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Intensive and Systematic Training in Working Memory: Does It Have Validity for Improving Reading Achievement?

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INTENSIVE AND SYSTEMATIC TRAINING IN WORKING MEMORY:

DOES IT HAVE VALIDITY FOR IMPROVING READING ACHIEVEMENT?

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Title: Intensive and Systematic Training in Working Memory: Does It Have Validity for Improving Reading Achievement?

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It is rarely challenged that deficits in working memory during childhood are related to academic difficulties. Poor working memory is linked to difficulties focusing, remembering and completing classroom instructions, planning and organizing information, solving problems, and monitoring progress during complex tasks. Researchers have consistently demonstrated a relationship between working memory and reading ability. Moreover, it is well established that students who have deficits in reading also perform poorly on working memory tasks when compared to same-aged peers. The current study assessed the effectiveness of adaptive training on working memory and reading achievement via the use of Cogmed. Cogmed is an evidenced-based intervention designed to improve working memory. Cogmed training uses a web-based computerized system and can be accessed in various locations. The training has been demonstrated to be a complementary intervention and will likely produce the greatest benefit when combined with other sources of interventions. Research has shown that adaptive training in working memory has led to gains in word reading, reading comprehension, mathematical ability, and improved attention. The current study examined the effects of intensive and systematic training in working memory strategies on reading performance. A series of one-sample *t*-tests and two ANCOVAs were used to statistically determine improvements in working memory performance and significant differences, if any, in reading comprehension and reading fluency achievement between treatment groups. The results indicated that Cogmed training significantly improved working memory performance for the students in the experimental group. However, it appears that the gains did not result in better reading comprehension and reading fluency performance compared to the control group without the working memory training. Implications for the field of school psychology are noted as well as recommendations for future research.

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CHAPTER I

INTRODUCTION

Working memory is a dynamic process that encompasses the ability to briefly store information while simultaneously processing other cognitively challenging tasks (Alloway, 2009; Beck et al., 2010; Savage et al., 2007). Working memory capacities are essential for the successful completion of many cognitive tasks, such as reading and comprehending the content outlined within this document. Working memory may be conceptualized as,

> A key feature of human intelligence in many aspects and is represented in nearly all day-to-day function, be they intellectual, academic, social, vocational, or recreational. Memory makes us who we are and preserves our identity. Without the ability to recall our own personal history, we would be in a near state of confusion and constant dilemma. Memory allows us to acquire skills and knowledge, to perform our jobs, and to recognize and respond appropriately to our loved ones (Reynolds & Voress, 2007, p. 1).

Memory has been the focus of many research studies for several centuries. Many of these studies have focused on separating attention from memory and distinguishing immediate from short-term memory. Memory problems are often apparent in children diagnosed with learning difficulties, depression, fetal alcohol syndrome, children that had been exposed to crack cocaine, having low birth weight, and those born to mothers addicted to drugs. The extent of these memory problems often varies and typically persists into adulthood (Reynolds & Voress, 2007). Dating back to the beginning of the 20th century, an examination of memory typically required the individual to answer questions about the current date, news, and to recite letters and words as a means of assessing the functioning of one's memory. The following sections provide a brief overview of the current theoretical models of working memory, the development of working memory, the relationship between working memory and intelligence, the relationship between working memory and reading, the influence of working memory on some childhood disorders, and finally interventions that may be used to improve working memory performance.

Over the decades, several models of working memory have been proposed. Three of the theoretical approaches pertaining to working memory often cited in the literature are the multicomponent model (Baddeley, 1999), the embedded-process model (Cowan, 1999), and the dual-component model (Unsworth and Engle, 2007). Historically, the multicomponent model has been the most widely studied of the working memory systems. This model divides the system into stimulus specific buffers and a stimulus independent component. These specific buffers are the phonological loop and visuospatial sketchpad while the central executive/attentional control is the domain independent component (McCabe et al., 2010). Unsworth and Engle (2007) have also suggested another model of working memory called the dual-component model. In this model, to complete a working memory task information is retrieved from long-term memory and brought into short-term memory. The participant has to switch attention between short and long-term memory. Lastly, Cowan (1999) conceptualizes working memory as a component of long-term memory. In his embedded-process model of working memory, Cowan purports that working memory is what is activated during the process of long-term memory. In the embedded-process model of working memory, "the capacity of the focus of attention is limited to four chunks of information, and all other items in working memory reside within, and must be retrieved from, the activated portion of long-term memory" (Rose et al., 2010, p. 472).

Working memory pertains to the maintenance of short-term information that is relevant to present goals. Presently, the origins of working memory are unknown. However, it appears to be heritable. Working memory performance does not appear to be affected by parental educational level or socio-economic status. There is some evidence to show that working memory performance may be increased via intensive training (Alloway et al., 2009). There is a preponderance of evidence to show that working memory capabilities vary from individual to individual and each person's unique working memory performance will determine the acquisition of new skills and their ability to execute complex cognitive tasks (Gathercole & Pickering, 2001). The development of working memory during childhood is astounding because of the steady improvements that are noted. This increase may be noted on performance on complex working memory span tasks. These tasks assess working memory performance by requiring maintenance, recall, and simultaneous processing of information. It has been suggested that the developmental improvement noted in working memory may be accounted for by the discovery of new strategies and changes in the manner a strategy is used (Camos & Barrouillet, 2011).

Working memory is central when attempting to understand cognitive functions. Playing an important role at the cognitive basis for intelligence is working memory. There is a crucial connection between working memory and learning during childhood. Academic skills such as reading and mathematics require significant use of working memory capacities. Differences in working memory skills have been shown to be related to several areas of higher order cognitive functions, such as language comprehension, mathematics, reasoning, and complex learning. Because working memory is strongly correlated to higher order cognitive functions, it has been referred to as ‘the hub of cognition’ (Swanson, 2008).

What is the relationship between working memory and reading comprehension? How do both constructs influence each other? It is rarely challenged that deficits in working memory during childhood are related to academic difficulties. Poor working memory is linked to difficulties focusing, remembering and completing classroom instructions, planning and organizing information, solving problems, and monitoring progress during complex tasks (Elliot et al., 2010). Researchers have consistently demonstrated a relationship between working memory and reading ability (Cain, Oakhill, & Bryant, 2004; Dahlin, 2011; de Jong, 2006; Henderson & Pimperton, 2008; Nation and Angell, 2006). Moreover, it is well established that students who have deficits in reading also perform poorly on working memory tasks when compared to same-aged peers (Gathercole et al., 2006).

Deficits in working memory often correlate with many disorders in childhood. Working memory is one of the cognitive processes that lay the foundation for individual learning ability. Children who experience difficulties with learning show impairments in their working memory performance. It has been demonstrated that these children show impairment in the phonological loop, visuospatial sketchpad, and the central executive. They often have difficulty with vocabulary acquisition, learning new words, reading, text comprehension, communication, spontaneous speed, and expressive language (Masoura, 2006). Moreover, working memory is an executive function process that garners the most attention when studying the academic/learning deficits in children with Attention-Deficit/Hyperactivity Disorder (ADHD). Working memory deficits are well established when looking at the behavioral profile of children with ADHD. It is critical to cognitive development, motor skills, academic achievement, and higher order functioning. Because working memory requires the use of attentional capacities, children with ADHD often demonstrate deficits with working memory and inhibitory control (Huang-Pollock & Karalunas, 2010). Even though much is known about the relationship between working memory and learning and its role as an executive function process, the role of memory in the cognitive function of individuals with autism is unclear. Some children seem to have strong rote memory skills while others seem to have severe deficits in their memory capacity (Williams et al., 2005). The working memory performance of children on the autism spectrum may be assessed using relatively simple tasks or tasks that are more complex, as in problem solving. Individuals with autism who also suffer working memory deficits show problems with behavioral regulation, cognitive flexibility, abstract reasoning, and difficulty with focusing and maintaining attention (Williams et al., 2005).

A majority of the studies in the literature regarding working memory fall in two categories. These are strategy training and cognitive training. Mnemonic strategy instruction has been proven to be effective for helping students who encounter difficulties learning novel information. With the use of visual and auditory cues mnemonic strategies aids in linking new information with prior knowledge allowing the information to be more concrete and accessible. This process allows information to be easily retrieved from storage. Mnemonic strategies that use systematic encoding procedures and direct retrieval links to information just learned are the most effective. Other effective mnemonic strategies are those that associate together image, pictures, or verbal phrases (Mastropieri et al. (2005). Direct training in cognitive processes and the ability to transfer the effects of this training to higher cognitive processes has gained much interest over the past few years. Specifically, direct training in working memory strategies via the use of a computer has been of interest. Researchers have paid more attention to studying the impact of working memory on children's learning (Dahlin, 2011; Elliot et al., 2010).

The remaining sections will review the reasoning for examining the effects of intensive and systematic training in working memory strategies (i.e., Cogmed) on reading performance. The theoretical framework and the relationship between working memory and reading achievement are described in further detail. Finally, assumptions and potential limitations in the current study are reviewed.

The Problem

Cogmed is an evidenced-based intervention designed to improve working memory. It may be used with children and adults ages four to 70 years and over (Cogmed, 2013a). Cogmed training uses a web-based computerized system and can be accessed in various locations. The training has been demonstrated to be a complementary intervention and will likely produce the greatest benefit when combined with other sources of interventions (Cogmed, 2013a). Research has shown that adaptive training in working memory has led to gains in word reading, reading comprehension, mathematical ability, and improved attention (Beck et al., 2010; Dahlin, 2011; Holmes et al., 2009). Since its inception, many researchers have demonstrated the efficacy of Cogmed through rigorous investigations of its treatment protocols and methods (Beck et al., 2010; Dahlin, 2011; Holmes & Gathercole, 2013).

Cogmed training holds great potential as an intervention for improving working memory. The present study evaluated the effects of adaptive training in working memory strategies on reading performance. It addressed a lingering question concerning the generalizability of this training to academic achievement. Specifically, does this training provide significant improvement in students' reading achievement beyond those associated with the typical reading intervention and instruction?

Problem Significance

As previously noted, Cogmed training maybe conceptualized as a complementary intervention that may improve the academic outcomes of at-risk learners when combined with other methods of intervention (Cogmed, 2013; Beck et al., 2010; Dahlin, 2011; Holmes et al., 2009). Because of this, it is then plausible to expect that if at-risk students are equipped with more efficient working memory strategies, there may be gains in reading achievement. Consistent with contemporary theories of memory functioning, in order to collect the necessary information to comprehend the text, a reader must have intact working memory skills (Cain, Oakhill, & Bryant, 2004; Nation et al., 1999; Seigneuric et al., 2000).

Within the Georgia public school system, the students who are struggling in the curriculum and/or the students who did not meet the criterion for a passing score on the state assessment are often provided additional services in the Early Intervention Program (EIP). The purpose of the EIP is to assist students who are at risk of not reaching or maintaining grade level performance. Students in this program receive additional instructional resources in an attempt to address specific areas of difficulty. EIP is a part of the Response to Intervention (RTI) framework for providing support to the students (Georgia Department of Education [GADOE], 2013). In compliance with the Georgia Department of Education, the program is staffed by certified teachers and presented in one of the following models: augmented (services are provided in the regular group class size), self-contained (reduce the class size), pull out (students are removed from the classroom for instruction by an additional certified teacher), reduced class model (combination of EIP students with regular education students in smaller classes), and reading recovery program (students are given 30 minutes of reading outside of the classroom –for at least 45 days) (GADOE, 2013).

Combining the Cogmed training and the academic instruction on strategies and skills in reading received in the Tier 2 intervention program will likely increase the students' reading fluency and understanding of text. This was important to study because providing adaptive training in working memory strategies in addition to Tier 2 interventions may reduce the number of students going on for additional reading support in Tier 3 and receiving a referral for Special Education services.

Theoretical Framework

What is working memory? How is it defined? As with many constructs in cognitive psychology, many researchers studying working memory differ in their definition of the construct. A general conception of working memory is that it is a dynamic process that encompasses the ability to briefly store information while simultaneously processing other cognitively challenging tasks (Alloway, 2009; Beck et al., 2010; Savage et al., 2007). Working memory capacities are essential for the successful completion of many cognitive tasks, such as reading and comprehending the content outlined within this document. An example of an everyday working memory task is holding a person's address in mind while listening to directions for how to get there. Working memory should not be considered synonymous with the related construct of short-term memory. These constructs are not the same. Unlike working memory, short-term memory does not require simultaneous storage and manipulation. Short-term memory only encompasses the temporary storage of information. This information is believed to be held passively and is not manipulated or transformed (Savage et al., 2007; