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UNIVERSITY OF NORTHERN COLORADO

Greeley, Colorado

The Graduate School

PRIMING EFFECTS ON WORD RECOGNITION IN STUDENTS WITH DYSLEXIA

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

Cynthia T. Johnson

College of Education and Behavioral Sciences
Department of School Psychology

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This Dissertation by: Cynthia T. Johnson

Entitled: *Priming Effects on Word Recognition in Children with Dyslexia*

has been approved as meeting the requirements for the Degree of Doctor of Philosophy in the College of Education and Behavioral Sciences in the Department of School Psychology

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ABSTRACT

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Given that children and adolescents with dyslexia may struggle academically as well as socially and emotionally, it is critical to understand and develop methods for early intervention. A growing body of research has focused on reading interventions that include word priming which typically involves numerous presentations of words that are phonologically or semantically related to a target word. The purpose of this study was to investigate the effect of word and picture priming on the reaction times of word recognition tasks for five youth with dyslexia, aged 7-16 with dyslexia. Results of this 25-session multiple-case multiple treatment reversal design study showed that picture priming treatments assisted all participants in reading target words more quickly. Word priming treatments assisted four of the five participants in reading target words more quickly. All participants demonstrated greater decreases in their reaction times reading target words with picture primes than with word primes.

The decoding ability of participants appeared to affect their perception of the benefits of the two types of intervention. Readers with less decoding ability preferred picture primes, while more advanced decoders believed word primes were more beneficial. Overall, results showed that younger and less-skilled readers showed enhanced effects of semantics as compared with older readers whose decoding skills were

relatively efficient. These findings are consistent with the proposition that the semantic pathway can compensate direct orthography-to-phonology translations when that process is slow and inefficient.

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CHAPTER I

INTRODUCTION

The acquisition of reading has been researched extensively over the last three decades resulting in enormous growth in the understanding of early reading development (National Reading Panel, 2000; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001; Stanovich, 2000). Reading is a complex skill utilizing multiple parts of the brain. To be a successful reader, one must rapidly access and integrate a vast circuit of neural networks across different areas of the brain with both great accuracy and remarkable speed. Theoretically speaking, this proposed "reading circuit" is composed of neural systems that support every level of language—phonology, morphology, syntax, and semantics—as well as visual and orthographic processes, working memory, mental processing speed, attention, motor movements, and higher-level comprehension, and cognition (Norton & Wolf, 2012).

Similar to this conceptualization of the reading circuit, current research regarding reading fluency also points to a multicomponent view (Berninger, Abbott, Billingsley, & Nagy, 2001). Reading fluency, or the rate at which one reads, is considered to be a product of phonological representation (i.e., the ability to mentally conceptualize the sounds and combinations of sounds that comprise words) and phonemic awareness (i.e., the ability to hear, identify, and manipulate individual sounds in spoken words), orthographic (letter-pattern) identification, decoding and word recognition, auditory and

visual perception (i.e., the ability to recognize or interpret *what is* heard and seen), attention, and short-term and long-term memory (Berninger et al., 2001). Together, these various foundational skills of reading come together in the process of learning to read fluently.

Learning to read fluently is a pivotal milestone of every child's schooling experience. Yet many children have a very difficult time and for them, reading remains slow and effortful. Some children experience such significant problems that they are considered to have a reading disability or disorder. One type of reading disability is called dyslexia. While some may use the terms reading disability and dyslexia in an interchangeable manner, reading disability is an umbrella term used to refer to any type of significant reading problem that might emerge. Dyslexia is a specific type of reading disability; a widely accepted current definition of dyslexia is that it is a neurodevelopmental disorder with a probable genetic basis. The core feature of dyslexia is a problem with word decoding, which in turn impacts spelling performance and the development of reading fluency (Snowling, 2013).

There are many proposed models for understanding the deficits involved in dyslexia. According to Torgesen, Wagner, Rashotte, Herron, and Lindamood (2010) there is no single test and no absolute criteria for diagnosing dyslexia. There are so many processes involved in reading that it is difficult to break down the cause of dyslexia. More than 100 years of research into dyslexia has yet to reveal a single explanation for all the symptoms of dyslexia (Norton & Wolf, 2012). However, certain patterns of deficits and potential deficits have begun to emerge. The purpose of this study is to explore a supplemental intervention that may enhance the reading ability of students with dyslexia.

Significance of the Problem

Dyslexia is a significant problem in education. It is widely established that children who do not learn to read by third grade are at risk of dropping out of school (Guilli, Mallory, & Ramirez, 2005; Torgesen et al., 1999). If dyslexia is not addressed, these students may become functionally illiterate because they lack the ability to carry out daily tasks due to poor skills in reading, spelling, and writing. From an emotional or psychological point of view, dyslexia may negatively affect self-esteem and create confusion and frustration, which then contributes to underachievement (Guilli et al., 2005).

Dyslexia is one of the most common neurobehavioral disorders affecting children, although there is some disagreement regarding the specific prevalence. While some researchers site the prevalence to range from 5-10% of schoolchildren in the United States (Vogel & Holt, 2003), others suggest these rates may be up to 17.5% (Guilli et al., 2005). While rates may vary on the specific prevalence of dyslexia, it is clear that many children are affected by this disorder, and their ability to read can be severely compromised.

Given that children with dyslexia may struggle academically as well as socially and emotionally, it is critical to understand and develop methods for early intervention. Accurate early identification and appropriate targeted intervention can improve reading ability and reduce the other potentially negative effects associated with dyslexia (Foorman, Francis, Shaywitz, Shaywitz, & Fletcher, 1997; Vellutino, Scanlon, & Tanzman, 1998). Thus, it is important to identify dyslexia early and to characterize the precise strengths and vulnerabilities of each individual child so that targeted intervention

can be provided to enhance accuracy and automaticity in each aspect of the reading system. In other words, if the risk for reading difficulties such as dyslexia can be identified and addressed very early, the chances of improving reading skills are much greater (Norton & Wolf, 2012).

Despite a recognition that fluent reading and comprehension depend on accuracy and automaticity at every level of language, few intervention programs reflect this emphasis (Norton & Wolf, 2012). Instead, most of these programs have a narrow focus on phonological decoding and do not explicitly address the multiple components of language, such as orthography (i.e., the visual perception necessary to deal with the form of letters and the spelling patterns within words), morphology (i.e. the structure of language), semantics (i.e., the meaning of words or language), and syntax (i.e., grammatical structure). Multicomponent programming may be especially effective for students with dyslexia because it is more likely to address the many systems that are involved in the disorder. For example, a study that examined the impact of a multicomponent intervention with 279 students with reading difficulties found that children who received multicomponent interventions demonstrated significantly greater growth than did participants in the other singularly focused intervention groups on their performance on timed and untimed word and non-word reading and passage comprehension (Morris et al., 2012). The multicomponent groups also maintained these levels of growth at follow-up one year after the interventions. Therefore, it may be important to integrate different types of strategies into reading intervention program that address multiple aspects of reading.

Theoretical Basis for the Study

Within a multicomponent model of reading, there are additional theories related to how each of the foundational skills are acquired. Over the last several years, it has been well documented that recognizing words is related to the speed of initial reading acquisition (Gottardo, Chiappe, Siegel, & Stanovich, 1999; Perfetti, 1985; Rayner et al., 2001). Additionally, there is evidence that this relationship is causal. That is, children who are more efficient at recognizing words are quicker at learning to read. Word recognition skills also lead to increased reading comprehension, especially in the early grades (Chall, 1989; Oakhill & Cain, 2000; Wise, Sevcil, Morris, Lovett, & Wolf, 2007). While reading comprehension is central to reading overall, the ability to recognize words is necessary before any type of comprehension is possible.

The Triangle Model provides one model for understanding the process by which word recognition develops in young readers (Plaut, McClelland, Seidenberg, & Patterson, 1996). Supporters of this model believe that word recognition is dependent on three separate abilities: phonological representation, orthographic representation, and semantics (Plaut et al., 1996). The Triangle Model grew from earlier models that only considered the phonological and orthographic components of word recognition skills, and neglected the semantics side of the triangle. With this updated model, Plaut et al. (1996) proposed a division of labor between semantic and phonological processes, rather than the standard dual-route account of orthographic and phonological pathways. This work directly refuted the claims of dual-route theorists who claimed that skilled word reading required phonological and orthographic separation when mapping print to sound. The Triangle Model was used in this study because of its multicomponent nature. It is

thought that the multicomponent view of the Triangle Model, which includes phonological and orthographic representation, along with semantics, is the most comprehensive model available today.

One of the hallmark symptoms of dyslexia is the inability to fluently recognize words (Berninger, Raskind, Richards, Abbott, & Stock, 2008). Dyslexia may occur because of deficits in many areas, either in isolation, or more likely, in concert. The most current research points to a hybrid, multiple deficit model, illustrating that dyslexia is due to deficits in phonological processing, mental processing speed, naming speed, and/or language skills either in isolation or in combination (Pennington et al., 2012). Any or all of these deficits would be expected to inhibit a child's ability to recognize letters, words, and/or read them fluently. Numerous researchers have found a statistically significant deficit in the ability to quickly encode, process, and provide output among readers with dyslexia (Catts, Gillispie, Leonard, Kail, & Miller, 2002; Pennington et al., 2012; Peter, Matsushita, & Raskind, 2011).

The connection between mental processing speed and dyslexia, specifically the association between rapid automatized naming (RAN) and reading fluency (Norton & Wolf, 2012) is the focus of this study. While RAN is simply a task that measures the speed at which and individual can name simple stimuli such as letters, numbers, colors, or objects, it represents the skill of automaticity, or fluency. This seemingly simple task of naming a series of familiar items as quickly as possible appears to represent the characteristic features of the later developing, more elaborated reading circuit (Norton & Wolf, 2012). In other words, helping students build their automaticity in letter, number, and object recognition may lay the foundation to ultimately assist them in quicker word

recognition. In turn, if a child is able to rapidly recognize words, there is a greater possibility that the child will be able to read fluently.

Problem Statement

Difficulty in word recognition and reading fluency are two of the major problems in children with dyslexia; their reading is slow, hesitant, and sometimes extremely laborious (Thaler, Ebner, Wimmer, & Landerl, 2004). Given that deficits in fluent word recognition is one of the hallmark characteristics of dyslexia, it seems that many children could benefit from interventions that specifically target these skills (i.e., fluency and word recognition) either in isolation or combination.

Interventions for word recognition come from a variety of phonological, morphological, and semantic areas. Some general phonological interventions involve activities targeting phonological awareness, phonemic decoding, and practice with repeated readings. For instance, phonological skills such as segmenting, blending, and phoneme manipulation have been significantly improved in some studies (Gillon & Dodd, 1997; Wright & Mullan, 2006). Other studies found improvement through training in sight word reading (repeated reading) and corrective feedback (Butler, 1999; Ferkis, Belfiore, & Skinner, 1997).

One program that combines phonological interventions with repeated reading is a commonly used, evidence-based program for developing word recognition called *The Lindamood Phoneme Sequencing Program for Reading, Spelling, and Speech (LIPS)* (Lindamood & Lindamood, 1998). *LIPS* provides explicit and systematic support for the development of phonemic awareness, phonemic decoding (and writing), and text reading accuracy through practice reading (Lindamood & Lindamood, 1998). Students learn to

recognize how their mouths produce the sounds of language. This kinesthetic feedback enables them to verify sounds within words and to become self-correcting in reading, spelling, and speech. Although many studies regarding the effectiveness of LIPS have been completed, only one has met the rigorous standards sufficient for the What Works Clearinghouse (Institute for Education Sciences, 2010). In a study of 50 children with reading disabilities, the LIPS program was found to have potentially positive effects on alphabetics and reading fluency, although no discernable effects were found for reading comprehension (Torgesen et al., 2010).

In a study comparing different interventions for students at-risk for dyslexia, Torgesen et al. (2010) compared first grade students who used the *LIPS* program to a control group of students who had only been exposed to their school's general reading program which consisted of both daily classroom teaching and additional small-group instruction in general phonological awareness. Results showed that after seven months of four 50-minute sessions per week, intervention students performed significantly better than students in the control group. Significant differences were obtained by the intervention group for phonemic awareness, phonemic decoding, reading accuracy, rapid automatic naming, and reading comprehension. A follow-up test at the end of second grade showed the gains in the intervention group persisted, although only differences in phonemic awareness, phonemic decoding, and rapid naming remained statistically reliable (Torgesen et al., 2010).

A growing body of research has focused on interventions that include word priming which typically involves numerous presentations of words that are phonologically or semantically related to a target word as a way to introduce the target

words. With repeated practice of similar words, the reader is able to more quickly identify the target words. Although several researchers have examined the effects of word priming interventions, these studies have generally included typical readers (Biggs & Marmurek, 1990; Hennessey & Kirsner, 1999; Wheeldon & Monsell, 1992), children with speech impairments (Bragard, Schelstraete, Snyers, & James, 2012), or adults with dyslexia (Crutch & Warrington, 2007).

Fewer studies have been carried out which focus on children and adolescents with dyslexia. One such study by Hennessey, Deadman, and Williams (2012) examined word and picture priming in children with dyslexia. They found that word naming significantly primed pictures, and that picture naming somewhat primed words. That is, when shown a series of words describing different objects, children were then able to name the pictures of that object more quickly. Conversely, when shown a series of pictures illustrating a word, children were able to name the corresponding words somewhat more quickly. This study also compared readers with dyslexia to typical readers of all ages. Similar to readers with dyslexia, children who were reading-age matched controls also used word priming. In sum, Hennessey et al. (2012) suggested that younger and less skilled readers used semantics to find meanings of words and to help them decode words, since their decoding skills were less efficient than older skilled readers. This finding is important because if we can learn about the various pathways that contribute to learning to read, and develop interventions that address each of them, then we can more accurately match the strategy to the specific struggles that children are having. Thus, if a child is struggling with both automaticity and decoding, an intervention that addresses both is likely to be more effective than one that only targets one of those skills.

Since there are multiple neural areas involved in reading, it makes sense that many children with dyslexia require different types of treatments including regular classroom reading instruction, embedded phonics training, text reading and writing instruction, and explicit, sequential direct teaching of phonemic awareness (Alexander & Slinger-Constant, 2004). The purpose of this study was to investigate the value added of implementing specific priming treatments for students with dyslexia, who were also receiving the LIPS® treatment. Specifically, this study investigated the effect of word and picture priming on the reaction times of word recognition tasks for five children and adolescents with dyslexia.

Research Questions

The following research questions will be addressed in this study:

Q1 For individual school-aged children and adolescents with dyslexia, do word recognition reaction times decrease when primed with related pictures?

Q2 For individual school-aged children and adolescents with dyslexia, do word recognition reaction times decrease when primed with phonologically similar words?

Q3 For each individual student, do word recognition reaction times decrease more when primed with pictures or words?

Definitions of Terms

Dyslexia. A neurodevelopmental disorder with a probable genetic basis. The core feature of dyslexia is a problem with word decoding, which in turn impacts spelling performance and the development of reading fluency.

Mental processing speed. One of the measures of cognitive efficiency. It involves the ability to automatically and fluently perform relatively easy or over-learned cognitive tasks, especially when high mental efficiency is required. That is, for simple

tasks requiring attention and focused concentration. It relates to the ability to process information automatically and therefore speedily, without intentional thinking through.

Morphological systems. The form or structure of morphemes, the smallest units of a language that have meaning, along with other linguistic units, such as root words, affixes, parts of speech, intonation/stress, or implied context.

Orthographic systems. Visual perception necessary to deal with the form of letters and the spelling patterns within words.

Phonological systems. The detection and manipulation of sounds of letters.

Semantics. The meaning of words or language.

Syntax. The grammatical structure of sentences.

Word priming. A reading intervention that involves numerous presentations of words that are phonologically or semantically related to a target word as a way to introduce the target word.

CHAPTER II

REVIEW OF THE LITERATURE

Children are born with a rich neural architecture in place to support the acquisition of oral language, which provides the foundation for written language. Certain brain areas are activated in response to the sounds and structure of language from infancy (Minagawa-Kawai et al., 2011). In sharp contrast, reading began so recently in the evolutionary history of our species that we have no innate biological processes devoted specifically to reading (Norton & Wolf, 2012). Each child must develop reading skills using brain structures that have evolved for other purposes, such as language, vision, and attention (Dehaene, 2009). In the foreword of her book entitled, *Why Our Children Can't Read and What We Can do About it: A Scientific Revolution in Reading*, McGuinness (1997) noted that children are born "wired" for language, "but print is an optional accessory that must be painstakingly bolted on" (pp. ix-x). The quest to further understand the reading process has fueled research over the past 50 years focused specifically on the skill of reading acquisition.

The understanding of early reading development has grown enormously over the last three decades. It has been more than a decade since the National Reading Panel (2000) established the five basic areas of reading as phonological awareness, the alphabetic principle, fluency, vocabulary, and comprehension. These five areas had long been recognized (Baker, Kameenui, Simmons, & Stahl, 1994), but it was not until this report

was published that the field of reading began to change. Since then, almost all research, reading programs, and reading intervention approaches are organized to address one or more of these basic components of reading (National Reading Panel, 2000).

Learning to read is a complex skill and for the most part, these discrete areas work together and build upon one another. Phonological awareness is defined as the ability to hear, identify, and manipulate phonemes (the smallest units of sound). The second principle, the alphabetic principle, or alphabetic understanding, is concerned with the mapping of print to speech and establishing a clear link between a letter and a sound, otherwise known as letter-sound correspondence. A beginning reader must come to know each letter as a discrete, self-contained visual pattern that can be printed or pointed to one by one (Adams, 1994). Phonological awareness and alphabetic understanding are used in concert to decode words, and these two concepts support growth in the ability to read text accurately (Share & Stanovich, 1995). The third foundational concept of reading is fluency, or automaticity with phonological/alphabetic code, otherwise known as the ability to translate letters-to-sounds-to words fluently (Baker et al., 1994). As reading abilities develop, each of these components work smoothly with both accuracy and speed; the reader develops what is called automaticity. As a cognitive process becomes automatic, it demands less conscious effort (Norton & Wolf, 2012). This combination of reading accuracy and speed is commonly known as reading fluency. The fourth and fifth "big ideas" of reading are vocabulary and reading comprehension.

These five foundational concepts work together to aid children in their reading efforts. As stated previously, phonological awareness and the alphabetic principle aid in decoding, while vocabulary and fluency aid in comprehension. In summary, the

connections between early growth of phonemic decoding skills and later development of reading fluency, as well as the relationships between fluency of reading text and growth of reading comprehension, have been firmly established (Ehri, 2002; Samuels & Farstrup, 2006). Of specific interest in this study are the constructs of word recognition and reading fluency because these two aspects of reading represent foundational skills that are critical to an individual becoming an efficient reader.

The History of Reading Fluency and Word Recognition Research

The research regarding reading fluency has waxed and waned over the years, with many years of intense focus followed by years of a dearth of research when the topic seems to be overlooked. An historical review of reading fluency starts in the early 1900s with William Cattell and Sir Edmond Huey. Cattell found that letters and words were named faster than other symbolic categories, such as colors, or semantic categories, such as pictured objects. He wrote about automatic-like rates of recognition achieved in letter naming and word reading, with words read as fast as letters and that reading speed increased when semantic (the meaning in language) and syntactic (grammatical structure) information were provided, as they are in sentences (as cited inWolf & Katzir-Cohen, 2001). Huey referred to the concept of automaticity when he described the development of fluent reading as involving the steady accumulation and synthesis of increasingly complex acts that were progressively welded together by practice (as cited in Wolf & Katzir-Cohen, 2001). Huey went on to explain the link between repetition and rate of processing by noting how it progressively freed the mind from attention to details, shortened the time, and decreased the mental work related to the process of reading (as cited in Wolf & Katzir-Cohen, 2001).

Over time, perspectives on reading began to align with more of an information-processing approach. LaBerge and Samuels (1974) proposed a model of automaticity, whereby reading became increasingly fluent as the result of the development of automaticity of subskills. Every language has frequently used spelling patterns or letter combinations and with sufficient exposure and practice, these patterns become quickly recognized. As noted in this model, word recognition and comprehension cannot be carried out simultaneously if the reader has to focus disproportionately on word recognition (LaBerge & Samuels, 1974).

Another highly influential contribution in the history of reading fluency research was the verbal efficiency theory proposed by Charles Perfetti. Perfetti (1985) worked within the information-processing model, and built upon Huey's work by explaining the "freeing" process. He thought that verbal fluency was related to the efficiency of local processes such as symbol activation and retrieval, recognition processes, lexical access and retrieval, and working memory. When the underlying systems were efficient, the individual was considered able to free cognitive resources to focus on higher-level demands in reading, which was important for comprehension. He also believed that the opposite was true; that an inefficient system resulting in a slow rate of word recognition could obstruct the individual's ability to hold large units of text in working memory, which, in turn would affect comprehension and recall (Perfetti, 1985). Perfetti used knowledge about retrieval and all components in verbal efficiency theory as ways to clarify individual differences in reading comprehension. Perfetti's work provided a figure-ground perspective from which to view fluency as a means to reading

comprehension (as cited in Wolf & Katzir-Cohen, 2001). Said in another way, the underlying systems and higher-level systems are integral to one another.

The most recent theories of reading espouse a more multicomponent view of reading fluency. For example, Berninger et al. (2001) promote a multidimensional theory with a systems approach to fluency that is widely used today. They found three factors that affect fluency. The first is the characteristics of the stimulus input, such as rate and persistence of a visual or speech signal. The second factor is the efficiency and automaticity of internal processes or systems, such as the development of phonological (e.g. the detection and manipulation of sounds of letters), orthographic (e.g. visual perception necessary to deal with the form of letters and the spelling patterns within words), and morphological (e.g. structure of language) systems. The third factor is the coordination of responses by the executive functions (e.g. attention, planning, memory). From this view, it has been posited that effortless and automatic recognition of letters, letter patterns, and whole words is a critical factor in the development of fluent reading.

This theory of reading fluency has important implications for teaching children to read with fluency. Berninger et al. (2001) described a step-by-step approach that begins with a child learning that each letter represents a sound, in a process aided by knowledge of letter names. When the child knows the letter names and is able to retrieve them quickly, then more attention can be devoted to letter sequences. This enables the child to build up an orthographic pattern. When this pattern is further associated with a sound, then a phonological-orthographic connection is constructed, enabling the child to further recognize and remember words. Thus, rapid processing at each level is what enables the child to progress to the level of rapid word recognition. Conversely, a disability in word

reading may result from a failure of the orthographic or the phonological code to develop, as well as from a failure of the codes to connect or to do so in the correct sequence (Berninger et al., 2001).

In summary, reading fluency is a combination of lower level attention and visual perception, orthographic (letter-pattern) representation and identification, auditory perception, phonological representation and phonemic awareness, short-term and long-term memory, lexical access and retrieval, semantic representation, decoding and word recognition, and connected-text knowledge and comprehension (Berninger et al., 2001).

This investigation focuses on one aspect of reading fluency, that of word recognition, because the ability to recognize words is the major determinant of reading fluency, and overall reading ability, in the early grades (Stanovich, 1991). In fact, in the first volume of *Handbook of Reading Research*, Gough (1984) stated that "Word recognition is the foundation of the reading process" (p. 225). While there is much more to reading than word recognition, readers must be able to identify words before being able to attach any meaning to them (Gough, 1984).

While researchers believe the extent of specific processes involved in word recognition are different, they all agree that the ability to recognize words utilizes visual perception, phonological and orthographic abilities, as well as working memory and long term memory working in concert (Stanovich, 2000). In other words, it is widely believed that the ability to recognize a word comes from the reader's ability to make sense of the letter shapes, the sounds of those letters, and the meaning of the word. The sounds of the letters serve as an access code to working memory allowing the reader to integrate text processes that in turn, construct meaning. If word recognition processes do not quickly

activate and produce a phonological representation of sufficient quality to sustain the word in working memory, then the reader does not have the raw materials to comprehend efficiently and understanding of the text will be impaired (Stanovich, 2000).

The hierarchical structure whereby the meanings of words are activated by the successful recognition of them are the building blocks for subsequent comprehension processes. To this end, efficient word recognition seems to be a necessary but not sufficient condition for good comprehension.

