolation, reading accuracy of words in isolation, and reading accuracy of connected text. By measuring fluency in a more comprehensive manner, future researchers may be able to design treatments addressing the various components of fluency not included in the present study.

Further understanding of the VA and RAN relationship.

Unfortunately, the exact nature of the reading to VA relationship is still not fully understood (Shaywitz et al., 2008). Multiple ideas exist as to the nature of this relationship, with theorists suggesting a wide variety of causal connections between poor attention and impaired reading, perhaps due to impairments in: reaction time and articulation (Neuhaus et al., 2001; Wile & Borowsky, 2004), a general timing deficit (e. g., Hawelka et al., 2010; Jones et al., 2010; Wolf et al., 2000), processing speed (i.e. Araújo et al., 2011; Christopher et al., 2012; Compton

et al., 2002, 2010), attentional shifting (Franceschini et al., 2012), visual search (Jones, Branigan, & Kelly, 2007), sustained attention ($r = .25$ in K, $r = .26$ in 1, $r = .39$ in 2nd) (Georgiou et al., 2010), and/or general inattention issues (5-8% of variance in RAN due to inattention) (Pham et al., 2011).

Questions specifically remain as to why VA was the only variable amenable to robust, clinically-significant improvement in the present study. If general attention or inhibitory difficulties mediated the relationship between RAN and VA, then differences between the lexical nature of the alphanumeric RAN task and the spatial nature of the VA task should have not mattered, as both tasks generally require rapid retrieval from long term store and rapid sequential naming. More specifically, if both skills (RAN and VA) were mediated by a common attention variable, VA should discriminate between single and double deficit groups as RAN did; bivariate correlations between VA and RAN should be stronger (than $r = .187$ to $.475$); and RAN skills should show improvement along with VA. Instead, RAN differentiated between deficit profiles while VA did not, while VA normalized without concomitant RAN normalization. This lack of relationship and profiling similarity between RAN and VA in the present study perhaps indicates (contrary to findings from Pham et al., 2011) the RAN deficit in dyslexics may be separate from a general inhibitory attention deficit. Instead, RAN may represent a linguistic-specific or orthographic attentional shifting ability based on fixation on individual letters, shifting between letters at an appropriate pace, and retrieval of letter names to correspond with visual graphemes (as theorized by Facoetti, Trussardi, et al., 2010; Geiger et al., 2008; Rodriguez et al., 2012). Future research is warranted to better understand the specific attentional and central executive mechanisms involved in the reading process and to more specifically show how RAN and VA are related.

Behavioral treatment studies for VA.

Future study of VA intervention as part of reading treatment is needed as the literature suggests that poor reading treatment response for those with RAN-type dyslexia may occur because underlying sublexical components are not considered as a part of initial treatment design (Wright, Conlon, Wright, & Dyck, 2011).While the correlational relationships between poor reading outcomes (RAN, rate) and impaired VA has been well researched in the last decade, very little research has focused on behavioral treatment of VA, as the present study did (Shaywitz et al., 2008). Questions remain, though, as to which portions of the treatment were most helpful in improving VA, thus future research should investigate if the serial visual search exercise alone or in combination with the flash word exercise and/or other elements of the multicomponent treatment were most effective in targeting VA improvement. Moreover, future studies should continue to include other reading outcome variables to investigate if treatment targeting VA might generalize to reading skills other than RAN and rate.

Effective treatments for older struggling readers.

As age impacted treatment outcomes for the present study, and as previous studies have indicated lack of treatment response for older struggling readers (Corrin et al., 2008; James-Burdumy et al., 2009; Kemple et al., 2008), future studies should examine reading treatment effectiveness for older students with RAN-type single and double deficit dyslexia. Few well designed studies have investigated treatment response in older students with treatment resistant deficit profiles (e. g. Vaughn, Cirino, et al., 2010; Vaughn et al., 2011; Vaughn & Fletcher, 2012; Vaughn, Wanzek, et al., 2010) and those studies have consistently shown moderate gains and limited effects. Clearly, more work is needed to better understand how to treat older children (beyond age 7) with severe reading impairments.

Future studies comparatively analyzing treatment response between age groups are also warranted. Little research focuses on the differential effects of fluency intervention implemented at different age bands (younger versus older elementary students, elementary versus middle school students). One small treatment study did compare fluency treatment for elementary and middle school students and evidenced no difference between age bands, as long as sufficient intervention time was planned (Tressoldi, Lorusso, Brenbati, & Domini, 2007). While longer treatments have generally produced more substantial results, further investigation into the time by age interaction is warranted as most treatment studies are short-lived in duration and/or do not consider age as a variable (Roberts, Torgeson, Boardman, & Scammacca, 2008). Moreover, future studies should look comparatively at various age bands with various treatment combinations to ascertain best practice for older struggling readers who, for whatever reason, do not receive effective early intervention.

Concluding Remarks

The difficulty seen in the present study in terms of improving RAN and rate still is unexplained. Recent theory suggests numerous underlying factors may play a role in reading difficulty (e.g., O'Brien et al., 2012). Genetic studies have found a constellation of genes contribute to the variance in dyslexic profiles (e.g. Naples, Chang, Katz, & Grigorenko, 2009; van Bergen et al., 2012); with a large percentage of dyslexics possessing a complex pattern of multiple deficits (Ziegler et al., 2008; Pennington et al., 2012). Specifically, Pennington et al. (2012) tested five cognitive structural equation models of dyslexia and indicated a hybrid model of various underlying causes (RAN, PA, language skills, processing speed) was the best fit for the data, with 30-36% of individuals showing a multiple deficit profile. These deficits may include difficulties with sustained attention, visual and spatial ability, central executive

functions, morphological knowledge, auditory processing, and a variety of other sensory and motor deficits in addition to RAN, PA, and VA (e.g. de Boer-Schellekens & Vroomen, 2012; McGrath et al., 2011; Menghini et al., 2009). As the present study only included and treated two sublexical deficits (RAN and VA), it remains undetermined if controlling for other variables might have produced a different treatment response.

Lack of statistically significant treatment response may be attributable to the paradoxical complexity of the seemingly simple RAN skill. There are at least seven processes related to RAN: attention to letter stimulus, visual discrimination and pattern identification of letters, integration of visual letter features with stored orthographic letter representations, access and retrieval of phonological labels, activation and integration of semantic and conceptual information with all other input, and motor activation leading to articulation (Norton & Wolf, 2012). Furthermore, RAN tasks stimulate frontal, parietal, occipital, and cerebellar regions, thus relying on a diverse network of locations within the brain. Although RAN seems simple in practice, in reality RAN is an index of synchronization and effective executive function (Christodoulou, 2010; Conrad & Levy, 2011). RAN improvement may rely, then, on improvement of a variety of individual underlying cognitive skills, as well as, efficient integration of these skills across a complex network of brain regions in order to access needed information for output (Brooks, Berninger, & Abbott, 2011; Jones et al., 2010). As such, treatment of RAN may necessitate a much more thorough and extensive treatment than provided by the present study.

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Appendix A

RAN Protocol

| b | m | r | s | a | m | r | s | a | b |

| r | s | a | m | b | a | r | s | b | m |

| a | m | b | s | r | m | s | r | a | b |

| m | s | a | r | b | r | b | a | s | m |

| s | m | r | a | b | r | s | b | m | a |

Appendix B

Sample Call for Participants

Does your child struggle with reading?

Children who struggle in reading, particularly those who read slowly or avoid reading are wanted for a

research study.

Participants must be:

- Ages 7-12
- Not receiving reading intervention from any source outside of daily school

Participants who qualify will receive:

- 30 minutes of reading intervention, 4 times per week for 4 weeks with a certified educator.
- All participants will be entered into a drawing for a Kindle Fire

For more information please contact:

The Reading Connection

Scott Olson, Research Coordinator

817-924-2000

info@readwithkary.com

Appendix C

Treatment Scope and Sequence

*For purposes of treatment fidelity, it is very important that you follow the daily script in terms

of how and when to implement activities. Deviation from this script could cause issues with

study outcomes.*

1. Visual Attention Therapy Ipad (5 min)
2. RAN (5 min)
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min)
   - Mon – fry phrase boom
   - Tues – fry phrase bingo
   - Wed - fry phrase dice dash
   - Thurs – fry phrase jack stack

6. Homework – send home fluency passage and parent recording sheet

* This is a very tight 30 minutes so please make sure you and students are on task at all times!!!

*If a student misses a day – just skip that day and go on to the next day in the script – be sure to

record attendance though!

Visual Attention Therappy Directions

1. This application is located on the Ipad under the folder Visual Attention.
2. Open the application and choose practice.
3. Make sure signal is set to none.
4. Choose level – Always choose similar letters.
5. Choose number – Always choose two targets.
6. The application will have the student do three trials in which it assigns two letters to touch.
7. Make sure the student scans right to left and top to bottom. Make sure the student touches the target letters in order.
8. After the student completes trial # 1 and #2, a message box will pop up with the time and score. Have the student click next.
9. After the student completes trial #3, the teacher will choose email results.
10. An email box will pop up with results that are automatically set to come to karyajohnson@sbcglobal.net. Push send.

    *It is very easy to push the wrong command on the message boxes so make sure that you supervise the student vigilantly when he/she first begins using this application.

RAN directions

1. In your teacher materials you have a master packet with RAN protocols #1-22. This is what each child will read from and should not be marked on in any way.
2. In each individual student folder, there will be an identical packet with RAN #1-22 with the child's name. This is the packet that you will mark times on. In white space on protocol mark the date and list times.
3. For all RAN protocols make sure that child knows correct identification and pronunciation of letter names, sounds and chunks by first modeling the entire protocol to the child. As you read your RAN protocol, have child follow along on his/hers
4. For RAN Protocols 1-5:
   a. First have the child rapidly read letter names three times. Mark times
   b. Then have child rapidly read letter sounds three times. Mark times.
      i. For vowels use short vowel sound
      ii. For c and g, use the hard sound
5. For RAN Protocols 6-22 have the child rapidly read the letter chunks (sound only as there are 2+ letters from this point on)

   Ideas to make RAN fun:
   1. Speedy Swig – take a drink of soda/water before each reading
   2. Jumping Jacks – between each RAN to energize student
   3. Victory Dance – when they break their RAN record
   4. Magic glasses – read RAN with sunglasses on
   5. Use minipointer to read!

Repeated Reading Directions

1. Each child will have 3 copies of 16 fluency passages at his or her independent reading level as measured from his/her GORT-IV pretest score. Passages will represent a range of independent levels and will be marked session 1 through 16 with increasing difficulty.
2. Each fluency passage will be read in session 2 times and sent home to read 3 times (see homework directions).
3. The following procedure should be used for fluency passages in session:
    a. Tell the child the title of the passage and make oral predictions about what the passage will be about.
    b. Model the fluency passage by reading it aloud orally, with appropriate intonation, phrasing, expression and prosody to the child.
    c. Then have the child read the passage aloud to you for the first time and do the following:
        i. Time him/her and record in seconds and mark on your copy of the passage.
        ii. Mark miscues
    d. After the child reads the passage the first time:
        i. Have the child retell the passage briefly in his/her own words. If child misses key information in the retell, ask questions (who, did what, when, where, why) to illicit response.
        ii. Determine the child's words per minute (reading rate), record wpm on your passage and have the child color his words per minute on the fluency graph bar in his folder. Make sure to put name of passage and date at the bottom of the graph.
        iii. Determine the percentage of words correct (accuracy) and record on your passage and indicate to the child any words that were missed and have the child highlight these words on his/her passage
    e. Have the child read the passage again. Repeat step c (time and mark miscues) and repeat step d ii and iii only.
    f. Send the passage home and instruct the child to read 3 more times with an adult listening/timing. Parent instructions for fluency passages are included in the homework folder.

Fry Flash Word Directions

1. This application is located on the Ipad under the file sight words.
2. Before using the application make sure that the settings are as follows:
   a. Sound – off
   b. Timing – set according to the week
      i. Week 1 – 5 seconds per slide
      ii. Week 2 – 3 seconds per slide
      iii. Week 3 – 2 seconds per slide
      iv. Week 4 – 1 second per slide
   c. Play mode – words only
   d. Looping – Looping off
   e. Customize flashcards – do not mark anything
   f. Capitalization – all lowercase
   g. Font size – large
   h. Font color –black
   i. Order type – random
3. Click on the assigned list for the session.
4. The application will flash the 12-15 Fry words from the list automatically and the student will attempt to read the words.
5. The student does not need to touch the Ipad during this exercise.
6. If the student misses a word, provide the correct word.
7. If the timing is too fast (student misses more than 50% of words), play the list again and provide teacher assistance by reading the word chorally with the student.

Fry Phrase Boom Directions

Materials:

1 set of fry phrase boom popsicle sticks and cup	Sticks contain phrases from first 100 fry words
Flat surface	This can be a table, desk, or even the floor.
Timer	

Directions:

1. Set timer for 5 minutes.
2. You and the student take turns pulling fry phrase sticks from the cup and reading the phrase.
   a. If the phrase is read correctly, you keep the phrase.
   b. If the phrase is read incorrectly the phrase must be returned.
   c. If a stick with BOOM is pulled, the person who pulls the stick must return all his sticks.
3. Play continues in this manner until the time is up.
4. At the end of five minutes, the player with the most sticks wins.

Fry Phrase Bingo Directions

Materials:

Fry Phrase Bingo Cards (8)	2 per assigned session with specific phrases but in different order in 5x5 grid
Fry Phrase Index Cards	Same as cards used in Jack Stack; contain phrases from first 100 fry words
Flat surface	This can be a table, desk, or even the floor.
Large Bag Skittles	

1. Use the assigned bingo card (1-4) depending on session day. Teacher and child will both have a bingo card with same phrases but in a different order.
2. Fry phase index cards should be placed in stack, face down. All phrases contained on the 4 bingo cards are included in your teacher packet. Take turns with the child turning over and reading the phrases from the index cards.
3. Cover each matching phrase on your bingo card with a skittle
4. You win the game and eat the skittles when you make a bingo (horizontal, vertical or diagonal).

Fry Phrase Dice Dash Directions

Materials:

1 die (real or virtual)	
Fry Phrase Column Charts (4)	
Flat surface	This can be a table, desk, or even the floor.

Directions:

1. Choose the correct dice dash card (1-4) to be used in specific session.
2. In this game the student rolls 1 die (either a real die or a virtual die on Ipad application "classroom dice").
3. The student is the only one who rolls the die.
4. He or she will read (as fast and accurately as possible) the fry phrases in the column that correspond with the number rolled. The student gets one point for each column read correctly.
5. If the student rolls the same number before the game is over, then the teacher must read the phrases in the corresponding column. If the teacher reads all phrases correct he/she gets a point.
6. If a number is rolled three times before the game is over, the student chooses any row he/she wants to read and if all phrases are read correctly a bonus point is given for that row.
7. The first person to reach 6 points wins.

Fry Phrase Jack Stack!

Materials:

1 set of large plastic jacks	
A flat, smooth surface	This can be a table, desk, or even the floor.
Fry Phrase Index Cards	These will have phrases from first 100 phrases – same as cards used in bingo
Timer	

Directions:

1. Set a time for 5 minutes
2. Turn all of the cards face down in a pile.
3. Begin building the jack stack as follows: The student will place a jack on the flat surface. The teacher will attach his jack to the jack that the student put down. Continue alternating in this way, putting jacks on the structure they have built until any part of the structure crashes. See photograph
4. Whoever causes the crash must count the number of jacks and draw and read the corresponding number of fry phrase cards as quickly as possible.
5. After these 10 cards are read, go back and repeat steps 2 and 3.
6. At the end of five minutes, the person with the smallest number of cards (hence the person who caused the stack to fall the least amount of times) wins.

Day 1

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 1 and RAN #2 (5 min) – letter names 3x and letter sounds 3x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min): Fry phrase boom

Day 2

1. Visual Attention Therapy Ipad (5 min)
2. RAN #2 and # 3 (5 min) - letter names 3x and letter sounds 3x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min): fry phrase bingo board 1

Day 3

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 3 and #4 (5 min) - letter names 3x and letter sounds 3x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min): fry phrase dice dash card 1

Day 4

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 4 and # 5 (5 min) - letter names 3x and letter sounds 3x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) - fry phrase jack stack

Day 5

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 6 (5 min) – sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min): fry phrase boom

Day 6

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 7 (5 min) - sounds only 6x

3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) - fry phrase bingo card 2

Day 7

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 8 (5 min) - sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) - fry phrase dice dash – card 2

Day 8

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 9 (5 min) - sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) - fry phrase jack stack

Day 9

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 10 (5 min) sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) - fry phrase boom

Day 10

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 11 (5 min) - sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) fry phrase bingo card 3

Day 11

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 12 (5 min) - sounds only 6x
3. Repeated Reading Fluency passage (10 min)

4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) – Fry phrase dice dash card 3

Day 12

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 13 (5 min) - sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) – Fry phrase jack stack

Day 13

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 14 (5 min) - sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) – Fry phrase boom

Day 14

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 15 (5 min) - sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) – Fry phrase bingo card 4

Day 15

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 16 (5 min) - sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) – Fry phrase dice dash card 4

Day 16

1. Visual Attention Therapy Ipad (5 min)
2. RAN # 17 (5 min) - sounds only 6x
3. Repeated Reading Fluency passage (10 min)
4. Fry Words Flash-Word Ipad (5 min)
5. Fry phrases Game (5 min) – Fry phrase jack stack

Daily Homework

1. Encourage the child to read fluency passages daily.
2. Send home a new Fluency Progress Chart and a copy of the daily fluency passage with child each day.
3. A parent or adult must listen to the child read and must fill in the Fluency Progress Chart.
4. Collect the Fluency Progress Chart the following day.
5. Please turn all Fluency Progress Chart's in to Kary Johnson with the child's name and date clearly marked.
6. Tracking home practice is important as it can vary the outcomes of the study.

Daily Fluency Progress Chart

Name: _____ Date Due: _____ Parent

Signature: _____

Explanation: Your child is currently working on improving his/her reading fluency during intervention time. We have talked a lot at school about fluency and what it means. Our definition of fluency is being able to read the words accurately with expression and proper speed. We have also talked a lot about reading the punctuation correctly so the story sounds right!

Directions: (1) Have your child take out the passage to read. (2) Set a timer for one minute. (3) Start the timer as soon as your child begins to read. (4) Mark any words your child misses as s/he reads to you on your sheet. (5) At the end of one minute talk to your child about what word(s) s/he missed. (6) Record the name of the passage the number of words read total (even if they missed the word) and the number of errors. (7) Complete steps 1-6 two more times.

Name of Passage	Level	Words per Minute 1st try	Words per Minute 2nd try	Words per Minute 3rd try
		Errors:	Errors:	Errors:

BIOGRAPHICAL NOTE

Kary A. Johnson is a bilingual reading specialist in private practice as the owner of The Reading Connection, a reading clinic in Fort Worth, TX. She graduated from Trinity Valley School in 1995 and received a BA in international relations from TCU in 1995. In 2003, Kary received her M.Ed. from Texas Wesleyan University in Reading and Bilingual Education. Prior to starting The Reading Connection, Kary was an elementary bilingual and ESL teacher, reading specialist and language arts curriculum coordinator at the district level in the Texas public school system. She earned her Doctorate of Education in Curriculum and Instruction in 2013 from Texas Wesleyan University. Currently, Kary continues to own and operate The Reading Connection, and serves as Board President of related nonprofit 501c3 Literacy United, which was created to serve struggling readers in the Tarrant County area who cannot afford the cost of private reading therapy.