Mental Processing Speed and Word Recognition Abilities

The ability to read employs many neurological processes such as working memory, attention, and mental processing speed. Of these different brain processes, mental processing speed, might be considered one of the foundational skills to reading fluency. Mental processing speed, defined as the ability to automatically and fluently perform relatively easy or over-learned cognitive tasks, develops and changes throughout the lifespan. It is known to increase rapidly in childhood, more slowly in early adolescence, reaches mature levels in mid-adolescence, and slows for older adults. As children mature, age-related faster processing speed resulted in improved memory, which linked to higher fluid performance (Kail, 1991). Fry and Hale (1996) described a "cognitive developmental cascade" or a sequence of processing stages within which the effectiveness of processing at the first stage has a flow-on effect for the next stage, which influences the next stage. They have found causal relations between increasing chronological age, processing speed, working memory, and fluid reasoning, by cross-sectional comparisons across youth ages 7 to19. Subsequent findings in developmental studies of speed and working memory continue to support the relationship among age,

speed, working memory, and fluid intelligence in children and adolescents (Fry & Hale, 1996).

There are two general theories regarding the specificity of mental processing speed and though they differ somewhat, there is support for both theories. Some researchers believe that processing speed is highly domain specific, meaning processing speed during a language task is independent from processing speed for a cognitive or motor task (Pinker, 1994). For example, the speed of perceptual processes might develop at a common constant rate that differs from the rate with which speed of cognitive processes develop. For instance, in a study of the development of mental processing speed, Kail (2006) found that among a group of 116 children ages 9-14, developmental change in processing speed was greater on nonlanguage tasks than on language tasks. He also found that language processing speed was faster than global processing speed at age 9, but not at age 14. Other studies have found support for a more global nature of processing speed (Peter et al., 2011). In a factor-analytic study comparing processing speed, working memory, verbal reasoning, language processes, executive function, and motor processing in individuals with low and typical reading ability, Peter et al. (2011) found that processing speed formed the first factor amongst all groups, meaning that slowed processing speed was the most common factor among individuals in the study. While there is support for both domain-specific and a more global nature of mental processing speed, it can be agreed that mental processing speed is used during the reading process, and that it likely affects reading fluency.

Mental Processing Speed and Reading Difficulties

Deficits in mental processing speed appear to play an important role in reading disabilities. For instance, in a study of processing speed and reading achievement, poor readers were proportionally slower than good readers across response time measures and on a rapid object-naming task suggesting a general deficit in speed of processing (Catts et al., 2002). Additionally, individuals with a reading disability and Attention Deficit/Hyperactivity Disorder (ADHD) were found to have processing speed deficits, although participants with a reading disorder demonstrated a greater processing speed deficit (Shanahan et al., 2006). These studies support the idea that processing speed may be one of the factors involved in the development of reading disabilities. Yet there may be differences in those individuals with reading disabilities in general, and those with dyslexia specifically.

When considering the connection of mental processing speed and dyslexia, research has pointed to the association between rapid automatized naming (RAN) and reading fluency. Specifically, many individuals with dyslexia have problems with rapid naming of letters, objects, numbers, and colors (Denckla, 1972; Denckla & Cutting, 1999; Denckla & Rudel, 1974; Ransby & Swanson, 2003; Wolf & Bowers, 1999; Wolf, Bowers, & Biddle, 2000). Denckla has explored the relationship between naming and reading. In the early 1970s, Denckla (1972) identified five boys who were slow and inconsistent in serial color naming for their age, despite typical intelligence and color vision (as cited in Norton & Wolf, 2012). Along with Rudel, Denckla created a speeded serial naming test, using objects, letters, and numbers as stimuli and used the term “rapid automatized naming” to describe these tasks (Denckla & Rudel, 1976). On the rapid

automatized naming task (RAN), Denckla and colleagues (1972, 1974) found that the speed at which participants could name information was correlated with their reading performance. Specifically, they found that children with dyslexia were more than one standard deviation below expected kindergarten norms on RAN colors.

The connection between RAN speed and reading performance has been replicated many times. For instance, in a study of 20 first grade children with dyslexia, Berninger, Abbott, Greep, and Reed (1997) found that 75% of these children had a RAN deficit, and 50% of them had a double-deficit in RAN and orthographic coding. In a study of 32 children in grades 1-6 with dyslexia, Raskind, Hsu, Berninger, Thomson, and Wijsman (2000) found that all the children had a RAN deficit, and none had a pure phonological deficit in phoneme segmentation. Thus, although difficulty in phoneme segmentation is an important factor in reading deficits, the speed at which the individual identifies and integrates stimuli also plays an important role.

A comprehensive review of the rapid naming literature concluded that deficits in automaticity of rapid serial naming and fluency measures are common among children with dyslexia (Savage, 2004). In fact, Tan, Spinks, Eden, Perfetti, and Siok (2005) described RAN as one of the universal processes that predict a young child's later ability to connect and automatize whole sequences of letters and words. They consider the ability to automate both the individual linguistic and perceptual components and the connections among them in visually presented serial tasks to be the major reason why RAN consistently predicts later reading (Tan et al., 2005).

In summary, over 40 years of studies have illustrated the connection between the ability of young children to quickly identify letters and numbers as a predictor of later

reading ability. A more in-depth review of dyslexia is provided to further highlight the specific deficits associated with this disability.

Understanding Dyslexia

The original theory regarding the cause of dyslexia was that visual deficits lay at the basis for the disorder. In fact, the term dyslexia means "word blindness" (Orton, 1925, p. 582). This idea was reinforced by the suggestion that dyslexic children saw letters and words as reversed (Orton, 1925). Orton made several important observations that influence the understanding and treatment of dyslexia. He noted that many of these struggling readers had average or above-average intellectual abilities and that symptoms of dyslexia were not likely due to a single brain abnormality (Orton, 1939). The next major development in the understanding of the core deficits in dyslexia revolved around both rapid automatized naming and phonological awareness.

In the 1960s, neurologist Norman Geschwind emphasized the importance of connectivity among brain regions, particularly "association areas," such as the angular gyrus, which acts as a switchboard or relay station for different brain regions (as cited in Norton & Wolf, 2012). Similar to earlier research by Cattell and Huey, Geschwind was interested in the laborious effort required for some of his patients to verbalize the names of colors, even though they could perceive color, and he devised a timed test of color naming (Geschwind & Fusillo, 1966). It was proposed that the deficit in color naming might be due to deficiency of the visual-auditory pathways of the brain and although it was not directly related to reading, color naming represented the neural processes that might be similar to those involved in reading (Geschwind & Fusillo, 1966). Geschwind was forward thinking in his belief that dyslexia might be due to a deeper, more abstract

ability, rather than being solely connected to visual processes (as cited in Norton & Wolf, 2012).

Later theories regarding deficits of dyslexia focused on the area of phonological processing, which involves the ability to identify and manipulate the sound components of words. Liberman (1971) speculated that reading depended on an explicit awareness of the sounds of language and that perhaps the greatest challenge facing young readers was learning to match the phonemes (sound units) of speech with the graphemes that represent them in print. This work was extended to show that children with dyslexia had trouble with phonological awareness. For instance, in a study of 60 children with dyslexia (of normal intelligence but 18 months or more behind average **reading** skill for their age) and 30 typical readers, it was found that **difficulties** in grouping words that were different but had shared sounds (e.g., rhyming words) may be a **symptom** of **reading** failure (Bradley & Bryant, 1978; Wagner & Torgesen, 1987). More recent research with 16 university students with dyslexia indicated a similar phonologic deficit (Ramus et al., 2003). Using an extensive battery of cognitive, motor control, auditory, and visual tests, Ramus et al. (2003) found that some of the students with dyslexia performed more poorly on auditory tasks, some on visual tests, and others on the motor control tests as compared to the control group. The only component that was present in all of the students with dyslexia was a phonologic deficit, and it was determined to be a sufficient cause of dyslexia (Ramus et al., 2003).

More recent work calls into question whether a phonological deficit is the single and universal cause of dyslexia. Capitalizing on the explosion of brain research from the 1990s, a more multicomponent conceptualization of reading has been examined. For

instance, Wolf and Bowers (1999) studied large groups of children identified with dyslexia in the United States and Canada. They found that phonological awareness and RAN contributed separately to reading ability. They proposed a "double deficit" hypothesis as a way to show how children can be characterized in various subgroups according to their performance on each set of processes (i.e., RAN and phonological processes). They found that some individuals with dyslexia had a deficit in phonologic awareness, while others had a rapid naming deficit that resulted in the disruption in the linkage between phonologic and orthographic information. This linking requires precise timing and, as stated previously, bears a specific relationship to reading fluency. A third group had both phonologic coding deficits and rapid naming deficits, referred to as having a double-deficit. This group with a double deficit was more impaired than those with a single deficit area (Wolf & Bowers, 1999).

Recent studies paint an even more nuanced picture. Pennington et al. (2012) investigated a single versus multiple deficit model of dyslexia in a study including 809 children with dyslexia from two large population-based samples from the United States, Australia, and Norway. Using a nested research design, the researchers considered five cognitive models of dyslexia; two single-deficit models, two multiple-deficit models, and one hybrid model. The first single-deficit model specifically included a phonological deficit; while a second single-deficit subtype included other deficits such as processing speed, naming speed, or language skill. The third model, one of the multiple deficit models, assumed a single phonological deficit was necessary but not sufficient to produce dyslexia, and therefore included a phonological core, along with at least one of the above-mentioned deficits (i.e. processing speed, naming speed, or language skill). A fourth

model was based on the assumption that two deficits were needed, and therefore included any two of the above-mentioned deficits (i.e. processing speed, naming speed, or language skill), but did not include a phonological deficit. The last cognitive grouping was a hybrid model, illustrating equifinality, where there were multiple possible pathways to dyslexia, some involving a single-deficit and some involving multiple deficits. In other words, this fifth model suggested that dyslexia was due to a combination of the models: a phonological deficit only; a single processing speed, naming speed, or language skill deficit; a phonological core plus either processing speed, naming speed or language skill deficit; or any two of the processing speed, naming speed or language skill deficits.

Results from the regression analysis rejected the single-deficit models. In fact, the hybrid model had the most support, with 46% of the entire sample fitting this model. From the Wolf and Bowers (1999), and Pennington et al. (2012) studies, it is evident that either a phonological deficit or fluency factors, such as processing speed and naming speed, or both, are likely deficit areas for many children with dyslexia. These most recent comprehensive studies appear to support a multicomponent view of the potential deficits involved in dyslexia.

Contributions of Neuroscience to Understanding Word Recognition and Dyslexia

Neuroimaging studies, and particularly the fMRI, are experimental tools that have helped advance the understanding of reading disabilities in the past 20 years. Historically, researchers were not able to fully appreciate the inner working of the brain, and had to use behavioral indicators to make hypotheses about brain processes. With the

development of advanced scanning technologies, researchers are beginning to have a more comprehensive understanding, as they can now see which areas of the brain may be activated, as well as the behavioral manifestation. It appears that these underlying neuroscience findings may help explain behavioral symptoms. When coupling these images with behavioral indicators, an increased understanding of both typical and atypical functioning may be available. To better illustrate how brain functions are different between the two groups of readers the following section provides a very brief overview of brain function during reading for typical readers, and those with dyslexia (for a more detailed description, see (Christodoulou et al., 2011; Maisog, Einbinder, Flowers, Turkeltaub, & Eden, 2008).

In a meta-analysis of functional neuroimaging studies of individuals with dyslexia, Maisog et al. (2008) concluded that reading-related tasks may occur in three main areas of the left hemisphere: the inferior frontal gyrus (IFG), temporoparietal area, and occipitotemporal area. The IFG has been implicated in a wide variety of reading and language-related functions, from semantic search to working memory. The temporoparietal aspect of the reading circuit includes regions called the "association area" that are responsible for the integration of information across visual and auditory modalities. The occipitotemporal region is used for orthographic processing. Generally speaking, the most consistent finding is that individuals with dyslexia seem to underutilize their left temporoparietal and left occipitotemporal areas as compared to those without dyslexia (Maisog et al., 2008). While these areas of the reading circuit show reduced activation in individuals with dyslexia, the right frontal and temporal lobes

showed greater activation. The alternative patterns of brain activation are thought to represent compensatory mechanisms or effortful processing (Hoeft et al., 2007).

Recent research has provided some support for these findings, and also offered insight into the neurological basis of RAN tasks in typical readers and those with dyslexia. Misra, Katzir, Wolf, and Poldrack (2004) and Christodoulou et al. (2011) asked adult participants to name stimuli on a screen during fMRI scanning. As seen in Figure 1a, the findings of both studies indicated that the RAN task appeared to engage the left IFG, left posterior middle frontal gyrus, and bilateral inferior occipital areas in typical readers.

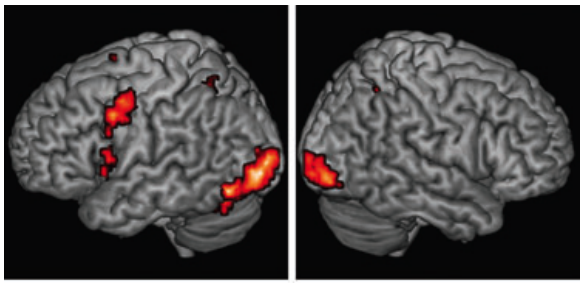

Figure 1. fMRI brain activations for a Rapid Automatized Naming (RAN) letters task from Christodoulou et al. (2011). (**a**)Whole-brain activations for RAN letters > visual fixation. N = 18 typical adults. Activations significant at height threshold of **p** < 0.05, FWE (family-wise error) corrected, k > 10 voxels.

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As seen in Figures 1 and 2, Christodoulou et al. (2011) compared RAN performance of age and ability matched typical adult readers and adults with dyslexia and found that typical controls used several posterior areas in the occipital and parietal regions bilaterally (shown in red) more so than did the group with dyslexia. Adults with dyslexia (shown in blue) showed greater activity than did controls in a variety of bilateral

temporal, motor, and left supramarginal gyrus (part of the temporoparietal area). These results suggest that readers with dyslexia may employ a more distributed network that may represent compensatory mechanisms for performing RAN tasks (as cited in Norton & Wolf, 2012). Said another way, the distributed network that readers with dyslexia may employ may represent a less efficient route than the more straightforward route used by readers without dyslexia. These studies provide vivid illustration showing the different parts of the brain utilized during RAN tasks of typical readers and those with dyslexia.

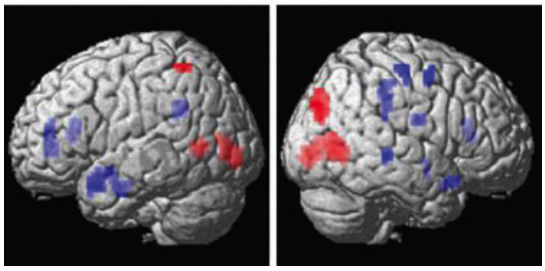

Figure 2. Whole brain differences for Rapid Automatized Naming (RAN) letters > visual fixation in typical adult readers (N = 9) versus adults with dyslexia (N = 9). Activations significant at height threshold of **p** < 0.05, FDR (false discovery rate) corrected, k > 10 voxels.

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Neuroscience has made an additional contribution to the study of dyslexia, providing information regarding the visual word form area (VWFA), an area of the brain theorized to be associated with dyslexia. The visual word form area is located in the anterior lateral occipitotemporal system, and recent research supports the notion that, in typical readers, it is potentially associated with the ability to read words fluently, the hallmark of a skilled reader (Cohen et al., 2000; Dehaene, Cohen, Sigman, & Vinckier, 2005; Dehaene et al., 2001; McCandliss, Cohen, & Dehaene, 2003).

Earlier research pointed to the existence of the VWFA, for instance Warrington and Shallice (1980) found support for the existence of a visual word-form system "which parses letter strings into ordered familiar units and categorizes these units visually" (p. 110). During the following decades, advances in neuroimaging provided convincing evidence that regions within ventral occipital-temporal cortex are part of the network for skilled reading (Cohen et al., 2000; Dehaene et al., 2005; Dehaene et al., 2001). Yet the specific functional role of the VWFA within the word-form system, specifically how it communicates with other brain areas has been debated. A review of the literature suggests that the VWFA performs computations that are unique to reading and cannot be reduced to generic visual recognition processes (Dehaene & Cohen, 2011). Other researchers have found that the VWFA distinguishes between words and their mirror images, an indispensable feature given the presence of mirror letters such as b and d in Latin-based alphabets (Dehaene & Cohen, 2011; Pegado, Nakamura, Cohen, & Dehaene, 2011).

In their work, Makuuchi and Friederici (2013) highlighted how the arcuate fasciculus (AF) plays a central role in language processing. The AF is the white matter fiber bundle in the brain connecting Broca's area, which is responsible for speech production, to Wernicke's area, which is responsible for comprehension of language. They found a clear hierarchical relationship between the visual system (VWFA), the working memory system, and the core language system (connected by the AF). Specifically, during sentence reading, information is first conveyed from the visual system to the working memory system, before effectively connecting to the language system (Makuuchi & Friederici, 2013).

Yet the connection between the VWFA and the language areas does not present as functioning in this way for people with dyslexia. A group of researchers in Switzerland found that readers with dyslexia have a significant disruption of functional connectivity between the VWFA and the left inferior frontal and left inferior parietal language area (van der Mark et al., 2011). Specifically, van der Mark et al. (2011) found reduced functional connectivity exists during reading acquisition in children with dyslexia that was linked to a specific left occipitotemporal region critical for visual word processing, the VWFA (van der Mark et al., 2011). While not the focus of their research, this lack of direct connectivity may result in the distributed network that readers with dyslexia used during RAN tasks as discussed above. Additionally, Figures 1a and 1b showing a more distributed network used during RAN tasks may illustrate the processing speed deficits to which van der Mark et al. (2011) and others have referred when discussing a multicomponent or double deficit hypothesis (phonological and RAN deficits) involved in dyslexia. If readers with dyslexia use a more distributed yet inefficient route during reading tasks, it makes intuitive sense that their processing speed could be negatively affected.

In summary, neuroimaging has provided us with an illustration of how different parts of the brain may be employed during reading tasks of typical readers and those with dyslexia. While it is not possible to know exactly why individuals with dyslexia have slower processing speed, it seems reasonable that the specific differences in brain activity between typical readers and those with dyslexia account for some of the difficulties with phonological processing and processing speed. It appears that direct connectivity between areas of the brain that are responsible for efficient reading may be compromised

for readers with dyslexia, requiring them to use less efficient compensatory measures in order to read. Therefore, a potential intervention for improving efficiency might focus on helping readers access a stimulus word more quickly by using a strategy called priming.

Methods of Word Recognition Priming Interventions in Children with Dyslexia

Various models have been proposed to assist young readers in their ability to recognize words. Some models involve different types of words in priming, or repeated reading activities, while others discuss priming with pictures and words. In an attempt to explain the relationship between picture and word naming, Biggs and Marmurek (1990) conceptualized a Processing Overlap model in which it was predicted that facilitation in naming the second of two items is a function of the overlap in processing accorded to the prime and the targets. They assumed that printed words were processed by a phonetic system that was rule-governed and separate from a general semantic system. The general semantic system includes semantic processing of words, referring to the processes of encoding the meaning of a word and relating it to similar words with similar meaning. Semantic processing of words follows from activation of the phonetic system. Unlike printed words, pictures representing objects have direct access to the semantic system (Biggs & Marmurek, 1990).

The concept was demonstrated in a study of 32 university students with typical reading abilities, in which picture naming was facilitated by prior naming of an identical, synonymous, or related picture, and by prior naming of a synonymous word. Word naming was only facilitated by the prior naming of an identical word (Biggs & Marmurek, 1990). An interesting finding of this study was that words facilitated picture naming but pictures did not facilitate word naming in support of a core assumption of this

model that picture naming follows access to semantic memory whereas word naming does not. Word naming benefits from prior naming to the extent that previous characteristics of the prime word are repeated. For instance, it could be beneficial to prime the word *pan* with the word *man,* where only the initial consonant changes. Picture naming is facilitated not only by the physical aspects of the stimuli and response, but also by the semantic relationships between successive items (Biggs & Marmurek, 1990). While this study is interesting in showing the overlap between prime and target words, it was completed with adult typical readers who were not struggling with the decoding process. Subsequent studies that have included children with dyslexia have yielded different results.

Assink, Soeteman, and Knuijt (1999) studied a group of 21 10-12-year old Dutch children with dyslexia by having them perform a word naming task under three priming conditions: repeated prime, related prime (same semantic category), and unrelated prime (different semantic category). Results suggested that differences between picture and word naming were not due to the overlap in processing, as in the Processing Overlap model. In contrast, this study showed an absence of priming effect for semantically related items, and that for readers with dyslexia, two independent sources of verbal skill seemed to contribute to poor reading. One source was associated with phonological coding, the other with semantic coding. The positive correlation of vocabulary and real word decoding, on the one hand, and the absence of correlation with picture naming, on the other, suggested that phonological and semantic coding were two relatively independent sources of reading problems (Assink et al., 1999). It is unknown whether

this difference was related to the age of the participants or whether the model could not be replicated.

A second model of word priming in people with dyslexia is called the dual-coding model (Paivio, 1991). Researchers using this model compared different types of words rather than pictures and words. Supporters of this model hypothesize that the critical difference between abstract and concrete words is that concrete items are represented in both imagery and linguistic codes, whereas abstract items are only coded linguistically (Paivio, 1991). More recently, this dual-coding model was demonstrated in a study of an adult with developmental dyslexia with very poor word reading skills (Crutch & Warrington, 2007). This adult performed semantic word-priming tasks, reading word lists containing concrete and abstract words which were related by semantic similarity (same category), semantic association (sharing a unitary, cohesive context), or no semantic relationship. Although very limited in scope, this study provided evidence of semantic priming in the reading of similar concrete words and associated abstract words. When concrete words were read, words that were semantically similar were read more quickly and accurately than unrelated words, but the priming showed no such advantage for semantically associated words. In contrast, when abstract words were read, words that were semantically associated were read quicker and more accurately, but there was no evidence of priming for semantically similar abstract words. From this observation it was surmised that priming abstract words with semantically associated words (e.g., witch/spell) is most beneficial, while priming concrete words with semantically similar words (e.g., tiger/lion) is most helpful (Crutch & Warrington, 2007). Consequently, it appears that conceptual knowledge of concrete terms is supported by a representational

framework based on a principle of semantic similarity, whereas knowledge of abstract terms is better supported by a representational framework based on the principle of semantic association (Crutch & Warrington, 2007). It is not known if a similar pattern would be present in younger populations.

Plaut et al. (1996) suggested a third model for understanding the effect of priming. The Triangle Model explained earlier describes word recognition as dependent on three separate abilities: phonological representation, orthographic representation, and semantics, which is similar to and reflects the multicomponent view of reading fluency consistent with the perspective of Berninger et al., 2001. This connectionist approach explains that the reading system gradually becomes sensitive to the structure among orthographic, phonological, and semantic representations (Plaut et al., 1996). Plaut et al. (1996) conceptualized this relationship as a division of labor between the phonological and semantic pathways such that neither pathway alone was completely sufficient and the two had to work together to support skilled word and nonword reading.

In summary, these three models provide different mechanisms or models to describe how the brain recognizes words. Supporters of the Processing Overlap Model conceptualize the phonetic system as separate from the semantic system. Supporters of the Dual-coding Model purport both imagery and linguistic codes, where abstract words are primed better by semantic association, while concrete words are primed by semantic similarity. While different types of words are primed differently, they both use the semantic pathway. Supporters of the third model, the Triangle Model, believe that word recognition is dependent on three separate abilities that work in concert, the phonological, orthographic, and semantic pathways. While these models differ in specifics, they all

agree that the semantic pathway contributes to word recognition. Most recent research regarding dyslexia and related interventions has supported the multicomponent view of the Triangle Model (Plaut et al., 1996).

If the semantic pathway is a significant contributor to word recognition, as described in each of these models, it would seem that deficits in semantics likely contribute to word decoding problems in children with dyslexia. Conversely, children with reading disabilities may use semantics to help them decode words since they cannot rely on their phonological skills alone. In support of this idea, Betjemann and Keenan (2008) recruited a sample of 280 twins with dyslexia and their siblings, ages 8-18, to perform visual and auditory word decision tasks. They found that children with dyslexia were found to have deficits in semantic (i.e. ship/boat), phonological/graphemic (i.e. goat/boat) and combined (i.e. float/boat) priming in both visual and auditory tasks. This finding suggested that the semantic deficits were not confined to reading. Children with dyslexia also showed less priming than reading-age matched controls, suggesting that their priming deficits are not simply due to lower reading level but are due to the reading disability in particular (Betjemann & Keenan, 2008).

Other researchers have found the activation of the semantic pathway to be helpful in the decoding efforts of struggling readers. Recalling the division of labor between the phonological and semantic pathways of the Triangle Model, it is known that this division exists in normal skilled reading (Plaut et al., 1996). For most words, activation spreads rapidly along the phonological pathway leaving little time for the semantic pathway to exert an influence on phonological output. However, the semantic pathway may compensate the phonological pathway when reading words with less familiar and atypical

spelling to sound associations (Plaut et al., 1996). Previous studies have shown that semantic variables, such as word imageability (how easily an image of the word can be recalled) can affect the naming of low-frequency exception words (i.e. boulder, comb) but not high-frequency exception words (i.e. steak, watch) or regular words (i.e. bill, black). It is thought that the orthographic to phonological link (the process that maps the written word to its corresponding sounds) is already established in the high-frequency words, so a semantic link is not necessary. In other words, it is proposed that semantics can influence spelling to sound translation in typical readers when the connection between orthography and phonology is likely to be less efficient. Consequently, if the semantic pathway is used more when the orthography to phonology pathway is less efficient in typical readers, what does that mean for those with dyslexia?

To examine the effects of priming on children with dyslexia, Hennessey et al. (2012) researched the semantic effects on word/picture priming on 60 children with dyslexia. They hypothesized that readers with dyslexia would show enhanced semantic effects when translating from orthography to phonology during rapid word naming (Hennessey et al., 2012). They tested one- and two-syllable words under three priming conditions: same-modality priming, different-modality priming, and unprimed. They found that readers with dyslexia showed a large same-modality priming effect for words and pictures, and a significant priming effect of picture naming from naming the corresponding word in the priming phase. Picture to word naming was faster than the unprimed condition by 78 milliseconds, but it was not significant for children with dyslexia. Yet they did find significance for reading age-matched controls. Overall, the priming effects were similar for the readers with dyslexia and reading age-matched

controls. These results suggest that younger and less-skilled readers are slower at decoding and show enhanced effects of semantics, compared with older readers, whose decoding skills are relatively efficient and provide less opportunity for indirect activation flow via semantics. These findings also suggest that compensation provided by the semantic pathway for the readers with dyslexia was associated with the presence of a phonological deficit (Hennessey et al., 2012).

The presence of word-to-picture priming reflects the activation of phonological codes for speech production via semantics on word naming, confirming a bias towards the semantic pathway during word naming for readers with dyslexia (Hennessey et al., 2012). This finding is consistent with the proposition that the semantic pathway can compensate direct orthography-to-phonology translation when that process is slow and inefficient (Hennessey et al., 2012). Therefore, it seems reasonable that strategies for enhancing the speed at which dyslexic readers access this semantic pathway may represent a promising intervention. Given the complex nature of dyslexia, it is not the only approach that would be used, but may serve as a helpful supplemental strategy to increase the speed at which dyslexic readers recognize individual words.

Summary

Learning to read is a pivotal skill for school-aged children. Research has informed our knowledge of the steps involved in the reading acquisition process. The central role mental processing speed and word recognition play in reading fluency is well researched, although there continues to be some conjecture on the exact mechanism for how these constructs impact reading. Theories that endorse the presence of multicomponent deficits provide the best explanation for the brain connectivity

challenges experienced by those with dyslexia who struggle to learn to read. Word and picture priming have been introduced as a potential avenue to help struggling readers learn to recognize words in a more fluent manner. Three models of word and picture priming were reviewed that discuss different mechanisms the brain uses to recognize words. While these models differ in specifics, proponents of all agree that the semantic pathway contributes to word recognition. While the semantic pathway is potentially beneficial for struggling readers in general, there is no research to date that has been found where word priming was used in addition to phonologically-based treatments for dyslexia to enhance fluid word recognition. As many children with dyslexia receive multiple treatments, this investigation is thought to resemble more realistic situations than when interventions are carried out in isolation.

CHAPTER III

METHODOLOGY

Research Design

This study used a multiple-case multiple treatment reversal design in order to document the functional relationships between the independent and dependent variables. Single-subject research employs within- and between-subject comparisons to control for major threats to internal validity and requires systemic replication to enhance external validity (Martella, Nelson, & Marchand-Martella, 1999). Each participant served as his or her own control. Performance prior to intervention was compared to performance during and after intervention.

For this study, the dependent variable of interest was the reaction time to word recognition tasks. For increased experimental control, a dependent variable that was not expected to change (i.e., processing speed) was measured. The independent variables were the time it took to read individual words under word priming and picture priming conditions.

Single-subject research designs typically compare the effects of an intervention with performance during a baseline, and/or comparison condition. An experimental effect is demonstrated when predicted change in the dependent variable covaries with manipulation of the independent variable (Horner et al., 2005). While multiple-case research is not generalizable across populations because one study cannot represent a

particular group, case studies represent an achievable means by which practitioners can evaluate their interventions without the need to recruit large groups of participants and control groups (Horner et al., 2005). The multiple treatment reversal design of this study included a five-phase design. As part of this reversal design, a decision rule was included stipulating that any intervention that appeared to be working would be repeated.

All participants began with an unprimed baseline phase, and continued with both picture and word priming phases. When a treatment appeared to be helpful, a baseline phase was reiterated to attempt to determine a functional relationship. The last phase was a repeat of the treatment that appeared to be most helpful to the participant.

Threats to internal validity included maturational influences. The threat of maturation increases with the length of intervention. Since each phase of intervention is only five days, the threat of maturation effects is lessened. Additionally, the repeated baseline measurement counteracted the threat of maturation since it happened later in time than the first baseline measurement. The inclusion of a dependent variable not expected to change also helped identify whether maturational effects were occurring.

Participants

Purposeful sampling was used in this multiple case study. With parental permission, five students ages 7:8 to 16:5 who were receiving cognitive rehabilitation for reading difficulties at the *Western Institute for Neurodevelopmental Studies and Interventions* (*WINSi*) in Boulder, Colorado, were recruited to participate in this study. WINSi provides multidisciplinary diagnostic and treatment services to children and adolescents with learning disabilities, ADHD, and related behavioral disorders. Their staff includes a physician, neuropsychologists, speech/language pathologists, and

occupational therapists who specialize in providing individualized intensive treatment to students with dyslexia. The rehabilitation program is a 10-week, five hour a day, five day a week program that the child attends instead of going to his or her home school. At the end of the 10-week program, the child is re-evaluated, and a decision is made as to whether the child needs extended therapy, or the child can proceed into a follow-up program. The follow-up program is an afterschool program the child attends at WINSi for one to five days a week for approximately one year. WINSi typically serves five to seven students at a time.

There were five individuals at WINSi who met criteria to be included in this study. Participant demographics are provided in Table 1. All participants' names reflect pseudonyms to maintain participant confidentiality. All students were of upper/middle socioeconomic backgrounds.

To receive treatment at WINSi, students have typically received diagnoses of a language-based learning difficulty, such as dyslexia or receptive-expressive language disorder. All participants in this study, except Carol, had been identified as having co-morbid conditions with their reading disorders. For example, two participants (Jayla and Devon) had been diagnosed with ADHD. Both Jayla and Raymond had been identified as having mixed receptive-expressive language disorder. Skylar also was diagnosed with Tourette's syndrome. As children with dyslexia typically have impaired reading accuracy, exclusionary criteria for this study was any student who was classified as average or above in their oral reading.

Table 1

Participant Demographics

Student	Gender	Ethnicity	Age	WINSi Start Date	Grade Level[a]	Word Rec. Grade Level[b]	Word Rec. Adjusted Gr. Level[c]
Jayla	F	Afr. Amer.	7:8	09/12	K	1	1
Carol	F	Hispanic	8:7	09/13	2	2	2
Devon	M	Caucasian	10:8	01/14	4	3	3-4
Skylar	F	Caucasian	12:11	09/13	7	5	5-6
Raymond	M	Caucasian	16:5	09/13	10	10	10-12

[a]Grade Level pertains to the grade participants were enrolled in when they left their home school and entered WINSi.

[b]Word Recognition Grade Level pertains to the level of difficulty from which participant word lists were originally created.

[c]Word Recognition Adjusted Grade Level pertains to the level of difficulty from which participant word lists were adjusted with the help of student's therapist and the Speech Language Pathologist at WINSi.

Instrumentation

Two different sources of data were collected for this study. When a child arrives at WINSi, a number of measures are used to assess overall achievement, reading fluency, receptive vocabulary, expressive language, verbal fluency, memory, and executive function. The selected measures included in this study are presented below. The second source of data was collected using E-Prime software to measure response time for reading specific words presented with and without different types of priming stimuli (discussed in more detail in the Procedure section).

Reading Fluency Measure

Reading fluency was assessed using the Gray Oral Reading Test-Fifth Edition (GORT-5). The GORT-5, designed for ages 6-18, contains 16 developmentally

sequenced reading passages with five comprehension questions each. The number of stories a child reads is dependent on age and reading ability. The GORT-5 provides a Fluency Score derived by combining the reader's performance in Rate (time in seconds taken to read each passage) and Accuracy (number of deviations from print made in each passage). The Comprehension Score is the number of questions about the stories that the student answers correctly. The open-ended format to the questions ensures that the items are passage dependent. The Fluency Score and the Comprehension Score combine to obtain an Oral Reading Index (Hennessey et al.). The mean score is 100, and the standard deviation is 15. Scaled scores were used for individual subtests, and sum of scaled scores were used for the ORI. The GORT-5 was used specifically to assess changes in reading rate and accuracy pre and post-intervention. For this study, the ORI scores were used to ensure that all participants were reading below average at the beginning of the treatment and to gauge overall change in reading fluency.

The normative sample for the GORT-5 assessment was a stratified sample that incorporated race, gender, ethnicity, and geographic region. The sample included more than 2,556 students in 33 states between the ages of 6 and 23. The reliability estimates based on this sample were found to be high in the normative sample; all average internal consistency reliability estimates were .90 or above. The alternate forms reliability coefficients for the ORI exceeded .90 with the sample population. A test-retest study of the normative sample was conducted over a two-week timeframe with all ages for which the test can be administered. The average test-retest coefficient for the ORI score for different forms (i.e., Form A to B, Form B to A) was .85. Correlations of the GORT-5 scores with those of other well-known reading measures such as the Nelson-Denny

Reading Test, the Test of Silent Reading Efficiency and Comprehension, and the Test of Silent Word Reading Fluency are large or very large in magnitude. There is a moderate to large correlation between the GORT-5 scores and FSIQ scores on the WISC-IV (Wiederholt & Bryant, 2010).

Word Recognition Measures

Word recognition was measured using the following assessments: Test of Word Reading Efficiency (TOWRE), Sight Word Efficiency (SWE) subtest (Torgesen, Wagner, & Rashotte, 2012); and the Woodcock Johnson III Tests of Achievement, Letter-Word Identification subtest (Woodcock & Johnson, 1977).

The TOWRE Sight Word Efficiency subtest, designed for ages 6 – 24:11, measures an individual's ability to pronounce printed words. Specifically it assesses the number of real words that an individual can accurately identify within 45 seconds. The subtest has two alternate forms, A and B. The two forms are of equivalent difficulty with internal correlations between .91 and .97 for individual age groups between the ages of 7 to 16. All words are presented as vertical word lists. The SWE Word Cards have a total of 112 real words; eight practice items on one side and 104 progressively difficult words on the reverse. Subtest standard scores have a mean of 100 and a standard deviation of 15. For this study, standard scores were used to allow comparison to other standardized assessments.

The TOWRE was normed on over 1,500 individuals ranging in age from 6 to 24 years residing in 30 states. The sample characteristics were stratified by age and keyed to the demographic characteristics reported in the 1997 Statistical Abstract of the United States. For the Sight Word Efficiency subtest, content sampling, time sampling, and

scorer reliability exceeded .90. In terms of predictive validity, scores from the Sight Word Efficiency subtest correlated with the GORT-3 at .80 for Rate and Accuracy, and .75 for Comprehension.

Word recognition was also measured using the Letter-Word Identification subtest from the Woodcock Johnson III Tests of Achievement. The Letter-Word Recognition subtest consists of a word list containing 13 letters and 60 one- to six- syllable words. The words become more difficult as the selected words appear less and less frequently in written English. A standard score for this subtest was used. Letter-Word Identification has a median reliability of .91 in the age 5 to 19 range. The sample population consisted of 8,818 subjects; including 1,143 preschool subjects; 4,784 kindergarten to twelfth-grade subjects; 1,165 college and university subjects; and 1,843 adult subjects. Since word recognition is central to this study, it is thought that these two measures provided a more comprehensive view than if only one measure was given (Woodcock & Johnson, 1977).

Rapid Naming Measures

Rapid naming measures were assessed using the Comprehensive Test of Phonological Processing (CTOPP) (Wagner, Torgesen, & Rashotte, 1999). The CTOPP is designed for individuals from kindergarten through college, and it assesses phonological awareness, phonological memory, and rapid naming. Rapid naming of verbal material is a measure of the fluid access to verbal names, in isolation or as part of a series, and related efficiency in activating name codes from memory (Wagner et al., 1999).

The CTOPP subtests that were used for this study included Rapid Digit Naming, and Rapid Letter Naming. These three subtests each contain 72-items which measure the

speed with which an individual can name the numbers or letters, on two pages, each containing four rows and nine columns. The individual's score is derived from the total number of seconds taken to name all of the numbers, and all of the letters. Interpretation involves the conversion of raw scores into percentile ranks and standard scores. The mean scaled score for subtests is 10, the standard deviation is 3 for subtests; for composite scores the mean is 100, and the standard deviation is 15. The Rapid Naming Composite Score is derived from the scaled scores of two subtests (i.e., Rapid Digit Naming and Rapid Letter Naming).

The CTOPP was normed on over 1,600 individuals ranging in age from 5 through 24 and residing in 30 states. Over half of the norming sample came from children in elementary school (through grade five). The demographic characteristics of the normative sample are representative of the U.S. population as a whole with regard to gender, race, ethnicity, residence, family income, educational attainment of parents, and geographic regions. The sample characteristics were stratified by age and keyed to the demographic characteristics reported in the 1997 Statistical Abstract of the United States. Reliability of the CTOPP was investigated using estimates of content sampling, time sampling, and scorer differences. Most of the average internal consistency or alternate forms reliability coefficients (content sampling) exceed .80. The test/retest (time sampling) coefficients range from .70 to .92. The magnitude of the coefficients reported from all the reliability studies suggests that there is limited error in the CTOPP and that examiners can have confidence in the results (Wagner et al., 1999).

Mental Processing Speed Measures

Mental processing speed was assessed using the Processing Speed Index (PSI) from the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV) (Wechsler, 1992). PSI is comprised of two core subtests; Coding and Symbol Search. Coding measures the child's short-term memory, learning ability, visual perception, visual-motor coordination, visual scanning ability, cognitive flexibility, attention, and motivation (Naglieri & Goldstein, 2009). Symbol Search measures processing speed, short-term visual memory, visual-motor coordination, cognitive flexibility, visual discrimination, and concentration. The mean scaled score for each subtests is 10 with a standard deviation of 3; for composite scores, the mean is 100 and the standard deviation is 15. Among the norm group of 2,200 individuals between the ages of 6 and 16, the reliability of the Processing Speed composite score was .85. (Wechsler, 2003).

Procedure

Prior to the start of this investigation, approval was provided by the Institutional Review Board at The University of Northern Colorado for research with human subjects. A copy of the IRB is provided in Appendix C. A formal agreement from WINSi was obtained and submitted as part of the IRB process. Samples of the WINSI consent forms are provided in Appendices D-G. Parents of the participants were asked to provide their informed consent and students, their assent, prior to starting data collection. The sessions occurred on-site at WINSi five days per week at the end of the participants' day, typically around 2:30 p.m. As noted, all participants were receiving other services (i.e., *LIPS* program) as part of the program at WINSi. The researcher conducted all sessions. Sessions took place in a room set up for this study that contained a computer, desk, and

two chairs. Sessions lasted approximately five minutes in length, and there were five sessions per phase (i.e., baseline, word prime, picture prime). Consequently, each of the five students participated in 25 sessions throughout the five phases. Each student missed approximately two sessions throughout the study. Raymond missed a few additional sessions. Make-up sessions were then given, which extended the timeframe by approximately one and a half weeks. These sessions occurred during Fall 2013 - Spring 2014.

Testing was conducted on a Dell computer, with an i7 processor, running Windows XP. This computer also had E-Prime 2.0, as well as Excel 2010. Test trials began with five white asterisks pasted centrally onto a black screen for two seconds to serve as a fixation point. The asterisks were then replaced by a picture or word prime, also pasted centrally, which remained on the screen until the child read the word or named the picture. When the child responded, the researcher pressed a specific button on the computer, triggering the reaction time to be figured in E-Prime. For example, the researcher pressed a '1' on the computer if the child named the picture or read the word correctly, and clicked the mouse if the child was incorrect. Asterisks were then pasted centrally for a two second interval before the target stimulus was presented. The target word was pasted centrally, and remained on the screen until the child responded. Again, the time to respond was recorded by the E-Prime software. Consequently, the cycle ran as follows: asterisks for two seconds, followed by the prime (which stayed onscreen until the researcher pressed a button), followed by two seconds of asterisks, followed by the target word (which stayed onscreen until the researcher pressed a button). The cycle then repeated, and went for 10 cycles until all 10 word or picture/word pairs were given. All

words were presented in Arial 48 point font. Each child was instructed to name each word and picture as quickly and accurately as possible with a standardized set of instructions. A set of five practice trials occurred before each session began. The child's responses were also recorded using Audacity recording software on the researcher's computer. At the end of each session, the researcher copied the data analysis information from E-Prime into a daily spreadsheet that was created for each participant.

In the baseline phases, 10 randomly selected target words were provided by E-Prime software, which was programmed to provide words in a random order. In word priming phases, 10 phonetically-similar word pairs (20 words) were given. Each prime word was followed by a phonetically similar target word (i.e. book/cook). In picture priming phases, 10 picture/word pairs (10 pictures/10 words) were given. Each picture was followed by its target word, which was the name of the item in the picture.

An individualized word bank of 90 one to five syllable words that were one year above participant's current reading level was created for each participant. Reading levels were originally based on the GORT-5 Accuracy score. Thirty words also had corresponding digitized photographs of everyday objects (i.e. prime = picture of dog/ target = word 'dog'). The remaining 60 words were split into pairs, and were phonetically similar (i.e. prime = book, target = cook). Consequently, each child had a word bank of the following: 30 picture primes/30 corresponding target words; 60 phonetically similar prime/target word pairs (i.e. book/cook). Individualized word lists took into account word length, familiarity, frequency, and regularity. They were created using resources such as *Rebecca Sitton's 1200 High-Frequency Words* (Sitton, 2010), *High Frequency Word lists by Grade Level* (Pinnell, Fountas, & Giacobbe, 1998),

Flocabulary (Farr, Conner, Haydel, & Munroe, 2009), and elementary through high school reading books. The speech language pathologist at WINSi monitored the creation of the word lists to ensure that word length, familiarity, frequency, and regularity were taken into account.

The word lists met the following criteria as set out in (Keller, 1982): (a) restricted to "relatively common" English words; (b) words with prominent or preferred single pronunciations; (c) exclusion of proper names, contractions, and abbreviations; (d) rhyming words were required to share common orthography, so that they would be phonetically similar; (e) word pairings could not result from simple prefix substitution (e.g. increase/decrease); and (f) separation of compound words into component words were avoided (e.g. backtrack/backpack).

The word lists were created by first constructing a master spreadsheet of over 1300 words for Grades 1-12. The master spreadsheet contained the following contents: the target word; grade level; whether it was a sight word or "play fair" word; if it was a high-frequency word; its pattern (cvc, ccvc, cvcc, cvvc, vccv); number of syllables; part of speech; whether it was a concrete, abstract, or emotion word; whether there was a picture associated with it; and all possible rhyming words. From the master spreadsheet, individualized spreadsheets were created for each participant that included the target word, grade level, whether it had an associated picture, and potential rhyme word, and the chosen rhyming prime word. Prime words were chosen from all the potential rhyming words on the master spreadsheet by attempting to match one of three things when possible; similar spelling, consonant pattern, or initial letter speech sounds. For instance, similar spelling was sought between target and prime words (i.e. beacon/deacon rather

than beacon/weaken). Secondly, if a target word had a consonant pattern of a 2-letter consonant blend at the beginning of the word, a 2-letter consonant blend was sought for the prime word (i.e., place/grace). The same procedure was used for a 3-letter consonant blend (i.e., strive/thrive). Yet if a target word started with a consonant, a prime word could also be a 2-letter consonant that made one sound (i.e. sink/think). Initial letter speech sounds were also considered. If a target word started with a consonant or vowel, a prime word was sought with the same type of initial speech sound. Sample words lists for each participant are provided in Appendix A.

Although reading levels were originally based a reading level that was one year above the GORT-5 Accuracy score, it was found during pilot testing that the word level selection was too easy for three of the participants. These participants easily decoded the words, when the goal was to include words that were slightly above the participants' reading level. The GORT-5 Accuracy measures accuracy during paragraph reading, yet the task of word recognition was simpler than paragraph reading. Consequently, the researcher worked with each student's language therapist and the speech language pathologist in crafting individualized word lists that included more difficult words for these three participants.

The programming of the E-Prime software consisted of creating 15 separate experiments. Each of the five participants needed a 'no prime', 'picture prime', and 'word prime' experiment created for them using their own individualized word list. Each individual experiment had a sign-in screen, a welcome screen, instructions, and a practice section consisting of 5-word practice trials during which participants needed to read correctly with 80% accuracy to advance to the real trials. Typically, the practice trials

included words that the participant could easily decode, as the purpose was to practice the procedure. Subsequently, the target or prime/target trails would be given. At the end of the session, a video of fireworks and an exclamatory screen with a closing remark (i.e., You Did It! Thank you and Goodbye!) was provided to help participants celebrate their effort.

The order of this five-phase study was decided on an individual basis, yet all participants received all five phases (variations of A, B, and C). For example, there were two baseline phases that were unprimed (only target words were given), along with a B-phase consisting of picture priming, and a C-phase consisting of word priming. The last phase was a repeat of the treatment phase that was most helpful to the participant. The flexibility inherent in this design allowed it to be optimized for each individual student. Table 2 illustrates the order of the phases completed by each participant.

Table 2

Multiple Treatment Reversal Design for Each Participant

Participant	Phase Design
Carol	ABACB
Devon	ABACB
Jayla	ABACB
Raymond	ACABB
Skylar	ACABC

Note. The phase design consists of variations of A (baseline), B picture priming, and C (word priming).

All participants started with a baseline phase (A). The decision of which phase to offer as the second phase, picture primes (B) or word primes (C), was decided randomly among the five participants. To establish the random order, a coin was flipped for each participant, with 'heads' determining to start with picture primes, and 'tails' determining to start with word primes. As reaction times to both picture and word primes decreased in the second phase for all participants, a baseline phase was then repeated in the third phase. Whichever treatment was given in the second phase, the alternative treatment was given for the fourth phase. For instance, if picture priming was given in the second phase, word priming was given in the fourth phase, and vice versa.

The decision of which phase to repeat in the fifth phase was decided according to how helpful each intervention was for the particular participant. For some participants, the choice was obvious. For instance, Carol, Devon, and Jayla, the younger and less experienced decoders, read target words primed by pictures much quicker than words primed by words. Consequently, picture primes were chosen for the fifth phase for these participants.

It was also decided that Raymond should receive picture primes for the fifth phase of this study. By the end of the fourth phase, Raymond's reaction time was quicker for picture primes, but he had not identified one type of intervention as being more helpful than the other, so picture primes were chosen for the fifth phase of the study.

Skylar, on the other hand, found the word priming to be much more helpful than picture priming (details will be discussed in the Results chapter). Considering the level of helpfulness that word primes offered over picture primes, it was decided that Skylar

should receive word primes for the fifth phase, even though her reaction times were approximately .5 sec longer for word primes than for picture primes.

Data Analysis

Data from this study were analyzed in a number of ways. One source of data was from the E-Prime software itself. Data collected from the E-Prime software included participant number, experiment name, session number, session date, trial number, prime word or picture, target word, prime word accuracy, target word accuracy, and target word reaction time (milliseconds). These data were put into a daily spreadsheet for each participant. Data were aggregated, and median response time for each session was calculated. Accordingly, there was one data point for the ten target words per individual session. The five median scores for each phase were averaged to determine a mean reaction time per phase. These data were plotted and displayed on a line graph over time for each participant to show within-person changes throughout the duration of the study.

A second source of data was the pre-post assessments from the eight assessments administered, namely the GORT-5, TOWRE: Sight Word Efficiency subtest, WJ III Letter Word Identification subtest, CTOPP Rapid Letter, and Rapid Digit Naming subtests, and WISC-IV PSI. Standard scores from before and after the interventions were plotted and displayed on a line graph over time for each child to show within-person changes from the beginning to the end of the study.

Two data analysis procedures were used to help answer the research questions presented in this investigation; visual analysis and effect size. Visual analysis is a helpful method for single case study because it can illustrate whether there was a functional relationship between the intervention and the behavior (Cooper, Heron, & Heward,

1987). The presence of a functional relationship, or a treatment effect should be visible to the naked eye when looking at the visual representation of data during each phase. Evaluation via visual inspection is accomplished by analyzing specific types of patterns in the data display (Kennedy, 2005).

Within-phase analysis of visually inspected data allows the examiner to see changes within a specified phase. When looking at within-phase data, three dimensions were examined; level of data, trend of the data, and variability. The level refers to the average or mean of all the data points within the phase. Attending to the level of data within the phase allows for the estimation of central tendency of the data during that phase. A second dimension used to visually inspect graphs is the trend of the data. The trend refers to the best-fit straight line that can be placed over the data within a phase. Trend has two distinct elements that simultaneously must be considered, slope, and magnitude. Slope refers to the upward or downward slant of the data within the phase; magnitude refers to the size or extent of the slope. A high-magnitude slope is a rapidly increasing or decreasing pattern in the data. A low-magnitude slope is a gradually increasing or decreasing pattern in the data (Kennedy, 2005). A third dimension is variability, which is the degree to which data points deviate from the overall trend. Taken together, level, trend, and variability are used to describe patterns that occur within each phase of the study (Kennedy, 2005).

Between-phase patterns can also be seen when data are visually inspected. In this study, two patterns of interest included immediacy and overlap. Immediacy refers to the changes in level and trend of the data from the previous phase. Overlap refers to the degree to which data in adjacent phases share similar quantitative values. Both patterns

help to determine if a functional relationship exists between the independent and dependent variables (Kennedy, 2005).

The second procedure used to analyze data was effect size. Effect size metrics can be an adjunctive support to the visual inspection of graphical illustration of data that include analysis of changes in slope and variability of data (Lenz, 2013). It provides researchers with an opportunity to consider whether the effect size yielded agrees with the overall trends of data observed during an intervention. Parker and Hagan-Burke (2007) suggested that effect size can provide a number of advantages over visual analysis alone. It can be an objective means of treatment effect, it has an increased precision of measurement, and it allows for cross-case comparisons. Effect size metrics in single-case research studies provide an estimation of practical changes between baseline and treatment phases that is content and situation specific (Lenz, 2013).

Among the most readily computed of the single case effect size measures are those that take into consideration the amount of nonoverlap between data points recorded in the baseline phase and those within the treatment phase of an intervention (Lenz, 2013). Two types of nonoverlap methods were used during this study. The first method was the Percentage of Nonoveralapping Data (PND). It is conceptualized as the percentage of treatment phase data that exceeds a single noteworthy point within the baseline phase. Strengths of this method are that it is easily calculated, and can be done with smaller data sets. Yet a limitation is that it is based on only one data point in the baseline phase, which may promote a Type II error (Lenz, 2013). To calculate PND, the most extreme baseline data point in the desired direction was noted (i.e., the lowest data point since reaction time was calculated). Then, all of the intervention phase data points

below that point were counted and framed as a percentage of all of the intervention data points (Parker, Hagan-Burke, & Vannest, 2007). When interpreting PND, Scruggs and Mastropieri (1998) suggested that effect sizes of .90 and greater are indicative of very effective treatments, those ranging from .70 to .89 represent moderate effectiveness, those between .50 to .69 are debatably effective, and scores less than .50 are regarded as not effective.

A second method is called the Improvement Rate Difference (IRD), an effect size that has been created for single case studies. Termed "risk difference" in medical research, IRD expresses the difference in successful performance between baseline and intervention phases (Parker, Vannest, & Brown, 2009). IRD has many advantages over standardized mean difference (i.e., Cohen's *d*). First of all, since IRD can be calculated from visual analysis, it can be easily interpreted, and is known for being very accessible. Secondly, it is compatible with PND from visual analysis, yet it is a more reliable measure as it uses all data points in the baseline phase rather than an individual data point. Finally, it has a proven track record in hundreds of cases of evidence-based medical research studies (Parker et al., 2009).

IRD is defined as the improvement rate of the treatment phases(s) minus the improvement rate of the baseline phase(s). Improved data in the baseline phase is defined as one that ties or exceeds any data point in the treatment phase. An improved data point in the treatment phase is defined as any which exceeds all data points in the baseline phase (Parker et al., 2009). Note that "exceeds" refers to the higher levels of behaviors wished to be seen. In this study, "exceeds refers to the faster reaction time, hence the lower number of milliseconds of response time to a given word or picture. The

maximum IRD score is 100% or 1.00, in which case all intervention phase scores exceeded all baseline scores. A low IRD score is 0%, in which case no intervention phase scores exceeded all baseline scores. A negative IRD score is possible, indicating deterioration below baseline levels. IRD scores > .70 = large or very large effects; .50 - .70 = moderate effects; < .50 = very small and questionable effects (Parker et al., 2009). Statistical calculations are provided in Appendix B.

CHAPTER IV

RESULTS

This study investigated the effect of word and picture priming on the reaction times for word recognition tasks for five individuals identified with reading disorders. A five-phase multiple-case multiple treatment reversal design was used.

Overall reaction time performance is displayed in Figures 3-7. The first three charts illustrate participant performance when picture primes were presented following baseline, and in the fifth phase (ABACB).

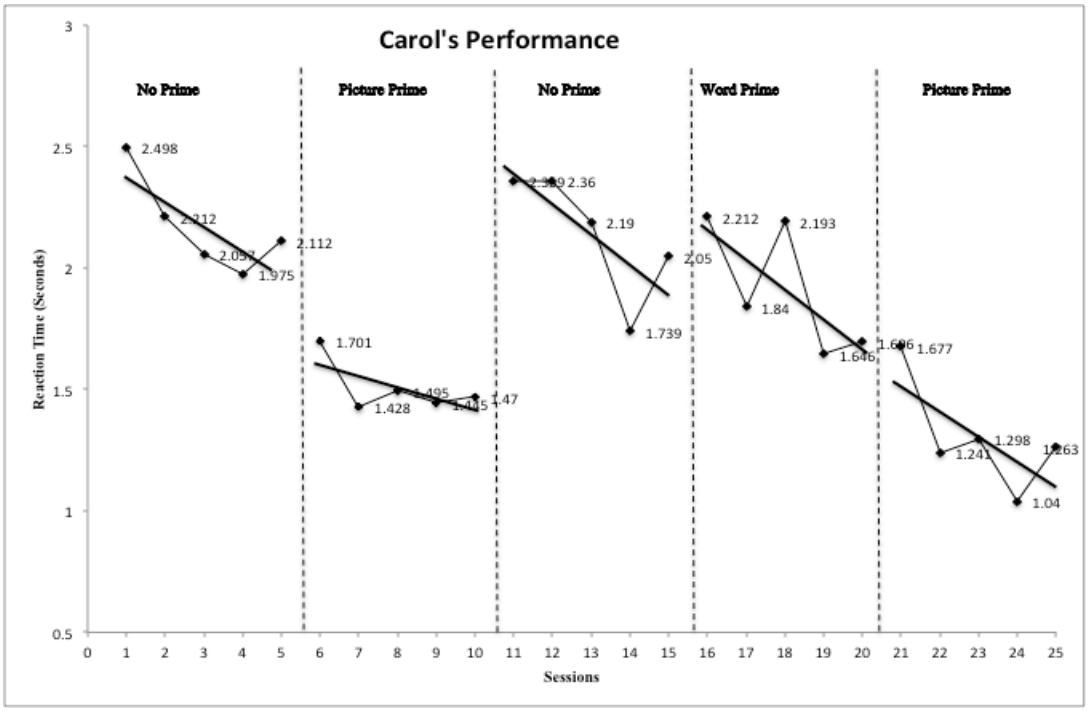

Figure 3. Participant reaction time to ABACB design including trend lines by phase.

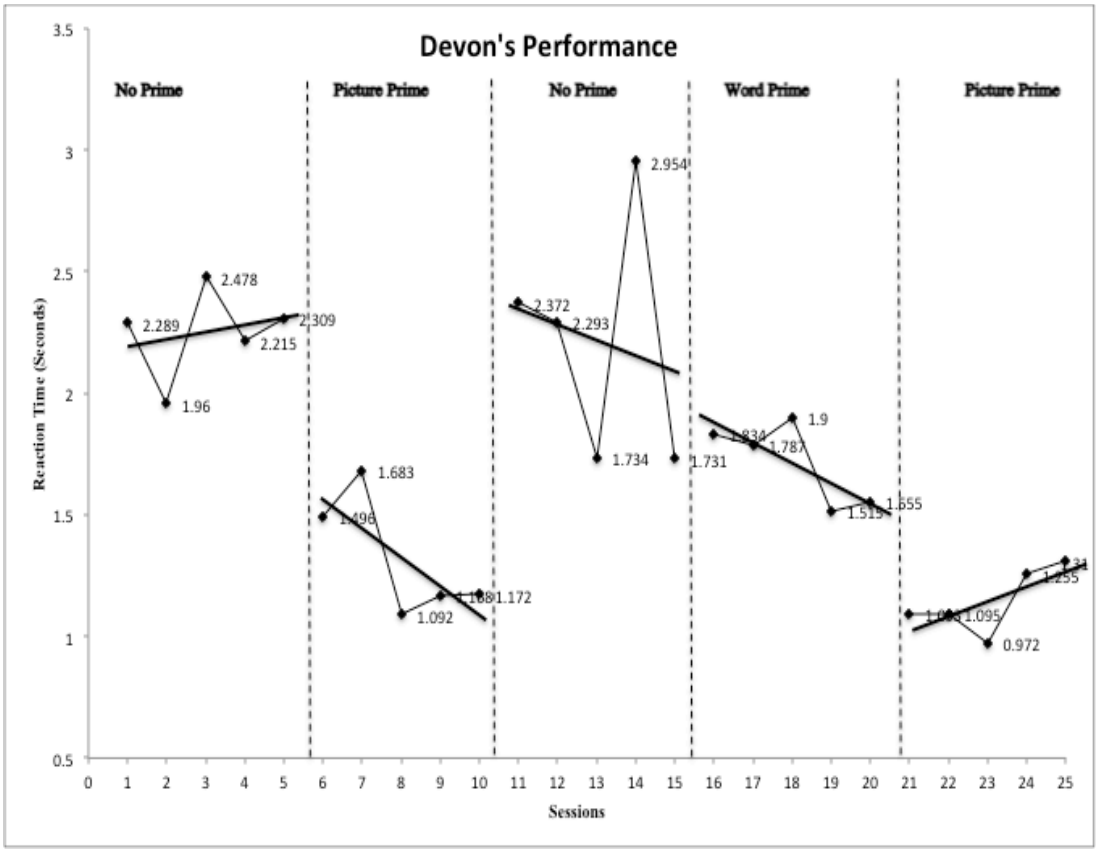

Figure 4. Participant reaction time to ABACB design including trend lines by phase.

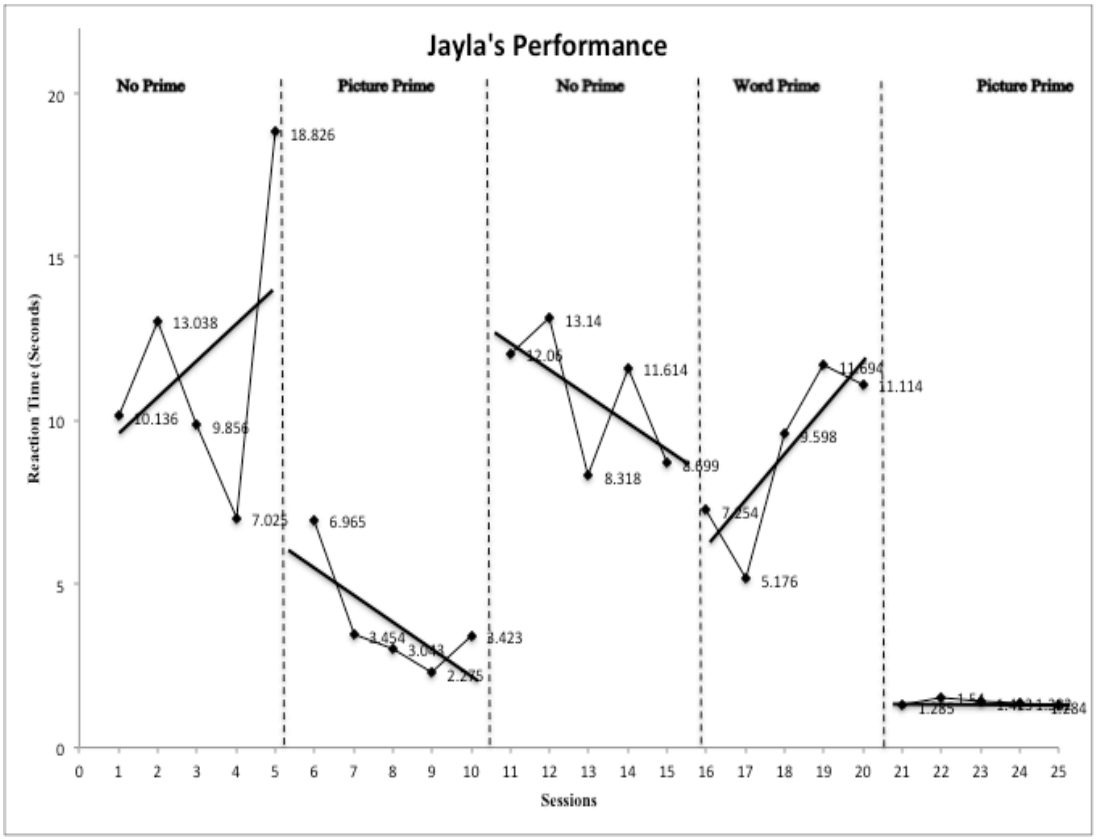

Figure 5. Participant reaction time to ABACB design including trend lines by phase.

The fourth chart illustrates performance when word primes were presented following baseline, and picture primes were presented in the fifth phase (ACABB).

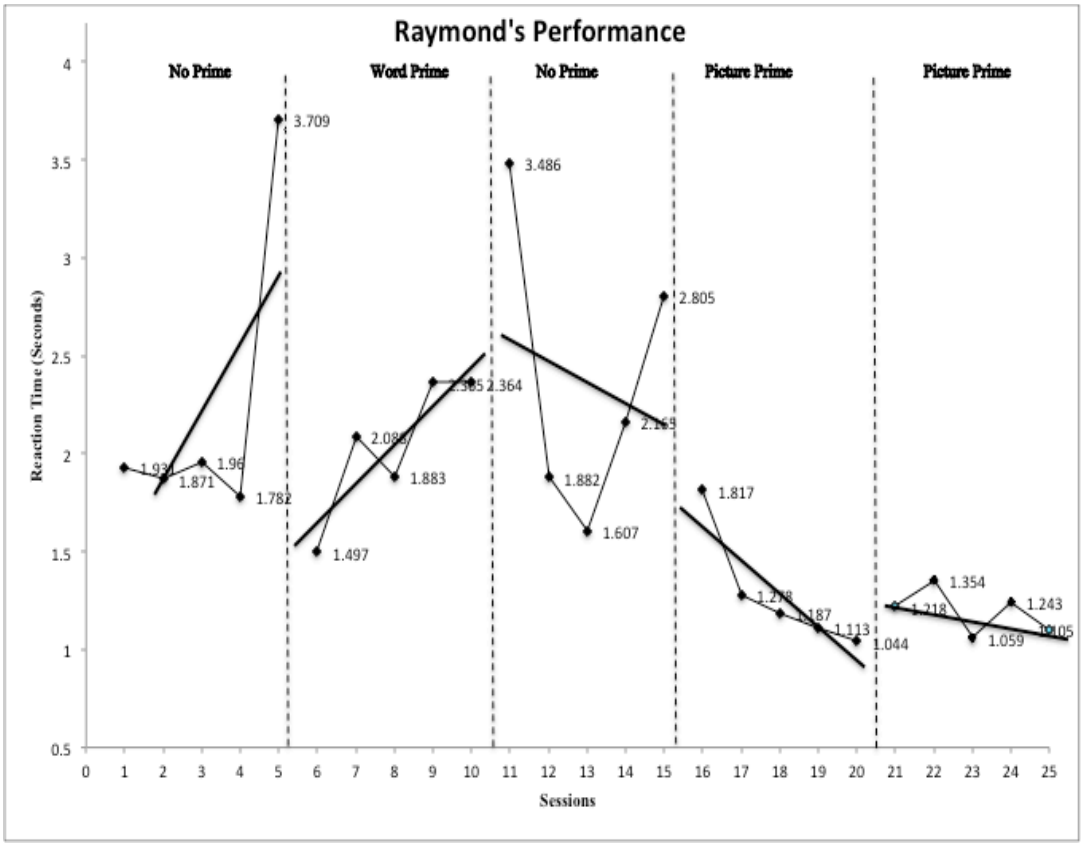

Figure 6. Participant reaction time to ACABB design including trend lines by phase.

The fifth chart illustrates performance when word primes were presented following baseline, and in the fifth phase (ACABC).

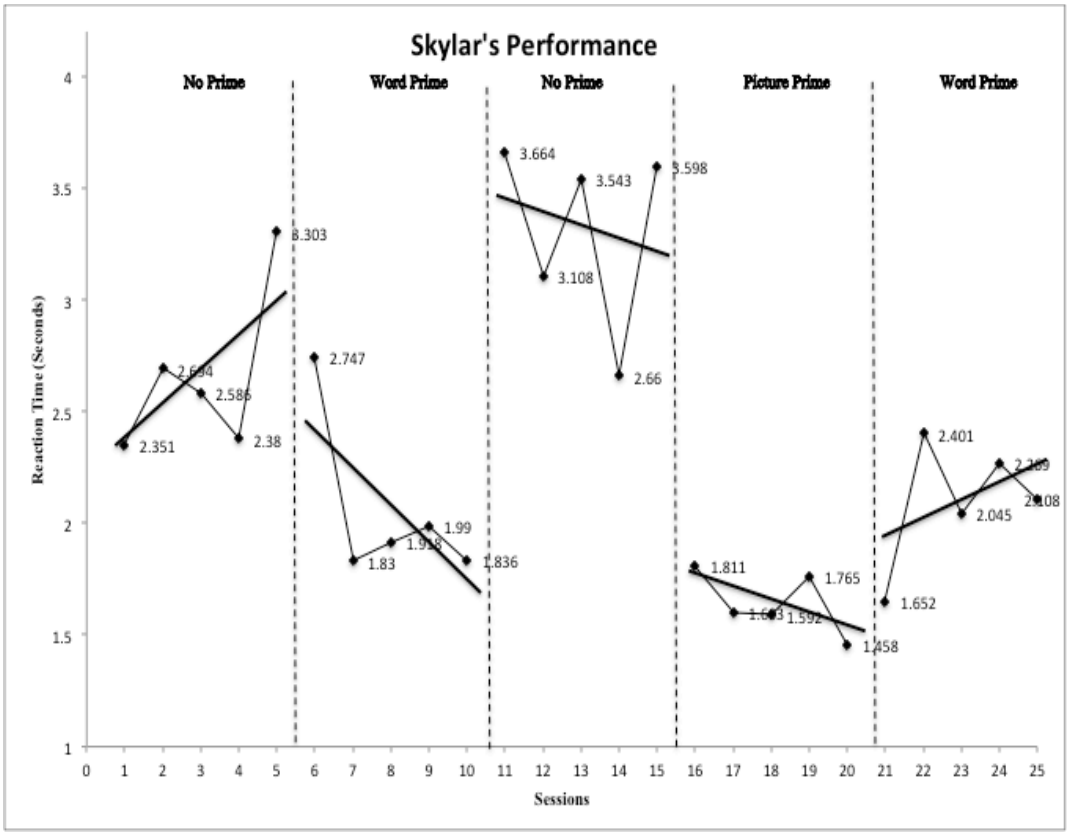

Figure 7. Participant reaction time to ACABC design including trend lines by phase.

Results of Baseline Stability and Threats to Internal Validity

Baseline stability was examined to detect the presence of maturation or history effects. Baseline was stable for Carol, as all words were read in 1.75 to 2.5 seconds. The trend did decrease throughout each baseline data point, perhaps showing some familiarity with the process. Additional information was gathered from Carol's pre/post WISC-IV PSI scores, as it was the dependent variable that was not expected to change. Her pre/post PSI score increased from a pre-test score of 78 to a post-test score of 85, providing further evidence of possible maturation effects.

The first baseline phase for Devon was stable, with all words read between 2 to 2.5 seconds. Yet his performance was more variable in the second baseline phase. He read words between 1.75 to 2.5 seconds in four of the sessions, yet the median score of one session was closer to three seconds. From these scores, it is evident that there were no maturation effects. Additional information was gathered from Devon's pre/post WISC-IV PSI scores. His pre/post PSI score remained stable, providing further evidence showing no maturation effects.

Jayla's performance was more variable. Her baseline trended downwards through the first baseline phase for four of the sessions with a range between 7 to 13 seconds. Yet the median score for one session was 18 seconds. During the second baseline phase, her performance trended downwards with a range of 8 to 13 seconds. Her WISC-IV PSI scores also showed variability. Her pre/post PSI score increased, providing some evidence of possible maturation effects. Yet caution should be taken in making any assumptions as this participant has been tested numerous times over the past three years.

Raymond's first baseline phase was stable for four sessions, with a range of 1.7 to 1.9 seconds, yet the median time for one session was closer to 3 seconds. His second baseline was stable for three sessions, with a range of 1.5 to 2 seconds. Yet two sessions were closer to 3 seconds. Since Raymond's and Jayla's performance both declined in the fifth session, additional research was required to determine if historical effects could have impacted their performance. For example, dates of assessments were examined, and participants were contacted to determine if anything happened that may have affected their performance. It was found that the fifth session was on different dates for each participant, and they reported nothing unusual to impact their performance. Additionally,

Raymond reported that his missed sessions due to a family situation did not impact his performance. Raymond's pre/post WISC-IV PSI score remained stable, providing further evidence of no maturation effects.

Skylar's performance was stable for four sessions of the first baseline phase, with a range of 2.3 to 2.7 seconds, yet the median time for one session was 3.3 seconds. Her performance during the second baseline phase trended downwards, with a range of 2.5 to 3.5 seconds. Additional information was gathered from Skylar's pre/post WISC-IV PSI scores. Skylar's pre/post WISC-IV PSI score decreased, providing further evidence of no maturation effects.

In summary, visual inspection of the data suggest that maturation and history effects were not present for Devon, Raymond, and Skylar. Jayla's performance was more variable, and therefore it was difficult to draw a conclusion regarding the presence of potential maturation or history effects. Carol, on the other hand, had a noticeably downward trend during the baseline phase, as well as an increase in her WISC-IV PSI. These changes suggested her overall performance may have been affected by maturity, and her word recognition performance may have been impacted by maturity or the phonological instruction received at WINSi.

Results of Research Question 1

Q1 For individual school-aged children and adolescents with dyslexia, do word recognition reaction times decrease when primed with related pictures?

Visual Analysis

During picture prime treatment, a mean decrease in word recognition reaction time was seen in all five participants, as shown in Figures 3-7 and Table 3. Examination

of change in trend revealed a noticeably large decrease in reaction time from baseline to treatment for all participants. Most notably, Jayla's mean reaction time decreased by more than 300% from baseline to treatment. One example illustrating how picture priming helped Jayla was evidenced on some of the individual words, such as the word 'girl'; Jayla incorrectly read the word during a baseline (no prime) phase. She then saw a picture of a 'girl' in a picture priming session, but she honed in on a flower barrette the girl was wearing in the picture, and said the word 'flower' rather than 'girl'. Yet when the word 'girl' was given after the picture, she correctly read the word. She originally responded incorrectly to both the target word and the picture prime, yet was still correct in reading the target word after the picture prime. The picture priming not only helped Jayla read words quicker, it also appeared to help with word recognition accuracy.

Effect Size

Results of PND analysis revealed the presence of a treatment effect, illustrating that the picture prime treatment appeared to be very effective (≥ .90) for all five participants. The Improvement Rate Difference (IRD) illustrated similar findings in all students with the exception of Raymond, for whom IRD showed picture priming to be moderately effective. Tables of IRD results are shown in Appendix C.

Table 3

Reaction Times, Level and Trend Change, and Effect Size for Picture Prime Treatment

Participant	Baseline Mean (seconds)	PP Mean (seconds)	PP Level Change	PP Trend Change	PND	IRD
Carol	2.155	1.406	Decreasing	High	1.0	1.0
Devon	2.234	1.234	Decreasing	High	1.0	1.0
Jayla	11.271	2.606	Decreasing	Very High	1.0	1.0
Raymond	2.320	1.242	Decreasing	High	0.9	0.7
Skylar	2.989	1.646	Decreasing	High	1.0	1.0

Results of Research Question 2

Q2 For individual school-aged children and adolescents with dyslexia, do word recognition reaction times decrease when primed with phonologically similar words?

Visual Analysis

During rhyming word prime treatment, a mean decrease in word recognition reaction time was also seen in all five participants, as seen in Figures 3-7 and Table 4. This can be interpreted that the word priming helped the participants read the word quicker than when no prime was available. Yet different from picture priming, examination of change in trend during word priming revealed a somewhat large decrease in reaction time from baseline to treatment for Skylar, and a low change in trend for Carol, Devon, Jayla, and Raymond.

Effect Size

Results of PND analysis revealed the presence of a moderate treatment effect for Skylar, meaning the word prime appeared to help decrease her word recognition time.

For Carol, Devon, Jayla, and Raymond, there was no treatment effect. It appeared that word priming was not an effective treatment for these four participants. IRD showed somewhat different results from PND or visual analysis. For all participants, IRD showed a more negative effect than PND or visual analysis. For example, while Skylar's PND was .8, her IRD was .3.

Carol, Jayla, and Raymond's negative IRD scores were noteworthy. These scores suggest that when words were primed with rhyming words, it took these participants longer to read the words than if there was no prime provided. Yet these scores are in contrast to their phase mean scores for baseline and treatment. For instance, the difference in Carol's mean score from baseline to treatment was .24 of a second, meaning Carol read a target word .24 of a second quicker under word prime conditions than she did under baseline conditions. So while the mean scores suggest the word priming treatment was slightly helpful, it was only by a very small amount. Interpretations regarding this contrast in analytical procedures will be discussed in the next chapter.

IRD analysis also showed a different result than PND for Skylar. While PND analysis showed word priming to be moderately effective, IRD analysis showed it to be questionably effective in terms of time necessary to read individual words.

Table 4

Reaction Times, Level and Trend Change, and Effect Size for Word Prime Treatment

Participant	Baseline Mean (seconds)	WP Mean (seconds)	WP Level Change	WP Trend Change	PND	IRD
Carol	2.155	1.917	Decreasing	Low	0.4	-.30
Devon	2.234	1.718	Decreasing	Low	0.4	.20
Jayla	11.271	8.967	Decreasing	Low	0.2	-.40
Raymond	2.320	2.039	Decreasing	Low	0.2	- .50
Skylar	2.989	2.080	Decreasing	High	0.8	.30

Results of Research Question 3

Q3 For each individual student, do word recognition reaction times decrease more when primed with pictures or words?

Visual Analysis

Reaction times for all participants decreased more when primed with pictures rather than words, as seen in Table 5. There are two ways at looking at these trends; namely who benefitted the most from each condition, and who benefitted the least from each condition. For instance, Carol, Devon, Jayla and Skylar appeared to benefit the most from picture prime treatments, while Raymond benefitted the least from picture prime treatment. For word prime treatments, Skylar appeared to benefit the most, while Carol, Devon, Jayla, and Raymond appeared to benefit the least from word prime treatments.

Effect Size

Both PND and IRD showed picture priming to be more effective than word priming in decreasing word recognition reaction time for all participants.

Table 5

Reaction Times for Picture Prime and Word Prime Treatments

Participant	Baseline Mean (seconds)	Picture Prime Mean (seconds)	Picture Prime PND	Picture Prime IRD	Word Prime Mean (seconds)	Word Prime PND	Word Prime IRD
Carol	2.155	1.406	1.0	1.0	1.917	0.4	-.30
Devon	2.234	1.234	1.0	1.0	1.718	0.4	.20
Jayla	11.271	2.606	1.0	1.0	8.967	0.2	-.40
Raymond	2.320	1.242	0.9	0.7	2.039	0.2	- .50
Skylar	2.989	1.646	1.0	1.0	2.080	0.8	.30

Error Rates

Although there was not a research question regarding error rates, data regarding error rates were collected during all baseline and treatment phases, and shown in Table 6. Error rates were variable and were affected by treatment type. While all participants made fewer target word errors during picture prime rather than word prime treatments, their specific results were highly individual. For instance, error rates for Jayla decreased from 63% at baseline to 5% for picture prime target words, even though she incorrectly named the prime picture in 21% of the trials. In other words, she was able to name the correct target word 95% of the time, even if she incorrectly named the picture prime 21% of the trials. Picture primes appeared to help Jayla read the target word accurately, as she was able to do so even when she incorrectly identified the picture prime. For the word

prime treatment, Jayla's target word error rates decreased from 63% at baseline to 18% for word prime target words, and she incorrectly named the prime word in 18% of the trials. In other words, every time Jayla incorrectly named a prime word, she also named the target word incorrectly.

Error rates for Skylar decreased from 24% to 0% from baseline to treatment for picture prime target words, even though she incorrectly named the prime picture in 20% of the trials. For the word prime treatment, Skylar's target word error rates decreased to 5%, even though she incorrectly named the prime word in 11% of the trials. Additional information regarding Skylar's ability to read words accurately with the word prime treatment is noteworthy. For example, when given the prime word "perform," Skylar incorrectly read "performance." When she saw the target word "transform," she read it correctly, then said, "Oh, that other word must have been 'perform.'" In another example, Skylar read the prime word "curricular" incorrectly, saying "circular." Yet again she read the target word "particular" correctly, then said, "That other word must have been 'curricular.'" These situations happened during the second word prime session, and Skylar subsequently appeared to use the rhyming word primes to help her decode target words, and vice versa.

In almost all cases, participants made more errors reading/identifying the prime pictures/words than they did reading the target words themselves. From this analysis, it appears that some experience with the primes, be it with picture primes or word primes, helped participants read the target words correctly. It is interesting to note that Raymond and Skylar had the most advanced decoding skills of the group, yet they also had more

errors identifying picture primes than the students with less advanced decoding skills. Potential reasons for this finding will be discussed in the following chapter.

Table 6

Errors Rates for Picture and Word Prime Treatments

			Picture Prime			Word Prime		
Participant	Baseline Mean (seconds)	Baseline Errors %	Picture Prime Mean (seconds)	Target Word Errors %	Prime Picture Errors %	Word Prime Mean	Target Word Errors %	Prime Word Errors %
Carol	2.155	42	1.406	4	15	1.917	22	24
Devon	2.234	20	1.234	1	17	1.718	12	28
Jayla	11.271	63	2.606	5	21	8.967	18	18
Raymond	2.320	27	1.242	9	27	2.039	12	4
Skylar	2.989	24	1.646	0	20	2.080	5	11

Participants completed eight pre and post-tests subtests, including the GORT-5, TOWRE: Sight Word Efficiency (SWE) subtest, WJ III Letter Word Identification subtest, CTOPP Rapid Letter and Digit Naming subtests, and WISC-IV PSI. Composite scores are shown in Table 7. An overview of this table illustrates the severity of impact that dyslexia and other language disorders have on these participants. Yet notably, Raymond, Devon, and Skylar increased their scores on the TOWRE Sight Word Efficiency (SWE) by 13, 9, and 9 points respectively.

Table 7

Pre- and Post-Tests in Word Recognition, Reading Fluency, Rapid Naming, and Processing Speed Measures

Participant	Test	GORT - 5 - ORI	TOWRE - SWE	WJ - III Letter-word ID	CTOPP - RN	WISC IV - PSI
Carol	Pre	78	74	84	82	78
	Post	78	77	80	79	85
Devon	Pre	78	77	75	91	94
	Post	81	86	77	91	94
Jayla	Pre	68	65	78	46	65
	Post	62	60	78	38	75
Raymond	Pre	89	87	101	100	88
	Post	102	100	111	106	88
Skylar	Pre	84	76	94	85	80
	Post	81	85	101	88	73

Note. WJ III Letter-word ID = Woodcock Johnson Letter-word Identification; GORT-5 ORI = Gray Oral Reading Test, Fifth Edition, Oral Reading Fluency Index; TOWRE SWE = Test of Word Reading Efficiency, Sight Word Efficiency; CTOPP – RN = Comprehensive Test of Phonological Processing, Rapid Naming composite; WISC IV – PSI = Wechsler Intelligence Scale for Children, Fourth Edition - Processing Speed Index.

Participant Reactions

While the reaction time and error rate provides some information regarding the effectiveness of the prime treatments, participant reaction to the treatment must also be considered. While the younger participants with less developed decoding ability preferred the picture primes more than the word primes, that was not the case for the older participants who had more developed decoding ability. Even though the older participants read the target words more quickly with picture primes, they described the pictures as less helpful than the word primes. For instance, Raymond said that the pictures could be interpreted in a number of ways, so the ambiguity did not help provide a clue for the target word. Skylar voiced similar objections, saying, “If you don’t know

what the picture is exactly, then it doesn't help you figure out the target word." Conversely, Skylar also believed that some pictures were so recognizable that the target word was obvious, which she described as "boring." However, she thought that the word primes gave helpful clues to the target word, saying, "Once I know how the first word sounds, it helps me figure out how the other word should sound." In fact, Skylar clearly demonstrated her preference for the word primes by asking, "Is this program that you made (referring to the e-Prime software with prime and target words) available as an iPhone app? Because I would totally use it if it were available." Preference of treatment type is important, as participants are more likely to use and benefit from the treatment they find more appealing.

Skylar exhibited the greatest personal change during the 25-session study. At the beginning of the study, she would not try to say a word if it were difficult. For instance, during initial baseline sessions, she did not attempt to read words such as "esteem," "material" and "predict." After the initial baseline sessions, she was given the word prime condition. There was a marked difference in her confidence from the beginning to the end of the word prime sessions as she figured out how the rhyming word primes could help her determine the target words. For example, after five word prime sessions she asked for a harder word to be included, saying, "I want a 10th grade word." Although her data could be negatively affected, one 10th grade word was added to her word list. It only appeared one time during a no-prime phase. When presented with this word, her excitement increased as she tried to decode the word. She read it incorrectly initially, but continued to try and sound it out. After she could read it, she wanted to know what it

meant. She found the definition, and used it in a sentence. Two weeks later, she explained how she used the word when speaking with her family.

Additionally, during a telephone conversation with Skylar's mother, she replied, "I don't know what you guys are doing there, but Skylar is coming home talking about words. She's never talked about words before." When it was explained to her mother that the rhyming word primes appeared to help Skylar, her mother replied, "Skylar has *never* rhymed before. All those years as a child, she could never 'get' rhyming." The therapists at WINSi also noticed how Skylar was becoming much more confident, as she began to ask about her performance on daily tasks. During the post-intervention data collection, Skylar asked if she could read the most difficult reading passage on the GORT-5. She knew the score would not count, but she wanted to read it, "just for fun." This remark showed a significant difference in Skylar's confidence level from the beginning of the study.

All the participants appeared to enjoy the sessions. The computer-based format of this activity appeared to entice the students to participate. Yet the main reason for their satisfaction appeared to be that they were being successful. They did not know if they were reading the words correctly or incorrectly, so they appeared to feel successful during each session. Additionally, a video clip of fireworks at the end of each session was added as a reinforcement for their efforts. The importance of success cannot be overstated. It is believed that part of the value of this intervention was providing the opportunity for participants to be successful with academics every day.

Summary of Data Findings

Picture priming treatments appeared to have assisted all participants in reading target words more quickly. Word priming treatments assisted four of the five participants in reading target words somewhat more quickly, but was not seen as being effective overall. All participants decreased their reaction time reading target words more when presented with picture primes than with word primes. Consequently, priming, and especially picture priming, helped participants increase their reading rate of individual words. All participants made fewer target word errors when presented with a primed picture or word. They also made fewer target word errors identifying picture primes rather than word primes. These findings suggest that priming, and especially picture priming, also helped students increase their accuracy in word recognition. Qualitative feedback from participants indicated that while the less experienced readers preferred picture primes, the more experienced readers preferred word primes even though they performed better with the picture primes.

CHAPTER V

DISCUSSION

Dyslexia is a significant problem in education because children who do not learn to read by third grade are at risk of dropping out of school (Guilli et al., 2005; Torgesen et al., 1999). From an emotional or psychological point of view, dyslexia may negatively affect self-esteem and create confusion and frustration, which then contributes to underachievement (Guilli et al., 2005). Given that children with dyslexia may struggle academically as well as socially and emotionally, it is critical to understand and develop methods for early intervention. Accurate early identification and appropriate targeted intervention can improve reading ability and reduce the other potentially negative effects associated with dyslexia (Foorman et al., 1997; Vellutino et al., 1998). Thus, it is important to identify dyslexia early and to characterize the precise strengths and vulnerabilities of each individual child so that targeted intervention can be provided to enhance accuracy and automaticity in each aspect of the reading system.

The purpose of this study was to investigate the effect of word and picture priming on the reaction times of word recognition tasks for five children and adolescents with dyslexia. Findings suggested that a functional relationship was found in word recognition when primed with pictures, as all students' reaction times to word recognition decreased when primed with a picture. Additionally, a functional relationship in word recognition was found when primed with words for two participants. Furthermore,

students' error rates on target words decreased when primed with either pictures or words, and error rates decreased the most when primed with pictures.

Level of Intervention Effectiveness Among Participants

High Level of Intervention Effectiveness of Picture Priming

Visual analysis of the participants' reaction times provide evidence to suggest that picture priming was highly effective for four of the participants (Carol, Devon, Jayla and Skylar). These participants showed a level change decrease from baseline to treatment. These participants also showed a large visual trend change from baseline to treatment, with Jayla showing a very large decrease. This finding is consistent with Plaut et al. (1996), who found a large priming effect for picture-to-word priming. Both PND and IRD showed large effect sizes for these four participants. These findings may also point to the depth of information processing during incidental learning. Craik and Tulving (1975) found that recognition and recall of information were increased when semantic information was provided related to a list of target words. Specifically, a series of experiments showed that participants' recall increased qualitatively and quantitatively when an image was shown associated with a target word, or when a rhyming word was provided. It was suggested that the enriched association of images yielded a deeper encoding of the word, which led to a more robust the recall of information. The deeper encoding associated with semantics appeared to help with recall, and therefore aided incidental learning. Schulman (1974) found that memory performance is enhanced to the extent that the context forms an integrated unit with the target word being presented. It

appears that offering picture primes may represent a beneficial way of increasing the depth of processing by presenting a context for the target words.

For all the participants of this study, and especially Jayla, whose mean reaction time decreased from 11.2 seconds to 2.6 seconds during picture priming, it appears that incidental learning was potentially occurring. Based on these findings, picture priming showed the highest level of treatment effectiveness for these participants.

Moderate Level of Intervention Effectiveness of Picture Priming

The most sensitive data findings (i.e., IRD) for one of the participants, Raymond, provide evidence to suggest that picture priming was moderately effective. While visual analysis shows a level change decrease from baseline to treatment for this participant, and the amount of visual trend change was still considered to be large, the effect sizes showed less effectiveness of picture priming for Raymond than for the other participants. Based on these findings, picture priming was only moderately effective for Raymond. Yet caution should be considered regarding picture priming with the more advanced decoders. As vocabulary became increasingly complex, the vocabulary that referenced pictures was somewhat easier than the vocabulary that referenced words. For example, some of the pictures Raymond had to name were words such as 'billiards', 'binoculars', and 'bungalow.' In contrast, some of the words Raymond had to name in the word priming (rhyming) phases included 'cantankerous', 'denomination', and 'fortuitous'. While all these words were in his Grade 10-12 word list, the words that represented pictures were somewhat easier. This difference in exact words may have been part of the reason for quicker reaction times to picture primes for the most advanced decoders.

High to Moderate Level of Intervention
Effectiveness of Word Priming

The findings for one of the participants (Skylar) provide evidence to suggest that word priming was effective. This participant showed a level change decrease from baseline to treatment through visual analysis. She also showed a large visual trend change from baseline to treatment. Yet PND and IRD showed different results. PND, the least sensitive effect size measure, showed a large effect size. In contrast, IRD, the most sensitive effect size measure, showed a very small effect size. The increased sensitivity of IRD appears to reduce the certainty that the word prime treatment was effective, so caution must be used in determining the degree of effectiveness of this intervention for Skylar. Nevertheless, word priming appeared to be most effective for this participant.

Marginal Level of Intervention
Effectiveness of Word Priming

Data findings for one of the participant (Devon) provided evidence to suggest that word priming was marginally effective. While there was a level change decrease from baseline to treatment for this participant, the amount of visual trend change was low. PND and IRD showed similar results in that word priming was only marginally effective for Devon. Based on these findings, word priming was not as helpful for Devon as it was for Skylar; yet it was more helpful for him than it was for Carol, Jayla, or Raymond.

No Effect to Negative Intervention
Effect of Word Priming

The most sensitive data findings for three participants (Carol, Jayla, Rayond) provided evidence to suggest that word priming was not effective. While there was a level change decrease from baseline to treatment for these participants through visual

analysis, the amount of visual trend change was low. Again, the effect size measures revealed somewhat different findings. The least sensitive measure, PND, did not support the effectiveness of word priming and the more sensitive IRD showed that the reaction time for the treatment had deteriorated below baseline. This finding is in contrast to the phase means that showed a faster reaction time to word primes than to the no prime situation of baseline. This discrepancy between phase mean and IRD may be due in part because the difference in mean score from baseline to treatment was very small for these three participants. The increased sensitivity of IRD highlighted the fact that there were more improvement points in baseline than in word priming. Considering all the findings, it was apparent that word priming was not effective for Carol, Jayla, or Raymond. This finding is consistent with previous findings suggesting that students with fewer decoding skills may benefit more from picture primes (Plaut et al., 1996). In relation to Raymond's performance, previous research has indicated that university students and adults did not find priming to be helpful, possibly due to more advanced decoding abilities (Biggs & Marmurek, 1990; Durso & Johnson, 1979).

Importance of Participant's Reactions Regarding Helpfulness of Interventions

While this study focused on reaction times to word and picture priming, participant reactions to the interventions were also considered. The purpose of this study was to provide information to these participants' therapists and future educators. Therefore, participant reactions regarding the helpfulness of each intervention are important, as participants are more likely to use the interventions they believe are most helpful to them. For example, by the end of the study, when Raymond had picture primes for two phases, he realized the picture primes could be more distracting than

helpful when he mentioned that the picture did not necessarily help determine the target word. This is an interesting finding in that pictures did help the younger, less experienced decoders determine the target word. Yet the less experienced decoders were reading words like 'horse', and 'children', which are nouns that have obvious pictures. In contrast, the more experienced decoders were reading words that could be illustrated in a number of different ways such as 'ponder' and 'symmetrical'. The simpler words had much more distinct pictures associated with them, making it easier for younger readers to determine the target word. In contrast, the more complex words had much more ambiguous pictures, making it more difficult to name the correct picture. This finding regarding the complexity of pictures was supported by the error rates of the advanced decoders who the highest number of errors in identifying the pictures themselves. In sum, Raymond, the most advanced decoder, did not think the pictures were very helpful, and made the most errors identifying pictures. Consequently, even though word primes (i.e. perception/conception) took Raymond a longer time to read (<1 sec.), the words themselves were more related to the decoding process. Therefore, by the end of the study, Raymond described the word primes as more helpful.

Skylar, who was also a more experienced decoder, found word primes to be much more helpful than picture primes. Skylar also noted the ambiguity of the picture primes. For instance, when looking at a picture of a soldier saluting, she said, "Is it a soldier, a man, army, or salute?" In contrast, when Skylar participated in word priming phases, she was able to use one of the words to determine the other word in the pair (i.e. perform/transform and curricular/particular). It was clear that she understood the similar patterns between the primes and the target words and the rhyming aspect of this

relationship, something that her mother described as new learning for her. In some ways, it was the qualitative aspects of Skylar's growth that was most compelling. Because she seemed to develop confidence and a deeper understanding of word relationships, it was evident that the word primes were most beneficial to Skylar. Consequently, even though it took Skylar a longer time to read a word prime than a picture prime (<.5 sec.), word primes were viewed as a more helpful intervention than picture primes.

Summary of Intervention Impact

From an overall perspective, there were four important general findings in this study. First of all, these results illustrate how children with dyslexia might use a distributed network to process information. Makuuchi and Friederici (2013) found that during sentence reading in typical readers, information is first conveyed from the visual system to the working memory system, before effectively connecting to the language system. Yet it was also found that the connection between the visual system and the language areas may not function in this way for people with dyslexia. Additionally, the *fMRI* photographs shown earlier in this study by Christodoulou et al. (2011) illustrated that readers with dyslexia may employ a more distributed network that may represent compensatory mechanisms for performing RAN tasks (as cited in Norton & Wolf, 2012).

When one considers the word recognition reaction time differences for picture priming for all participants, it is apparent that these participants likely employed a distributed network to process information. Additionally, this finding may point to the ways in which a compensatory mechanism can be utilized when doing these types of tasks. This finding is most apparent for Jayla, whose reaction time decreased more than 300% during the picture prime intervention.

Yet Hennessey et al. (2012) did not find significance for picture priming for children with dyslexia, although they did find significance for reading age-matched controls. The participants in both this study and Hennessey et al. (2012) were somewhat similarly affected by dyslexia, in that reading and word recognition scores were one to two standard deviations below the expected norm for all participants. Yet Hennessey et al. (2012) reported a mean decrease in reaction time to picture primes by 78 milliseconds; while this study found a mean decrease of approximately 2570 milliseconds. It is difficult to understand why these findings were so different other than that each used substantially different procedures. In Hennessey et al. (2012), the experiment consisted of two phases, which lasted 30 minutes in total and participants came in contact with the pictures/words one time. The present study included 25 sessions, and participants came in contact with specific pictures and words 3-6 times throughout the study. While these methodological approaches may account for some of the differences, but decreases in reaction time to picture primes appeared the first time participants were provided pictures in this study. Accordingly, for four of the five participants, experience seeing the pictures multiple times over the length of the study only impacted their reaction time by a small amount.

There is an additional explanation as to why significance was not found in picture-to-word priming in the Hennessey et al. (2012) study. In Hennessey et al. (2012), both priming conditions (picture-to-word and word-to-picture) were combined because there was no interaction between priming and stimulus type. Although Hennessey et al. (2012) lacked sufficient power to find significance in picture-to-word priming as a stand alone condition, it is possible that the picture-to-word priming effect (relative to the

unprimed condition) would be there for the children with dyslexia and poor phonological processing (Hennessey, 2014, personal communication).

Other researchers have found differing levels of priming effects in participants according to their levels of decoding ability. Plaut et al. (1996) found that word recognition develops in young readers using the semantic pathway, hence there is a large priming effect for picture-to-word priming. Conversely, Biggs and Marmurek (1990) found that pictures did not facilitate word naming for university students with typical reading abilities.

Overall, the present study contributes to a growing body of evidence suggesting that younger and less-skilled readers are slower at decoding and show enhanced effects of semantics, compared with older readers, whose decoding skills were relatively efficient. These findings are consistent with the proposition that the semantic pathway can compensate for direct orthography-to-phonology translations when that process is slow and inefficient (Hennessey et al., 2012). Additionally, the use of the semantic pathway to assist the orthography-to-phonology translations lends further support to the idea that children with dyslexia may use a distributed network to process information.

Second, the use of a distributed network to process information may be conceptually related to the Triangle Model. Plaut et al. (1996) described how word recognition is dependent on a combination of phonological, orthographical, and semantic processes. For most words, activation spreads rapidly along the phonological pathway leaving little time for the semantic pathway to exert an influence on phonological output. However, the semantic pathway may compensate for the phonological pathway when

reading words with less familiar and atypical spelling to sound associations (Plaut et al., 1996).

Some of the latest research sheds additional light on the Triangle Model. For example, O'Brien, Van Orden, and Pennington (2013) studied the extent to which individuals with dyslexia were constrained by phonology in making semantic judgments while reading. Thirty-two children with dyslexia aged 7.0 to 9.2 completed a computerized semantic categorization task. They were given a category (i.e. flowers), then given a pair of homophone (i.e. rows) and pseudohomophone (i.e. roze) foils. After each foil, they were asked to push the 'yes' button if the word belonged to the category, and push a 'No' button if it did not. It was anticipated that readers with dyslexia would make fewer false positive responses when judging non-word pseudohomophones foils compared to age-matched controls, because those with dyslexia should lack access to the phonology of pseudohomophones. Surprisingly, readers with dyslexia made more false positive responses to both pseudohomophone and homophone foils, indicating that they were accessing phonology. Yet these participants accessed the phonology of the words after they had determined the connection to the category at hand. For instance, the category 'flowers' primed examples (i.e. 'rose') of the category. Then the target word (either misspelled homophone or pseudohomophone) could be matched to the example of the category. Thus, a meaning-based context serves to compensate for the decoding deficit, which is in concert with the Triangle Model.

The results from this study align with the Triangle Model. The participants, especially less experienced decoders, benefitted greatly from semantic processes. This

effect was seen when reaction times decreased significantly when primed with pictures, and also decreased when primed with phonetically-similar words.

The third general finding of this study was that participant results were consistent with the multicomponent view of reading fluency. For example, there was growth in a few of the components of reading fluency, namely phonemic awareness, and word recognition. Specifically, four of the five participants improved their performance from pre-test to post-test on the TOWRE: Sight Word Efficiency (SWE) subtest and three of five participants improved their performance on the WJIII Letter-Word Identification subtest. While some participants showed growth in these particular areas of reading fluency, only two participants improved their performance on the GORT-5 ORI, an overall reading fluency measure. These findings suggest that while participants were able to improve on some components of reading fluency, such as phonemic awareness and word recognition, only two of the five participants were able to improve their reading fluency overall. This finding is consistent with Berninger et al. (2001), who found that reading fluency is considered to be a product of multiple components, namely phonological representation, phonemic awareness, orthographic identification, decoding and word recognition, auditory and visual perception, attention, along with short-term and long-term memory.

Since there are so many components to reading fluency, it makes intuitive sense that increases in fluency typically happen over a long period of time. This priming intervention was approximately three months in duration. It would be interesting to continue priming interventions, along with the phonological awareness interventions that participants were receiving at WINSi, to determine changes over a longer period of time.

It would also be interesting to tease out participant progress due to WINSi treatment versus progress due to WINSi treatment plus these priming interventions.

Fourth, the deficits noted in the standardized assessments of these participants may also reinforce the multiple deficit model of dyslexia. Wolf and Bowers (1999), and Pennington et al. (2012) found that either a phonological or language skill deficit; or fluency factors, such as processing speed, naming speed, or both phonological and fluency factors, are likely deficit areas for many children with dyslexia. The participants in this study did appear to reflect these different areas of deficit. For example, Jayla and Carol both appeared to have a phonological deficit, along with processing speed and naming speed deficits. Raymond reportedly had a phonological and language skills deficits. Skylar was identified as having phonological and processing speed deficits. Only Devon appeared to have a single phonological deficit. In this study, it was seen that four of the five participants had multiple deficits associated with dyslexia.

In sum, participants in this study appeared to use a distributed network to process information, and also apparently used a combination of phonological, orthographical, and semantic processes as described in the Triangle Model. Additionally, participants' increased in some, but not all, aspects of reading fluency providing support for the multicomponent view of reading fluency. Lastly, the different areas of deficit noted in the current study sample reflected the multiple deficit model of dyslexia.

Assessment of Data Analysis Procedures

Although several data analysis procedures were employed in this study, some were more helpful than others. For instance, visual analysis of level change was not that helpful since the level change decreased with both interventions for all participants.

While knowing that both interventions helped all participants, more targeted information was necessary. Trend change provided more meaningful information when examining the data visually, as the magnitude of change became evident through this data analysis procedure.

Consistency Between Visual Analysis and Effect Size

Effect size can provide a number of advantages over visual analysis alone. It can be an objective means of treatment effect. Additionally, it has an increased precision of measurement, and it allows for cross-case comparisons (Parker & Hagan-Burke, 2007). Analyzing the consistency between visual analysis and the effect size measures in this study yielded some interesting findings.

For the picture priming treatment, both effect size measures were consistent with visual analysis illustrating the effectiveness of the treatment for four of the participants (Carol, Devon, Jayla, Skylar). For Raymond, IRD indicated the picture priming treatment was only moderately effective, whereas PND and visual analysis revealed that the treatment was highly effective.

There was slightly more variability in the word priming findings. While findings were most consistent between effect size and visual analysis showing a low amount of effectiveness for Devon, findings were only somewhat consistent between effect size and visual analysis for Carol, Jayla, and Raymond. For these three participants, the phase mean showed improvement from baseline to word prime treatment; yet one of the effect size measures (IRD) showed a deterioration from baseline. This finding represented a a good example of how IRD is more sensitive than phase mean. There was more inconsistency between effect size and visual analysis for Skylar. For example, Skylar's

results showed that there was inconsistency between IRD, which showed word priming to not be effective, while visual analysis showed that word priming was effective.

Consistency Between Effect Size Measures

Since two effect size measures were used, and they often indicated different rates of effectiveness during this study, it is useful to explore why these differences may be occurring. Of the two effect size procedures, IRD provided the most sensitive information since it included multiple baseline points, whereas PND only included a single baseline data point. Since IRD is relatively new to single case research, Parker et al. (2009) compared PND and IRD findings from 166 A versus B contrasts from published data to investigate the differences between the two effect size measures. Overall, they found that IRD correlated .83 with PND, and .86 with the more well-known Pearson *R* effect size. Specifically, they found IRD correlations with R^2 were over 10 points higher than those achieved my PND. They believe that this high-moderate size relationship lends considerable support to IRD as a new index.

For this study, IRD and PND reported similar levels of effectiveness for four of five participants in picture priming, and for one of five participants in word priming. While IRD showed word priming to be less effective than PND for Carol, Jayla, and Raymond, both measures agreed that word priming was not effective for these participants.

The largest discrepancy between PND and IRD in this study was for Carol and Raymond during word priming; IRD scores were .7 worse than PND for both participants. Yet while there was a large difference in the two effect size measures, both effect sizes concluded that the intervention was not effective for these participants. As

stated earlier, the increased sensitivity of IRD illuminated the fact that there were more improvement points in baseline rather than in word priming for these two participants.

Overall, IRD showed increased sensitivity, and therefore provided the most specific results. Yet these participants showed a lot of variability in their performance throughout the study. With this high amount of variability in performance, it is difficult to obtain consistent results between effects size measures, or between effects size and visual analysis measures. In other words, when performance is variable, analysis of performance using different outcome measures will likely show variability.

Implications for Therapists and Educators

Various models have been proposed to assist readers with dyslexia in their ability to recognize words. Some models involve using different types of words in priming, or repeated reading activities, while others discuss priming with pictures and words. The presence of picture-to-word priming reflects the activation of phonological codes for speech production via semantics on word naming, confirming a bias towards the semantic pathway during word naming for readers with dyslexia (Hennessey et al., 2012).

Participants in this study greatly benefitted from exposure to both picture and word priming. Readers with less developed decoding skills especially benefitted from picture priming. Findings from this study can inform current therapists working with these participants, as well as special education teachers and professionals in specialized clinics who are working with children with dyslexia.

For instance, future therapists and teachers of children with less well-developed decoding skills, such as Jayla, Carol, and Devon, can use picture priming as a preliminary activity before introducing new vocabulary words. For children with severely affected

reading abilities, picture priming appeared to be especially helpful. Picture priming can allow them to access phonology through semantics, while it can also be reinforcing for them as they become more successful in their reading efforts. In this way, picture priming can support independent reading efforts.

Future therapists and teachers of children and adolescents with more well-developed decoding skills, such as Skylar, may want to use word priming as a preliminary activity before introducing new vocabulary words. . These word priming activities may also help solidify rhyming skills and the relationship between certain word patterns. Children with similar neurodevelopmental profiles to Skylar may have experienced difficulty with rhyming abilities and be delayed in developing these skills. If rhyming is a newly developed skill for these students, they can now employ rhyming to increase their decoding abilities. Additionally, Skylar's therapists and teachers can benefit from knowing how much Skylar appeared to enjoy being given a challenge once she began to experience success and gain confidence in her reading skills. This willingness to be challenged was a new behavior for Skylar, and may be due in part to the success she found through rhyming. This type of reaction is not unique to Skylar. Once children and adolescents, including those with learning disabilities, find an avenue in which they can be successful, it can help fuel their desire to learn more. This newly found confidence and desire for a challenge can be capitalized upon to promote further learning.

Future therapists and teachers of students with the most well-developed decoding skills, such as Raymond, can benefit from knowing that these children and adolescent's decoding abilities are advanced enough that priming does not appear to be helpful for

them. While Raymond's reaction time to word recognition decreased when primed with pictures, he did not find it to be very helpful overall. These therapists and teachers can benefit more from doing increasingly advanced vocabulary and reading comprehension work with these more advanced decoders.

Limitations and Future Research

There were a number of limitations in this study. First, since a purposeful sample was used with students already receiving services at WINSi, there was a lot of variability in the sample; some participants had received treatment for two years, while others were just getting started. Along with this variability, there was not the ability to control for different starting levels of skill. For example, Raymond had much more well-developed decoding skills than many of the other participants. Second, there was limited generalization due to small sample size. Furthermore, it is not possible to differentiate the specific effect of the picture and word priming interventions from the effect of the phonological treatment that participants received at WINSi. The use of a control group to tease out effects of these additional interventions versus the usual treatment at WINSi would have been helpful.

In future research, it would be interesting to replicate this study with a control group and reading-age, and chronological-age matched controls, over a longer period of time. Additionally, studies with larger samples, along with an increased variety of ethnic, cultural, and socioeconomic backgrounds would increase the integrity of the findings. Furthermore, it would be interesting to study another group at WINSi after participants have been there for a period of time. In that case, pre-priming data could measure progress with the LIPS treatment alone. Data could then be gathered pre-and post-

priming interventions to measure how students made progress with LIPS treatment alone, versus their progress with the priming interventions added.

Since there are multiple neural areas involved in reading, it makes sense that many children with dyslexia require different types of treatments. The treatment needs to address an individual's unique areas of weakness. This study supported this finding in that some participants benefitted from picture priming, some benefitted from word priming, and one participant did not benefit from either intervention. A direction for future research might be the development of a screening tool to help determine which students are likely to respond best to a given intervention, then incorporate this approach into their treatment. For instance, once it is determined which students would benefit from word priming, computer-based programs or other technology could be used to allow students to practice strategies that work for them. Skylar, for example, said that if word priming (rhyming) interventions were on her iPhone, she would definitely use them. Providing individualized technology specifically aimed to help students practice targeted interventions may prove to be a beneficial supplement to more broad-based empirically supported treatments for dyslexia.

Conclusion

Findings from this study suggested that a functional relationship was found in word recognition when primed with pictures for most participants. In addition, a functional relationship was found when target words were primed with phonologically similar words for one participant. Along with these findings, students' accuracy in reading target words increased as error rates on target words decreased when primed with either pictures or words. Overall, picture priming was helpful for readers with less-well

developed decoding skills, while word priming was helpful for a reader with slightly more advanced decoding skills. Furthermore, students appeared to enjoy this intervention, it was able to be delivered in a relatively efficient manner (e.g., about 5 minutes per day), and for at least one student, seemed to bolster her confidence in reading and deepen her understanding of word relationships. Consequently, this intervention appears to be a good adjunct treatment for some readers, and is suggested for students with similar neurodevelopmental profiles.

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APPENDIX A

SELECTED INDIVIDUAL WORD LISTS

SELECTED INDIVIDUAL WORD LISTS

(30 selected words from each participant's word list of 90 words)

Jayla – Gr. 1
bad
big
came
cat
dig
dog
fan
fun
gas
girl
hot
kit
lap
leg
mad
man
nap
net
play
red
rim
rug
six
some
sum
sun
tag
tub
van
wax

Carol – Gr. 2
back
books
catch
cheer
children
earth
factory
friends
games
grade
happy
island
jump
lake
light
make
motor
night
ocean
parade
peach
rain
room
sack
school
teach
think
watch
world
yard

Devon – Gr. 3-4
animals
benches
blimp
bright
change
crave
dark
fire
found
globe
ground
high
house
knew
light
lizard
might
mountain
number
page
picture
rather
river
second
should
table
treasure
walked
white
year

Skylar – Gr. 5-7
accord
ahead
batteries
bracelet
chimney
curricular
discover
dolphin
electricity
elephant
feather
gaunt
iceberg
jockey
linger
machine
oxygen
period
quest
quick
reception
record
solider
stapler
terminate
tycoon
unique
urban
weather
woman

Raymond – Gr. 10-12
aerospace
aesthetic
archeology
binoculars
bungalow
circadian
constellation
denomination
disposition
dynamic
evocative
exposition
hemisphere
ponder
rancorous
innocuous
obtuse
photographs
inscrutable
loquacious
lugubrious
magnanimous
obstreperous
rendezvous
scripture
supercilious
symmetrical
terrarium
transcript
voracious

APPENDIX B

STATISTICAL CALCULATIONS

STATISTICAL CALCULATIONS

Percentage of Nonoverlapping Data (PND) (adapted from Parker, Vannest, & Brown 2009)

1. Find the most extreme baseline data point in the desired direction (i.e. for this study, the lowest data point since reaction time was calculated).
2. Count all of the intervention phase data points above or below that point, depending on direction of desired effect.
3. The answer is framed as a percentage of all of the intervention data points (e.g. 9 of 10 data points in treatment were higher (lower) than the baseline data point.
4. Convert answer to decimal (e.g. 9/10 = .9)
5. The .9 answer reflects an PND of .9, which is referred to as a very effective or large effect size.

Improvement Rate Difference (IRD) (adapted from Parker, Hagan-Burke, & Vannest, 2007)

1. Compare baseline and intervention data points. Count total number of points in each phase (e.g. Phase A = 10 points, phase B = 10 points)
2. Write an "improvement rate" fraction for each phase.
    a. For the baseline phase(s), calculate the number of improved data points when compared to a specific treatment. Improved data in the baseline phase is defined as one that ties or exceeds any data point in the treatment phase. Note that "exceeds" refers to the higher levels of behaviors wished to be seen. In this study, "exceeds" refers to the faster reaction time, hence the lower number of milliseconds of response time to a given word or picture. Divide the number of improved data points by all the data points in the phase (e.g. 2 of 10 baseline data points improved compared to treatment = 2/10 or .2)
    b. For a specific treatment phase(s), calculate the number of improved data points when compared to baseline phase(s). An improved data point in the treatment phase is defined as any which exceeds all data points in the baseline phase. Once again, "exceeds" refers to a lower number of milliseconds. Divide the number of improved data points by all the data points in the phase (e.g. 9 of 10 treatment data points improved compared to baseline = 9/10 or .9)
3. Subtract the baseline fraction from the treatment fraction (e.g. 9/10 – 2/10 = 7/10).
4. Convert answer to decimal (e.g. 7/10 = .7).
5. The .7 answer reflects an IRD of .7, which is referred to as a moderate effect size.

APPENDIX C

INSTITUTIONAL REVIEW BOARD APPROVAL

UNIVERSITY of
NORTHERN COLORADO

Institutional Review Board

DATE: September 29, 2013

TO: Cynthia Johnson
FROM: University of Northern Colorado (UNCO) IRB

PROJECT TITLE: [511035-2] Priming Effects on Word Recognition in Children with Dyslexia
SUBMISSION TYPE: New Project

ACTION: APPROVED
APPROVAL DATE: September 29, 2013
EXPIRATION DATE: September 29, 2017
REVIEW TYPE: Expedited Review

Thank you for your submission of New Project materials for this project. The University of Northern Colorado (UNCO) IRB has APPROVED your submission. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on applicable federal regulations.
Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require that each participant receives a copy of the consent document.

Please note that any revision to previously approved materials must be approved by this committee prior to initiation. Please use the appropriate revision forms for this procedure.
All UNANTICIPATED PROBLEMS involving risks to subjects or others and SERIOUS and UNEXPECTED
adverse events must be reported promptly to this office.
All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of September 29, 2017. Please note that all research records must be retained for a minimum of three years after the completion of the project.

If you have any questions, please contact Sherry May at 970-351-1910 or Sherry.May@unco.edu. Please include your project title and reference number in all correspondence with this committee.

Cynthia –

Hello. Thank you for making the revisions requested by Dr. Collins, the first reviewer. I've reviewed the revisions and all original materials and have no further modifications to request.

Please use the materials revised during this review in your participant recruitment and data collection.

Don't hesitate to contact me with any IRB-related questions or concerns.

Sincerely,
Dr. Megan Stellino, UNC IRB Co-Chair

APPENDIX D

PARENT CONSENT FORM

UNIVERSITY of
NORTHERN COLORADO

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO

Project Title: Priming Effects on Word Recognition in Children with Dyslexia

Researcher: Cynthia Johnson Ed.M.; Ph.D. Student in School Psychology

Phone: 303-413-8780 E-mail: john4830@bears.unco.edu

Research Advisor: Dr. Robyn S. Hess, Professor of School Psychology, Chair of the School Psychology programs
Phone: 970-351-1636 E-mail: robyn.hess@unco.edu

I am researching the effect of word and picture priming on word recognition tasks for children with dyslexia. I would like to investigate whether seeing an associated word or picture first helps your child read an associated word shortly thereafter. If you grant permission and if your child indicates to us a willingness to participate we will adjourn to a quiet room with a computer to do a reading task on the computer. Your child will be asked to read a word (or say the name of a picture) on the computer, and then read an associated word. A program on the computer will track the time it takes for your child to say a word, and I will note any errors. Your child will be asked to read 10-20 words per session. Each session will take 5 – 10 minutes, and will be done at the end of their day at WINSi, so their time getting treatment at WINSi will not be affected. Sessions will take place 4 days a week, and there will be approximately 25 sessions in total throughout the Fall 2013/Spring 2014 timeframe.
I foresee no risks to students beyond those that are normally encountered while getting treatment at WINSi. Your child's participation will not be solicited during treatment, snack, or lunch times. At the conclusion of this study, the outcomes of this study will be available to you upon your request, and will be given to WINSi to inform their future treatment plans for your child. Secondly, your child will receive a gift card to Target in the amount of $15 for his/her participation.

I will audio record these sessions to back up the notes that I take. Be assured that I intend to keep the contents of these audio recordings private. The purpose of audio recording is solely for me to be able to verify student responses. Audio recordings will use the numeric identification system to protect your child's identity. I will be the only person who will have access to the recordings. These audio recordings will be destroyed at the conclusion of the study.

Data from this study will be stored on a home computer that is password protected. Only I will have access to the data. Participants' identity will be protected by the use of a numeric identification system. Through the use of the numeric identification system, data will not be able to be traced back to the original source from identifiers used in the records. While it is impossible to *guarantee* confidentiality, everything will be done to ensure that records remain confidential.

Please feel free to phone me if you have any questions about this research and please retain one copy of this letter for your records.

Thank you for assisting me with my research.

Sincerely,

_____

Participation is voluntary. You may decide not to allow your child to participate in this study, and if (s)he begins participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not affect the treatment your child is currently receiving at WINSi. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact the Office of Sponsored Programs, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-2161.

_____	_____
Child's Full Name (please print)	Child's Birth Date (month/day/year)
_____	_____
Parent/Guardian's Signature	Date
_____	_____
Researcher's Signature	Date

APPENDIX E

WRITTEN STUDENT ASSENT FORM

UNIVERSITY of
NORTHERN COLORADO

(Note: This form is for participants above the age of 10 yrs. They will read it, or will have it read to them. They will then sign the document.)

ASSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH

UNIVERSITY OF NORTHERN COLORADO

Hi,

My name is Cynthia. You've seen me around here at WINSi, and I've probably done some reading tasks with you. I'm also a student who's learning how to work with kids who are smart but having a hard time learning some things. I'm doing a study to see if a new type of reading activity will help you read some words. I will be working with some of the kids here at WINSi. If you want, you can be one of the kids with whom I work.

If you want to work with me, we'll be doing an activity on the computer. The computer program will show you a word or a picture, and I'll ask you to read that word or name that picture. Then you'll see another word on the computer, and I'll ask you to read that word. You'll be reading 10-20 words each time we meet. This activity will take about 5 minutes each time we meet.

We'll meet at the end of your day at WINSi, so it won't get in the way of the other stuff you're doing at WINSi. We'll meet 4 days a week from October through December. We may meet again the Springtime depending on absences etc… If you decide you want to do this computer activity with me this Fall, you'll receive a gift card to Target in the amount of $15 when the study is done. Talking with me might or might not help your future activities at WINSi. But it definitely won't hurt you. Your parents have said it's okay for you to work with me, but you don't have to. It's up to you. Also if you say 'yes' but then change your mind, you can stop any time you want to.

I will audio record these sessions to back up the notes that I take. Be assured that I intend to keep the contents of these audio recordings private. No one else will listen to these audio recordings. These audio recordings will be destroyed at the end of the study.

I will keep data from this study will be stored on a home computer that is password protected. That means that other people won't be able to see it. The data will be destroyed at the end of the study.

Do you have any questions for me about my study?
If you want to me in my study, and do the computer activities, sign your name below and write today's date next to it. Thanks!

_____ _____
Student's Signature Date

_____ _____
Researcher's Signature Date

APPENDIX F

VERBAL STUDENT ASSENT FORM

UNIVERSITY of
NORTHERN COLORADO

(Note: This form is for participants above the age of 10 yrs. They will read it, or will have it read to them. They will then sign the document.)

Hi,

My name is Cynthia. You've seen me around here at WINSi, and I've probably done some reading tasks with you.
I'm doing a study to see if a new type of reading activity will help you read some words. I will be working with some of the kids here at WINSi. If you want, you can be one of the kids with whom I work.

If you want to work with me, we'll be doing an activity on the computer.
The computer program will show you a word or a picture, and I'll ask you to read that word or name a picture. Then you'll see another word on the computer, and I'll ask you to read that word. You'll be reading 10-20 words each time we meet. This activity will take about 5-10 minutes each time we meet.

We'll meet at the end of your day at WINSi, so it won't get in the way of the other stuff you're doing at WINSi.

We'll meet 4 days a week from October through December, and maybe some days in the Spring. If you decide you want to do this computer activity with me this Fall, you'll receive a gift card to Target in the amount of $15 when the study is done.

Your parents have said it's okay for you to work with me, but you don't have to. It's up to you. Also if you say 'yes' but then change your mind, you can stop any time you want to.

I will audio record these sessions to back up the notes that I take. No one else will listen to these audio recordings. These audio recordings will be thrown away at the end of the study.

I will keep data from this study will be stored on a home computer that is password protected. That means that other people won't be able to see it. The data will be thrown away at the end of the study.

Do you have any questions for me about my study? If you want to me in my study, and do the computer activities, sign your name below and write today's date next to it. Thanks!

_____ _____
Student's Signature Date

_____ _____
Researcher's Signature Date

APPENDIX G

WINSi CONSENT FORM

(Note: The Western Institute for Neurodevelopmental Studies and Interventions (WINSi), has provided the consent form and privacy practices that they have parents sign prior to treatment for their child. I have included the most relevant consent forms here. Signed consent forms are kept on file at WINSi.)

WINS*i*

WESTERN INSTITUTE FOR NEURODEVELOPMENTAL STUDIES AND INTERVENTIONS
2501 Walnut Street, Suite 102
Boulder, CO 80302
Telephone: (303) 442-4750 ⌘ Fax: (303) 443-4682

Kytja K.S. Voeller, M.D., Director	**Karen Majesky, B.A., ASL Interpreter, Therapist**
Jill Gitten Aloia, Ph.D., Associate Director, Neuropsychologist	**Maya Gammon, B.A., Therapist**
Jean Riordan, Ph.D. CCC/SLP, Associate Director, L.D. Speech/Language Therapy Supervisor	**Star Slade, B.S., Therapist**
	Noah Goldstein, B.S., Therapist
Joshua Morris, B.A. Operations Manager, Recreational Therapist	**Holly Sroymalai, M.A., Therapist**
	Julie Swan, B.A., Therapist
Natalie McKechnie, OTR, Occupational Therapist	**Grant Chambers, M.A., Therapist**

INFORMED CONSENT/CONTRACT FOR TREATMENT

PATIENT NAME: _____

I hereby consent to treatment of _____ to be administered at the Western Institute of Neurodevelopmental Studies and Interventions (WINSi). I certify that, that I have the legal authority to request such treatment. I understand that it is my responsibility to maintain scheduled appointments, provide payment for services rendered, and provide an accurate and complete account of current and past evaluations, treatment, symptoms and complaints. _____ _____

Signature of Parent/Guardian Date

Mr./Mrs./Ms./Dr._____ _____
Please Print Name Relationship to Patient

_____
Witness Signature /Print/Date

AUDIOVISUAL CONSENT FORMS

PATIENT NAME: _____

I understand that WINSi will periodically use audiovisual materials (video and audio recording) to keep a record of my child's response to therapy. It may be helpful for me to watch the treatment program in action (children often behave differently when a parent is observing). These materials form a chronology of therapy activities and enable WINSi to track progress. They also enable WINSi to use the tapes for training WINSi staff.

I, therefore, give my permission to have my child filmed and/or recorded during therapy.
I will be informed in advance of the filming dates and will have the opportunity to review any film taken of my child in the facility.

_____ _____
Signature of Parent/Guardian Date

Mr./Mrs./Ms./Dr. _____ _____
Please print name Relationship to Patient

_____
Witness Signature/Print/Date

PATIENT NAME: _____

Certain videotapes may clearly demonstrate some of the specific problems of a child with dyslexia and how these problems respond to specific treatment strategies, and would be useful in presentations to educators and researchers in this field. I, therefore, give my permission to WINSi to use audiovisual materials for this purpose.

_____ _____
Signature of Parent/Guardian Date

Mr./Mrs./Ms./Dr. _____ _____
Please print name Relationship to Patient

_____

APPENDIX H

SUMMARY OF STUDY IN ARTICLE FORMAT

Priming Effects on Word Recognition in Students with Dyslexia

Cynthia T. Johnson

University of Northern Colorado

Abstract

Given that children and adolescents with dyslexia may struggle academically as well as socially and emotionally, it is critical to understand and develop methods for early intervention. A growing body of research has focused on reading interventions that include word priming which typically involves numerous presentations of words that are phonologically or semantically related to a target word.

The purpose of this study was to investigate the effect of word and picture priming on the reaction times of word recognition tasks for five children and adolescents aged 7 – 16 with dyslexia. Results of this 25-session multiple-case multiple treatment reversal design study showed that picture priming treatments assisted all participants in reading target words more quickly. Word priming treatments assisted four of the five participants in reading target words more quickly. All participants decreased their reaction time reading target words more when presented with picture primes than with word primes.

Yet the decoding ability of participants affected their perceptions of the benefits of the two types of intervention. While readers with less decoding ability preferred picture primes, more advanced decoders felt word primes were more beneficial. Overall, results showed that younger and less-skilled readers showed enhanced effects of semantics, compared with older readers, whose decoding skills were relatively efficient and provide less opportunity for indirect activation flow via semantics. These findings are consistent with the proposition that the semantic pathway can compensate direct orthography-to-phonology translations when that process is slow and inefficient.

Reading disabilities are a significant problem in education. Dyslexia affects 5-10% of the population (Vogel & Holt, 2003), and children who don't learn to read by third grade are at risk of dropping out of school (J. K. Torgesen et al., 1999). It is known that reading is a very complex skill, and utilizes many different parts of the brain. To be a successful reader, one must rapidly integrate a vast circuit of brain areas with both great accuracy and remarkable speed. This "reading circuit" is composed of neural systems that support every level of language—phonology, morphology, syntax, and semantics—as well as visual and orthographic processes, working memory, mental processing speed, attention, motor movements, and higher-level comprehension and cognition. As our reading abilities develop, each of these components works smoothly with both accuracy and speed; the reader develops what is called automaticity. As cognitive process becomes automatic, it demands less conscious effort (Norton & Wolf, 2012). This combination of reading accuracy and speed is commonly known as reading fluency.

Similar to this conceptualization of the reading circuit, current research regarding reading fluency also points to a multicomponent view (Berninger, Abbott, Billingsley, & Nagy, 2001). Reading fluency, or the rate at which one reads, is considered to be a product of phonological representation (i.e., the ability to mentally conceptualize the sounds and combinations of sounds that comprise words) and phonemic awareness (i.e., the ability to hear, identify, and manipulate individual sounds in spoken words), orthographic (letter-pattern) identification, decoding and word recognition, auditory and visual perception (i.e., the ability to recognize or interpret *what is* heard and seen), attention, and short-term and long-term memory (Berninger et al., 2001). Together, these

various foundational skills of reading come together in the process of learning to read fluently.

Much research has also gone in to examining reading fluency. According to Wolf and Katzir-Cohen (2001), reading fluency refers to "a level of accuracy and rate where decoding is relatively effortless; where oral reading is smooth and accurate with correct prosody; and where attention can be allocated to comprehension" (p. 219). Difficulty in reading fluency is one of the major problems in children with reading disabilities: their reading is slow, hesitant, and sometimes extremely laborious (Thaler, Ebner, Wimmer, & Landerl, 2004). Before discussing reading difficulties, or dyslexia further, a definition of dyslexia is necessary. Dyslexia is actually a very specific type of reading disability; a widely accepted current definition of dyslexia is that it is a neurodevelopmental disorder with a probable genetic basis. The core feature of dyslexia is a problem with word decoding, which in turn impacts spelling performance and the development of reading fluency (Snowling, 2013).

According to J. K. Torgesen, Wagner, Rashotte, Herron, and Lindamood (2010) there is no single test and no absolute criteria for diagnosing dyslexia. This is in part due to the fact that there are so many processes in reading that can break down to cause reading failure. Inaccuracy at any level of language or processing or a lack of automaticity in connecting any of these circuits can lead to poor reading. More than 100 years of research into developmental reading difficulties has yet to reveal anything resembling one single explanation for all the symptoms of dyslexia (Norton & Wolf, 2012). Yet recent research has named the different processes likely to be responsible for reading difficulties. Rather than a single deficit always being the culprit, Pennington et

al. (2012) found that a phonological deficit, or fluency factors such as processing speed and naming speed may work in concert to cause reading disabilities for many children.

Various models have been proposed to assist young readers in their ability to recognize words. Some models involve different types of words in priming, or repeated reading activities, while others discuss priming with pictures and words. In an attempt to explain the relationship between picture and word naming, Biggs and Marmurek (1990a) conceptualized a Processing Overlap model in which it was predicted that facilitation in naming the second of two items is a function of the overlap in processing accorded to the prime and the targets. They assumed that printed words were processed by a phonetic system that was rule-governed and separate from a general semantic system. The general semantic system includes semantic processing of words, referring to the processes of encoding the meaning of a word and relating it to similar words with similar meaning. Semantic processing of words follows from activation of the phonetic system. Unlike printed words, pictures representing objects have direct access to the semantic system (Biggs & Marmurek, 1990a).

A second model of word priming in people with dyslexia is called the dual-coding model (Paivio, 1991). Researchers using this model compared different types of words rather than pictures and words. Supporters of this model hypothesize that the critical difference between abstract and concrete words is that concrete items are represented in both imagery and linguistic codes, whereas abstract items are only coded linguistically (Paivio, 1991).

Plaut, McClelland, Seidenberg, and Patterson (1996) suggested a third model for understanding the effect of priming. The Triangle Model describes word recognition as

dependent on three separate abilities: phonological representation, orthographic representation, and semantics, which is similar to and reflects the multicomponent view of reading fluency consistent with the perspective of Berninger et al., 2001. This connectionist approach explains that the reading system gradually becomes sensitive to the structure among orthographic, phonological, and semantic representations (Plaut et al., 1996). Plaut et al. (1996) conceptualized this relationship as a division of labor between the phonological and semantic pathways such that neither pathway alone was completely sufficient and the two had to work together to support skilled word and nonword reading (Plaut et al., 1996).

In summary, these three models provide different mechanisms or models to describe how the brain recognizes words. Supporters of the Processing Overlap Model conceptualize the phonetic system as separate from the semantic system. Supporters of the Dual-coding Model purport both imagery and linguistic codes, where that abstract words are primed better by semantic association, while concrete words are primed by semantic similarity. While different types of words are primed differently, they both use the semantic pathway. Supporters of the third model, the Triangle Model, believe that word recognition is dependent on three separate abilities that work in concert, the phonological, orthographic, and semantic pathways. While these models differ in specifics, they all agree that the semantic pathway contributes to word recognition. Most recent research regarding dyslexia and related interventions has supported the multicomponent view of the Triangle Model (Plaut et al., 1996).

Interventions for word recognition come from a variety of phonological, morphological, and semantic areas. Some general phonological interventions involve

activities targeting phonological awareness, phonemic decoding, and practice with repeated readings. For instance, in a meta-analysis of word recognition intervention research, some studies found improvement in teaching phonological skills such as segmenting, blending, and phoneme manipulation (Gillon & Dodd, 1997; Wright & Mullan, 2006). A commonly used, evidence-based program for developing word recognition is *The Lindamood Phoneme Sequencing Program for Reading, Spelling, and Speech* (LIPS). LIPS provides explicit and systematic support for the development of phonemic awareness, phonemic decoding (and writing), and text reading accuracy through practice reading (Lindamood & Lindamood, 1998). Students learn to recognize how their mouths produce the sounds of language.

In addition, a growing body of research has focused on interventions that include word priming which typically involves numerous presentations of words that are phonologically or semantically related to a target word as a way to introduce the target words. With repeated practice of similar words, the reader is able to more quickly identify the target words. Although several researchers have examined the effects of word priming interventions, these studies have generally included typical readers (Biggs & Marmurek, 1990b; Hennessey & Kirsner, 1999; Wheeldon & Monsell, 1992), children with speech impairments (Bragard, Schelstraete, Snyers, & James, 2012), or adults with dyslexia (Crutch & Warrington, 2007). Fewer studies have been carried out which focus on children with dyslexia. One such study by Hennessey, Deadman, and Williams (2012) examined word and picture priming in children with dyslexia. In sum, Hennessey et al. (2012) found that younger and less skilled readers used their semantic pathways to find meanings of words to help them decode words, since their decoding skills were less

efficient than older skilled readers. This is important because if we can learn about the various pathways that contribute to learning to read, and develop interventions that address each of them, then we can more accurately match them to the specific struggles that children are having. While the semantic pathway is potentially beneficial for struggling readers in general, there is no research to date that has been found where word priming was done in addition to phonologically-based treatments for dyslexia. As many children with dyslexia receive multiple treatments, this investigation is thought to resemble more realistic situations than when interventions are done in isolation.

The purpose of this study was to investigate the value added of implementing a word priming program for children with dyslexia, who are also receiving a phonological (*LIPS*) treatment. Specifically, this study investigated the effect of word and picture priming on the reaction times of word recognition tasks for five children and adolescents with dyslexia.

The following research questions were addressed in this study:

Q1 For individual school-aged children and adolescents with dyslexia, do word recognition reaction times decrease when primed with related pictures?

Q2 For individual school-aged children and adolescents with dyslexia, do word recognition reaction times decrease when primed with phonologically similar words?

Q3 For each individual student, do word recognition reaction times decrease more when primed with pictures or words?

Method

This study used a multiple-case multiple treatment reversal design in order to document the functional relationships between the independent and dependent variables. For this study, the dependent variable of interest was the reaction time to word recognition tasks. For increased experimental control, a dependent variable that was not

expected to change (i.e., processing speed) was measured. The independent variables were the time it took to read individual words under word priming and picture priming conditions.

This study featured a five-phase design that included baseline phases, word priming phases and picture priming phases. All participants began with an unprimed baseline phase, and continued with both picture and word priming phases. When a treatment appeared to be helpful, a baseline phase was reiterated to attempt to determine a functional relationship. The last phase was a repeat of the treatment that appeared to be most helpful to the participant.

Participants

Purposeful sampling was used in this multiple case study. Five children aged 7 - 16 who are currently receiving services for dyslexia at the *Western Institute for Neurodevelopmental Studies and Interventions* (WINSi) in Boulder, Colorado, were recruited to participate in this study. WINSi provides diagnostic and treatment services to children with learning disabilities, attention deficit/hyperactivity disorder, and related behavioral disorders. To receive treatment at WINSi, children have typically received diagnoses of a language-based learning difficulty, such as dyslexia, receptive, or expressive language disorder.

WINSi's rehabilitation program is a 10-week, five hour a day, five day a week program that the child attends instead of going to his or her home school. At the end of the 10-week program, the child is re-evaluated, and a decision is made as to whether the child needs extended therapy, or the child can proceed into a follow-up program. The follow-up program is an afterschool program the child attends at WINSi for one to five

days a week for approximately one year. WINSi typically serves five to seven students at a time. There were five individuals at WINSi who met criteria to be included in this study. Three of the participants started their WINSi treatments in September 2013, one had received treatment for a year, and one participant was a follow-up student, meaning she attended the afterschool program at WINSi two days a week.

All but one participant (Carol) had been identified as having co-morbid conditions in addition to their reading disorders. For example, three participants (Jayla, Alexia, and Devon) had been diagnosed with ADHD. Both Jayla and Raymond has been identified as having mixed receptive-expressive language disorder. Skylar was also diagnosed with Tourette's syndrome. As children with dyslexia often have impaired reading accuracy, exclusionary criteria for this study include students classified as Average or above in Oral Reading (based on the Oral Reading Index of the Gray Oral Reading Test-Fifth Edition).

Participant demographics are provided in Table 1. All participants' names reflect pseudonyms to maintain participant confidentiality. All students were of upper/middle socioeconomic backgrounds.

(Insert Table 1 here.)

Instrumentation

Two different sources of data were collected for this study; normative measures and reaction time measures from E-Prime software. First, a number of measures were used to assess reading fluency, word recognition, rapid naming, and mental processing speed. Specifically, reading fluency was assessed using the Gray Oral Reading Test-Fifth Edition (GORT-5). Word recognition was measured using the following assessments: Test of Word Reading Efficiency (TOWRE), Sight Word Efficiency (SWE) subtest (J.

Torgesen, Wagner, & Rashotte, 2012); and the Woodcock Johnson III Tests of Achievement, Letter-Word Identification subtest. Rapid naming measures were assessed using the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999). Mental processing speed was assessed using the Processing Speed Index (PSI) from the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV).

The second source of data was collected using E-Prime software to measure response time for reading specific words presented with and without different types of priming stimuli (discussed in more detail in the Procedure section).

Procedure

Prior to the start of this investigation, approval was provided by the Institutional Review Board (IRB) at The University of Northern Colorado for research with human subjects. Although informal permission has already been provided by WINSi, a more formal agreement was obtained as part of the IRB process. Parents of the participants were asked to provide informed consent form, and students were asked for their assent.

The sessions occurred on-site at WINSi five days per week at the end of the participants' day. As noted, all participants were receiving other services (i.e. *LIPS* program) as part of the program at WINSi. The researcher conducted all sessions. Sessions lasted approximately five minutes in length, and there were five sessions per phase (i.e. baseline, word prime, picture prime). Consequently, each of the five students participated in 25 sessions throughout the five phases.

Testing was conducted on a Dell computer, with an i7 processor, running Windows XP. This computer also had E-Prime 2.0 software on it, as well as Excel 2010

software. Test trials began with five white asterisks pasted centrally onto a black screen for two seconds to serve as a fixation point. The asterisks were then replaced by a picture or word prime, also pasted centrally, which remained on the screen until the child read the word or named the picture. When the child responded, the researcher pressed a specific button on the computer, which triggered the reaction time to be figured in E-Prime. For example, the researcher pressed a '1' on the computer if the child named the picture or read the word correctly, and clicked the mouse if the child was incorrect. Asterisks were then pasted centrally for a two second wait before the target stimulus was presented. The target word was pasted centrally, and remained on the screen until the child responded. Again, the time to respond was recorded by the E-Prime software. Consequently, the cycle ran as follows: asterisks for two seconds, followed by the prime (which stayed onscreen until the researcher pressed a button), followed by two seconds of asterisks, followed by the target word (which stays onscreen until the researcher pressed a button). The cycle then repeated, and went for 10 cycles until all 10 word or picture/word pairs were given. All words were presented in Arial size 48 font. Each child was instructed to name each word and picture as quickly and accurately as possible with a standardized set of instructions. A set of five practice trials occurred before each session began.

In the baseline phases, 10 randomly selected target words were provided by E-Prime software, which was programmed to provide words in a random order. In word priming phases, 10 phonetically-similar word pairs (20 words) were given. Each prime word was followed by its phonetically similar target word (i.e. book/cook). In picture

priming phases, 10 picture/word pairs (10 pictures/10 words) were given. Each picture was followed by its target word, which was the name of the item in the picture.

An individualized word bank of 90 one to five syllable words that were one year above participant's current reading level was created for each participant. Reading levels were originally based on the GORT-5 Accuracy score. Thirty words also had corresponding digitized photographs of everyday objects (i.e. prime = picture of dog/ target = word 'dog'). The remaining 60 words were split into pairs, and were phonetically similar (i.e. prime = book, target = cook). Consequently, each child had a word bank of the following: 30 picture primes/ 30 corresponding target words; 60 phonetically similar prime/target word pairs (i.e. book/cook). Individualized word lists took into account word length, familiarity, frequency, and regularity. They were created using resources such as *Rebecca Sitton's 1200 High-Frequency Words* (Sitton, 2010), *High Frequency Word lists by Grade Level* (Pinnell, Fountas, & Giacobbe, 1998), Flocabulary (Farr, Conner, Haydel, & Munroe, 2009), and elementary through high school reading books. The speech language pathologist at WINSi monitored the creation of the word lists to ensure that word length, familiarity, frequency, and regularity were taken into account.

The word lists were created by first constructing a master spreadsheet of over 1300 words for Grades 1-12. The master spreadsheet contained the following contents: the target word; grade level; whether it was a sight word or play fair word; if it was a high-frequency word; its pattern (cvc, ccvc, cvcc, cvvc, vccv); number of syllables; part of speech; whether it was a concrete, abstract, or emotion word; whether there was a picture associated with it; and all possible rhyming words.

Although reading levels were originally based a reading level that was one year above the GORT-5 Accuracy score, it was found during pilot testing that the word level selection was too easy for three of the participants. These participants easily decoded the words, when the goal was to include words that were slightly above the participants' reading level. As it turned out, the GORT-5 Accuracy scored measures accuracy during paragraph reading, yet the task of word recognition was simpler than paragraph reading. Consequently, the researcher worked with each student's therapist and the speech language pathologist in crafting individualized word lists that included more difficult words for these three participants.

The programming of the E-Prime software consisted of creating 15 separate experiments. Each of the five participants needed a 'no prime', 'picture prime', and 'word prime' experiment created for them using their own individualized word list. Each individual experiment had a sign-in screen, a welcome screen, instructions, and a practice section consisting of 5-word practice trials that participants needed to read correctly with 80% accuracy to advance to the real trials. Typically, the practice trials included words that the participant could easily decode, as the purpose was to practice the procedure. Subsequently, the target or prime/target trails would be given. At the end of the session, a video of fireworks and an exclamatory screen with a closing remark (i.e. You Did It! Thank you and Goodbye!) were provided to help participants celebrate their effort.

The order of this five-phase study was decided on an individual basis, yet all participants received all five phases. For example, there were two baseline phases that were unprimed (only target words were given), along with a B-phase consisting of picture priming, and a C-phase consisting of word priming. The last phase was a repeat of the

treatment phase that was most helpful to the participant. The flexibility inherent in this design allowed it to be optimized for each individual student. Table 2 illustrates the order of the phases completed by each participant.

(Insert Table 2 here.)

All participants started with a baseline phase (A). The decision of which phase to offer as the second phase, picture primes (B) or word primes (C), was done randomly among the five participants. To establish the random order, a coin was flipped for each participant, with 'heads' determining to start with picture primes, and 'tails' determining to start with word primes. As reaction times to both picture and word primes decreased in the second phase for all participants, a baseline phase was then repeated in the third phase. Whichever treatment was given in the second phase, the alternative treatment was given for the fourth phase. For instance, if picture priming was given in the second phase, word priming was given in the fourth phase, and vice versa.

The decision of which phase to repeat in the fifth phase was decided according to how helpful the intervention was for the particular participant. For some participants, the choice was obvious. For instance, Carol, Devon, and Jayla, the younger and less experienced decoders, read target words primed by pictures much quicker than words primed by words. Consequently, picture primes were chosen for the fifth phase for these participants.

It was also decided that Raymond should receive picture primes for the fifth phase of this study. By the end of the fourth phase, Raymond's reaction time was quicker for picture primes, and he hadn't yet mentioned one type of intervention being more helpful than the other, so picture primes were chosen for the fifth phase of the study.

Skylar, on the other hand, found the word priming to be much more helpful than picture priming (details will be discussed in the Results chapter). Considering the level of helpfulness that word primes offered over picture primes, it was decided that Skylar should receive word primes for the fifth phase, even though her reaction times were approximately .5 sec longer for word primes than for picture primes.

Data Analysis

Data from this study was analyzed in a number of ways. One source of data was from the E-prime software itself. Data collected (milliseconds reaction time) from the E-prime software will be exported to Excel software to calculate median time of response to the word recognition tasks, along with error rate. This data was plotted and displayed on a line graph over time for each child to show within-person changes throughout the duration of the study.

A second source of data was the pre-post assessments from the eight assessments given, namely the TOWRE: Sight Word Efficiency subtest, WJ III Letter Word Identification subtest, CTOPP Rapid Letter Naming and Rapid Digit Naming subtests, GORT-5, and WISC Coding, and Symbol Search subtests. These data will also be plotted and displayed on a line graph over time for each child to show within-person changes from the beginning to the end of the study.

To answer the three research questions, two procedures were implemented; visual analysis and effect size. In terms of visual analysis, within-phase analysis was analyzed by looking at level of data, trend of the data, and variability. Between-phase patterns were analyzed by looking at immediacy and overlap. Both patterns help to determine if a

functional relationship exists between the independent and dependent variables (Kennedy, 2005).

The second procedure to analyze data was effect size. Two types of nonoverlap methods were used during this study. The first method was the Percentage of Nonoveralapping Data (PND). It is conceptualized as the percentage of treatment phase data that exceeds a single noteworthy point within the baseline phase (Lenz, 2013).

A second method of gathering effect size data is called the Improvement Rate Difference (IRD). The important difference between PND and IRD is that IRD uses all data points, rather than a single data point in the baseline phase. The goal of IRD is to compare improvement in intervention phase to improvement in baseline phase. Improvement in intervention phase is defined as data below any baseline points. Improvement in baseline phase is defined as data equal to or below any treatment points. For IRD, results of <.50 = very small and questionable effects; .50 -.70 = moderate effect; >.70 = large or very large (Parker, Vannest, & Brown, 2009).

Results

Picture priming treatments appeared to have assisted all participants in reading target words more quickly. Word priming treatments assisted four of the five participants in reading target words more quickly. All participants decreased their reaction time reading target words more when presented with picture primes than with word primes. Consequently, priming, and especially picture priming, helped participants increase their reading rate of individual words.

Overall reaction time performance is displayed in Figures 1-5. Note that figures 1-3 are participant reaction time to ABACB design. Figure 4 refers to participant

reaction time to ACABB design. Figure 5 refers to participant reaction time to ACABC design.

(Insert Figures 1-5 here.)

Picture Priming

During picture prime treatment, a mean decrease in word recognition reaction time was seen in all five participants, as shown in Figures 1-5 and Table 3. Examination of change in trend revealed a noticeably large decrease in reaction time from baseline to treatment for all participants. Most notably, Jayla's mean reaction time decreased by more than 300% from baseline to treatment. One example illustrating how picture priming helped Jayla was evidenced on some of the individual words, such as the word 'girl'; Jayla incorrectly read the word during a baseline (no prime) phase. She then saw a picture of a 'girl' in a picture priming session, but she honed in on a flower barrette the girl was wearing in the picture, and said the word 'flower' rather than 'girl'. Yet when the word 'girl' was given after the picture, she correctly read the word. She originally responded incorrectly to both the target word and the picture prime, yet was still correct in reading the target word after the picture prime. The picture priming not only helped Jayla read words quicker, it also appeared to help with word recognition accuracy.

Results of PND analysis revealed the presence of a treatment effect, illustrating that the picture prime treatment appeared to be very effective ($\geq .90$) for all five participants. Improvement Rate Difference (IRD) illustrated similar findings in all students with the exception of Raymond, for whom IRD showed picture priming to be moderately effective.

(Insert Table 3 here.)

Word Priming

During rhyming word prime treatment, a mean decrease in word recognition reaction time was also seen in all five participants, as seen in Figures 1-5 and Table 4. This can be interpreted that the word priming helped the participants read the word quicker than when no prime was available. Yet different from picture priming, examination of change in trend during word priming revealed a somewhat large decrease in reaction time from baseline to treatment for Skylar, but only a moderate change in trend for Devon, and a low change in trend for Carol, Jayla, and Raymond.

Results of PND analysis revealed the presence of a moderate treatment effect for Skylar, meaning the word prime appeared to help decrease her word recognition time. For Carol, Devon, Jayla, and Raymond, there was no treatment effect. It appeared that word priming was not an effective treatment for these four participants. IRD showed somewhat different results from PND or visual analysis. For Carol, 3 of 10 data points in baseline were improved for a score of .3. In the word priming phase, 2 of 5 data points were improved for a score of .4. The baseline score (.3) was then subtracted from the treatment score (.4) to get an overall IRD of .10. Similar to PND, this score suggested that word priming was not an effective treatment for Carol. Yet even though Devon's PND score was the same as Carol's, a more sensitive IRD score illustrates a different result. For Devon, 2 of 10 data points in baseline were improved for a score of .2. In the word priming phase, 5 of 5 data points were improved for a score of 1, for a total IRD of .8. While word priming was not effective according to PND, IRD showed that it was effective.

Raymond's negative IRD score was noteworthy. For Raymond 7 of 10 data points in the baseline phase were improved for a score of .7. In the word priming phase, only 1 of 5 data points were improved for a score of .2, for an overall IRD score of -.5. This score suggests that when words were primed with rhyming words, it took Raymond longer to read the words than if there was no prime provided. This score is in contrast to his phase mean scores for baseline and treatment. For instance, the difference in his mean score from baseline to treatment was .3 of a second, meaning Raymond read a target word .3 of a second quicker under word prime conditions than he did under baseline conditions. So while the mean scores suggest the word priming treatment was somewhat helpful, it was only by a very small amount. Interpretations regarding this contrast in analytical procedures will be discussed in the next chapter.

IRD analysis also showed a different result than PND for Skylar. For Skylar, 5 of 10 data points in the baseline phase were improved for a score of .5. In the word priming phase, 8 of 10 data points were improved for a score of .8. Baseline scores were then subtracted from the word priming scores for an overall IRD score of .3. While PND analysis showed word priming to be moderately effective, IRD analysis showed it to be questionably effective in terms of time necessary to read individual words.

(Insert Table 4 here.)

Picture Priming vs. Word Priming

Reaction times for all participants decreased more when primed with pictures rather than words, as seen in Table 5. When comparing the two treatments, Carol, Devon, Jayla and Skylar appeared to benefit the most from picture prime treatments. In contrast, Jayla and Raymond appeared to benefit the least from word prime treatments.

Both PND and IRD showed picture priming to be more effective than word priming in decreasing word recognition reaction time for all participants.

(Insert Table 5 here.)

Participants completed eight pre and post-tests subtests, including the GORT-5, TOWRE: Sight Word Efficiency (SWE) subtest, WJ III Letter Word Identification subtest, CTOPP Rapid Letter and Digit Naming subtests, and WISC Coding, and Symbol Search subtests. Composite scores are shown in Table 6. An overview of this table illustrates the severity of impact that dyslexia and other language disorders have on these participants. Yet notably, Raymond and Skylar increased their scores on the TOWRE Sight Word Efficiency (SWE) by 13 and 9 points respectively.

(Insert Table 6 here.)

Participant Reactions

While the reaction time provides some information regarding the effectiveness of the prime treatments, participant reaction to the treatment must also be considered. While the younger participants with less developed decoding ability preferred the picture primes more than the word primes, that was not the case for the older participants with more developed decoding ability. Even though the older participants read the target words more quickly with picture primes, they felt the pictures were less helpful than the word primes. For instance, Raymond said that the pictures could be interpreted in a number of ways, so the ambiguity didn't help provide a clue for the target word. Skylar voiced similar objections, saying, "If you don't know what the picture is exactly, then it doesn't help you figure out the target word." Potential reasons for the participants with more advanced decoding skills having a more difficult time naming pictures than the less

experienced decoders will be discussed in the following chapter. Skylar also felt that some pictures were so recognizable that the target word was obvious, which she felt was boring. She also felt that the word primes gave helpful clues to the target word, saying, "once I know how the first word sounds, it helps me figure out how the other word should sound." Preference of treatment types is important, as participants are more likely to use and benefit from the treatment they find more appealing.

Discussion

The purpose of this study was to investigate the effect of word and picture priming on the reaction times of word recognition tasks for five children and adolescents with dyslexia. Findings suggested that a functional relationship was found in word recognition when target words were primed with pictures, as all students' reaction times to word recognition decreased when primed with a picture. Yet reaction times decreased by a large amount for four of the participants, and at a more moderate amount for one student. Consequently, picture priming was regarded as highly effecting for four students, and moderately effective for one student.

Additionally, a functional relationship in word recognition was found when target words were primed with phonologically similar words for two participants. Findings suggested a high to moderate amount of effectiveness for word priming for one participant, and a moderate amount of effectives for the second student. Conversely, for two students with the least well-developed decoding skills, word priming was only seen as marginally effective. For the oldest adolescent with the most advanced decoding skills, word priming was not effective. This finding is consistent with researchers working with university students and adults who found that priming is not helpful for

older students with more advanced decoding abilities (Biggs & Marmurek, 1990; Durso & Johnson, 1979).

While this study focused on reaction times to word and picture priming, participant reactions to the interventions were also considered. Participant reactions regarding the helpfulness of each intervention are important, as participants are more likely to use the interventions they believe are most helpful to them. For example, by the end of the study, when Raymond had picture primes for two phases, he realized the picture primes could be more distracting than helpful when he mentioned that the picture didn't necessarily help determine the target word. This may have been becasue the more experienced decoders were reading words such as 'ponder', a verb in which can be illustrated in a number of ways; and 'symmetrical', an adjective that can also be illustrated in numerous ways. The more complex words had ambiguous pictures, making it more difficult to name the correct picture. In sum, Raymond, the most advanced decoder, did not think the pictures were very helpful, and made the most errors identifying pictures. Consequently, even though word primes (i.e. perception/conception) took Raymond a bit longer to read (<1 sec.), the words themselves were more related to the decoding process. Therefore, by the end of the study, Raymond described the word primes as more helpful.

Skylar, who was also a more experienced decoder than the younger participants, found word primes to be much more helpful than picture primes. Skylar also spoke of the myriad things a picture could be. For instance, when looking at a picture of a soldier saluting, she said, "Is it a soldier, a man, army, or salute?" In contrast, when Skylar participated in word priming phases, she was able to use one of the words to determine

the other word in the pair (i.e. perform/transform and curricular/particular), she was, according to her mother, using rhymes for the first time ever. Additionally, her mother explained that Skylar came home "talking about words", which she had never done before. The fact that her mother exclaimed what a difference this study has made in Skylar's bourgeoning affinity for words, it became evident that the word primes were helpful to Skylar. Consequently, even though it took Skylar a bit more time in reading a word prime than a picture prime (<.5 sec.), word primes were considered the more helpful intervention.

From an overall perspective, there were four general findings that supported information discussed earlier in this study. First of all, results may illustrate how children with dyslexia might use a distributed network to process information. Makuuchi and Friederici (2013) found that during sentence reading in typical readers, information is first conveyed from the visual system to the working memory system, before effectively connecting to the language system. Yet it was also found that the connection between the visual system and the language areas does not function in this way for people with dyslexia. Additionally, the *fMRI* photographs shown earlier in this study by Christodoulou et al. (2011) illustrated that readers with dyslexia employ a more distributed network that may represent compensatory mechanisms for performing RAN tasks (as cited in Norton & Wolf, 2012).

When one considers the word recognition reaction time differences for picture priming for all participants, it is apparent that these participants may employ a distributed network to process information, and may point to the ways in which they may use compensatory mechanisms when doing these types of tasks. This finding is most

apparent for Jayla, whose reaction time decreased more than 300% during the picture prime intervention.

Yet Hennessey et al. (2012) did not find significance for picture priming for children with dyslexia, although they did find significance for reading age-matched controls. The participants in both this study and Hennessey et al. (2012) were somewhat similarly impacted by dyslexia, in that reading and word recognition scores were one to two standard deviations below the expected norm for all participants. Yet Hennessey et al. (2012) reported a mean decrease in reaction time to picture primes by 78 milliseconds; while this study found a mean decrease of approximately 2570 milliseconds. It is difficult to understand why these findings were so different other than that each used substantially different procedures. In Hennessey et al. (2012), the experiment only consisted of two phases, which lasted 30 minutes in total. The participants only came in contact with the pictures/words one time. This study included 25 sessions, and participants came in contact with specific pictures and words 3-6 times throughout the study. Yet in this study, decreases in reaction time to picture primes happened the first time participants were provided pictures. Accordingly, for four of the five participants, experience seeing the pictures multiple times over the length of the study only impacted their reaction time by a small amount.

Dr. Hennessey provided a primary reason why significance was not found in picture-to-word priming. In Hennessey et al. (2012), both priming conditions (picture-to-word and word-to-picture) were combined because there was no interaction between priming and stimulus type. Although Hennessey et al. (2012) lacked sufficient power to find significance in picture-to-word priming as a stand alone condition, it is likely that the

picture-to-word priming effect (relative to the unprimed condition) would be there for the children with dyslexia and poor phonological processing (Hennessey, 2014, personal communication).

Other researchers have found differing levels of priming effects in individuals according to levels of decoding ability. Plaut et al. (1996) found that word recognition develops in young readers using the semantic pathway, hence a large priming effect for picture-to-word priming. Conversely, Biggs and Marmurek (1990) found that pictures did not facilitate word naming for university students with typical reading abilities.

Overall, the present study contributes to a growing body of evidence suggesting that younger and less-skilled readers are slower at decoding and show enhanced effects of semantics, compared with older readers, whose decoding skills were relatively efficient. These findings are consistent with the proposition that the semantic pathway can compensate for direct orthography-to-phonology translations when that process is slow and inefficient (Hennessey et al., 2012). Additionally, the use of the semantic pathway to assist the orthography-to-phonology translations lends further support to the idea that children with dyslexia may use a distributed network to process information.

Second, the use of a distributed network to process information may be conceptually related to the Triangle Model. Plaut et al. (1996) described how word recognition is dependent on a combination of phonological, orthographical, and semantic processes. For most words, activation spreads rapidly along the phonological pathway leaving little time for the semantic pathway to exert an influence on phonological output. However, the semantic pathway may compensate for the phonological pathway when

reading words with less familiar and atypical spelling to sound associations (Plaut et al., 1996).

Some of the latest research sheds additional light on the Triangle Model. For example, O'Brien, Van Orden, and Pennington (2013) studied the extent to which individuals with dyslexia were constrained by phonology in making semantic judgments while reading. Thirty-two children with dyslexia aged 7.0 to 9.2 completed a computerized semantic categorization task. They were given a category (i.e. flowers), then given a pair of homophone (i.e. rows) and pseudohomophone (i.e. roze) foils. After each foil, they were asked to push the 'yes' button if the word belonged to the category, and push a 'No' button if it did not. It was anticipated that readers with dyslexia would make fewer false positive responses when judging non-word pseudohomophones foils compared to age-matched controls, because those with dyslexia should lack access to the phonology of pseudohomophones. Surprisingly, readers with dyslexia made more false positive responses to both pseudohomophone and homophone foils, indicating that they were accessing phonology. Yet these participants accessed the phonology of the words after they had determined the connection to the category at hand. For instance, the category 'flowers' primed examples (i.e. 'rose') of the category. Then the target word (either misspelled homophone or pseudohomophone) could be matched to the example of the category. Thus, a meaning-based context serves to compensate for the decoding deficit, which is in concert with the Triangle Model.

The results from this study align with the Triangle Model. The participants, especially less experienced decoders, benefitted greatly from semantic processes. This

effect was seen when reaction times decreased significantly when primed with pictures, and also decreased when primed with phonetically-similar words.

The third general finding of this study was that participant results were consistent with the multicomponent view of reading fluency. For example, there was growth in a few of the components of reading fluency, namely phonemic awareness, and word recognition. Specifically, four of the five participants improved their performance from pre-test to post-test on the TOWRE: Sight Word Efficiency (SWE) subtest and three of five participants improved their performance on the WJIII Letter-Word Identification subtest. While some participants showed growth in these particular areas of reading fluency, only two participants improved their performance on the GORT-5 ORI, an overall reading fluency measure. These findings suggest that while participants were able to improve on some components of reading fluency, such as phonemic awareness and word recognition, only two of the five participants were able to improve their reading fluency overall. This finding is consistent with Berninger et al. (2001), who found that reading fluency is considered to be a product of multiple components, namely phonological representation, phonemic awareness, orthographic identification, decoding and word recognition, auditory and visual perception, attention, along with short-term and long-term memory.

Since there are so many components to reading fluency, it makes intuitive sense that increases in fluency typically happen over a long period of time. This priming intervention was approximately three months in duration. It would be interesting to continue priming interventions, along with the phonological awareness interventions that participants are receiving at WINSi, to see results over a longer period of time. It would

also be interesting to tease out participant progress due to WINSi treatment versus progress due to WINSi treatment plus these priming interventions.

Fourth, the deficits of the participants in this study may also reinforce the multiple deficit model of dyslexia. Wolf and Bowers (1999), and Pennington et al. (2012) found that either a phonological or language skill deficit; or fluency factors, such as processing speed, naming speed, or both phonological and fluency factors, are likely deficit areas for many children with dyslexia. This study had similar findings. For example, the participant diagnoses that were on file at WINSi, and the pre-post testing scores from this study were examined. Accordingly, Jayla and Carol both appear to have a phonological deficit, along with processing speed and naming speed deficits. Raymond appears to have a phonological and language skills deficits. Skylar appears to have phonological and processing speed deficits. Only Devon appears to have a single phonological deficit. In this study, it was seen that four of the five participants have multiple deficits associated with dyslexia.

In sum, participants in this study appeared to use a distributed network to process information, and also apparently used a combination of phonological, orthographical, and semantic processes as described in the Triangle Model. Additionally, participants' increase in some, but not all, aspects of reading fluency provides supports for the multicomponent view of reading fluency. Lastly, the multiple deficit model of dyslexia was reinforced when the deficits of each participant were fully scrutinized.

Implications for Therapists and Educators

Various models have been proposed to assist readers with dyslexia in their ability to recognize words. Some models involve different types of words in priming, or

repeated reading activities, while others discuss priming with pictures and words. The presence of picture-to-word priming reflects the activation of phonological codes for speech production via semantics on word naming, confirming a bias towards the semantic pathway during word naming for readers with dyslexia (Hennessey et al., 2012).

Participants in this study greatly benefitted from exposure to both picture and word priming. Readers with less developed decoding skills especially benefitted from picture priming. Findings from this study can inform current therapists working with these participants at The Western Institute for Neurodevelopmental Interventions and Studies (WINSi), as well as special education teachers and professionals in specialized clinics who are working with children with dyslexia.

For instance, future therapists and teachers of children with less well-developed decoding skills, such as Jayla, Carol, and Devon, can use picture priming as a preliminary activity before introducing new vocabulary words. For children with severely impacted reading abilities, picture priming appeared to be especially helpful. Picture priming can allow them to access phonology through semantics, while it can also be reinforcing for them as they become more successful in their reading efforts.

Future therapists and teachers of children and adolescents with more well-developed decoding skills, such as Skylar, can use word priming as a preliminary activity before introducing new vocabulary words. It will be important for these professionals to know that children with similar neurodevelopmental profiles to Skylar may have experienced difficulty with rhyming abilities, and been late to develop these skills. For instance, whereas children with typically developing reading skills discover rhyming at ages three through seven, Skylar didn't start to use rhyming until ages 11-12. If rhyming

is a newly developed skill for these students, they can now employ rhyming to increase their decoding abilities. Additionally, Skylar's therapists and teachers can benefit from knowing how much Skylar appeared to enjoy being given a challenge (i.e. when she asked for a 10th grade word in to be included in her word list, when she asked to read the hardest reading level possible in her post-test of the GORT-5). This penchant for a challenge was a new behavior for Skylar, and may be due in part to the success she found through rhyming. Once she found that she could successfully read increasingly complex words, her confidence appeared to soar. This finding can be broadened to many children and adolescents with learning disabilities. Once they find an avenue in which they can be successful, it can fuel their desire to learn more. This newly found confidence and desire for a challenge can be capitalized upon to promote further learning.

Future therapists and teachers of students with the most well-developed decoding skills, such as Raymond, can benefit from knowing that these children and adolescent's decoding abilities are advanced enough that priming does not appear to be helpful for them. While Raymond's reaction time to word recognition decreased when primed with pictures, he didn't find it very helpful overall. These therapists and teachers can benefit more from doing increasingly advanced vocabulary and reading comprehension work with these more advanced decoders.

Limitations and Future Research

There were a number of limitations in this study. First, since a purposeful sample was used with students already receiving services at WINSi, there was a lot of variability in the sample; some participants had received treatment for two years, while others were just getting started. Along with this variability, there was not the ability to control for

different starting levels of skill. For example, Raymond had much more well-developed decoding skills than many of the other participants. Second, there was limited generalization due to small sample size. Furthermore, it is not possible to differentiate the specific effect of the picture and word priming interventions from the effect of the phonological treatment that participants received at WINSi. The use of a control group to tease out effects of these additional interventions versus the usual treatment at WINSi would have been helpful.

In future research, it would be interesting to replicate this study with a control group and reading-age, and chronological-age matched controls, over a longer period of time. Additionally, studies with larger samples, along with an increased variety of ethnic, cultural, and socioeconomic backgrounds would increase the integrity of the data. Furthermore, it would be interesting to study another group at WINSi after participants have been there for a period of time. In that case, pre-priming data could measure progress with WINSi treatment alone. Data could then be gathered pre-and post priming interventions to measure how students made progress with WINSi treatment alone, versus their progress with the priming interventions added.

Since there are multiple neural areas involved in reading, it makes sense that many children with dyslexia require different types of treatments. The treatment needs to specifically fit with an individual's specific areas of weakness. This study supported this finding in that some participants benefitted from picture priming, some benefitted from word priming, and one participant did not benefit from either intervention. Something that could be helpful for future research would be the ability to find a more reliable way to determine which students will respond best to a given intervention, then incorporate

this approach into their treatment. For instance, once it is determined that a student would benefit from word priming, it could be very beneficial to create technology that allows students to practice strategies that work for them. Skylar, for example, said that if word priming (rhyming) interventions were on her iPhone, she would definitely use them. Providing individualized technology specifically aimed to help students practice targeted interventions may prove to be especially beneficial.

Conclusion

Findings from this study suggested that a functional relationship was found in word recognition when primed with pictures for most participants. Similar results were found when target words were primed with phonologically similar words for two participants. Overall, picture priming was helpful for readers with less-well developed decoding skills, while word priming was helpful for a reader with slightly more advanced decoding skills. Furthermore, students appeared to enjoy using these interventions, and the ability to use word priming to help decode words appeared to bolster one student's confidence in reading. Consequently, this intervention appears to be a good adjunct treatment for some readers, and is suggested for students with similar neurodevelopmental profiles.

Table 1

Participant Demographics

Student	Gender	Ethnicity	Age	Grade Level[a]	Word Recognition Grade Level[b]	Word Recognition Adjusted Grade Level[c]
Jayla	F	Afr. Amer.	7:8	K	1	1
Carol	F	Hispanic	8:7	2	2	2
Devon	M	Caucasian	10:8	4	3	3-4
Skylar	F	Caucasian	12:11	7	5	5-6
Raymond	M	Caucasian	16:5	10	10	10-12

[a]Grade Level pertains to the grade participants were enrolled in when they left their home school and entered WINSi.
[b]Word Recognition Grade Level pertains to the level of difficulty from which participant word lists were originally created.
[c]Word Recognition Adjusted Grade Level pertains to the level of difficulty from which participant word lists were adjusted with the help of student's therapist and the Speech Language Pathologist at WINSi.

Table 2

Multiple Treatment Reversal Design for Each Participant

Participant	Phase Design
Carol	ABACB
Devon	ABACB
Jayla	ABACB
Raymond	ACABB
Skylar	ACABC

Table 3

Reaction Times, Level and Trend Change, and Effect Size for Picture Prime Treatment

Participant	Baseline Mean (seconds)	PP Mean (seconds)	PP Level Change	PP Trend Change	PND	IRD
Carol	2.155	1.406	Decreasing	High	1.0	1.0
Devon	2.234	1.234	Decreasing	High	1.0	1.0
Jayla	11.271	2.606	Decreasing	Very High	1.0	1.0
Raymond	2.320	1.242	Decreasing	High	0.9	0.7
Skylar	2.989	1.646	Decreasing	High	1.0	1.0

Table 4

Reaction Times, Level and Trend Change, and Effect Size for Word Prime Treatment

Participant	Baseline Mean (seconds)	WP Mean (seconds)	WP Level Change	WP Trend Change	PND	IRD
Carol	2.155	1.917	Decreasing	Low	0.4	.10
Devon	2.234	1.718	Decreasing	Moderate	0.4	.80
Jayla	11.271	8.967	Decreasing	Low	0.2	.10
Raymond	2.320	2.039	Decreasing	Low	0.2	- .50
Skylar	2.989	2.080	Decreasing	High	0.8	.30

Table 5

Reaction Times for Picture Prime and Word Prime Treatments

Participant	Baseline Mean (seconds)	Picture Prime Mean (seconds)	Picture Prime PND	Picture Prime IRD	Word Prime Mean (seconds)	Word Prime PND	Word Prime IRD
Carol	2.155	1.406	1.0	1.0	1.917	0.4	.10
Devon	2.234	1.234	1.0	1.0	1.718	0.4	.80
Jayla	11.271	2.606	1.0	1.0	8.967	0.2	.10
Raymond	2.320	1.242	0.9	0.7	2.039	0.2	- .50
Skylar	2.989	1.646	1.0	1.0	2.080	0.8	.30

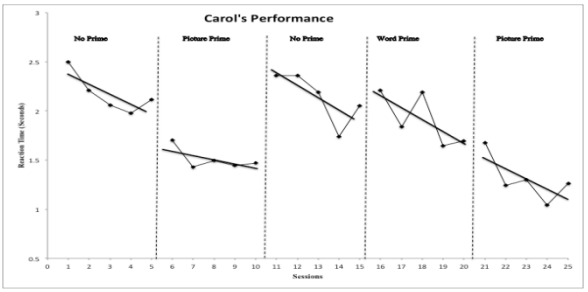
Table 6

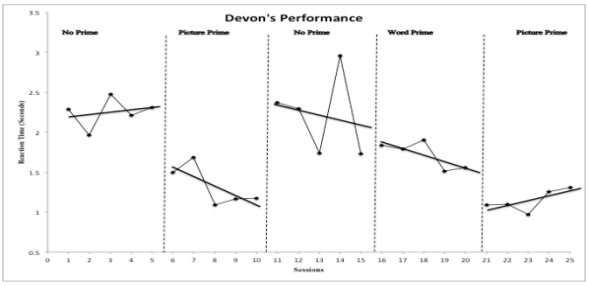
Pre- and Post Tests in Word Recognition, Reading Fluency, Rapid Naming, and Processing Speed Measures

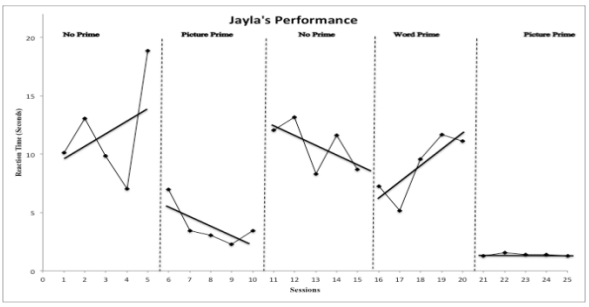
Participant	Test	GORT - 5 - ORI	TOWRE - SWE	WJ - III Letter-word ID	CTOPP - RN	WISC IV - PSI
Carol	Pre	78	74	84	82	78
	Post	78	77	80	79	85
Devon	Pre	78	77	75	91	94
	Post	81	86	77	91	94
Jayla	Pre	68	65	78	46	65
	Post	62	60	78	38	75
Raymond	Pre	89	87	101	100	88
	Post	102	100	111	106	88
Skylar	Pre	84	76	94	85	80
	Post	81	85	101	88	73

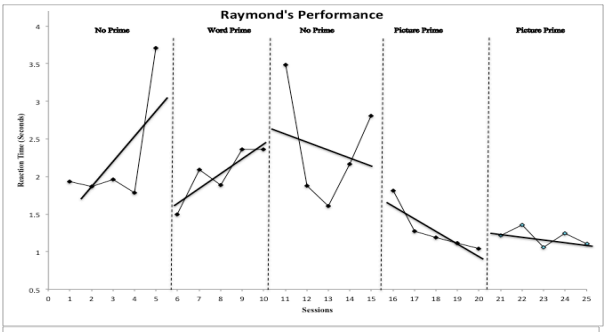
Note. WJ III Letter-word ID = Woodcock Johnson Letter-word Identification; GORT-5 ORI = Gray Oral Reading Test, Fifth Edition, Oral Reading Fluency Index; TOWRE SWE = Test of Word Reading Efficiency, Sight Word Efficiency; CTOPP – RN = Comprehensive Test of Phonological Processing, Rapid Naming composite; WISC IV – PSI = Wechsler Intelligence Scale for Children, Fourth Edition - Processing Speed Index.

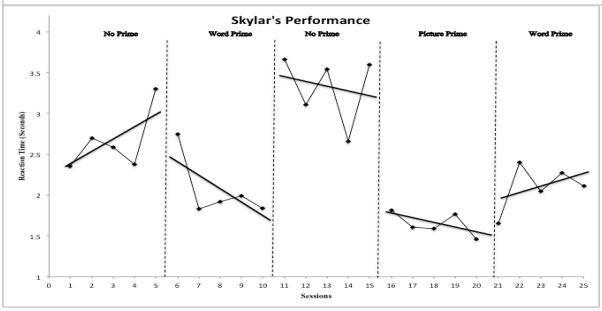
Figures











Figures 1-5. Participant reaction times, including trend lines by phase.

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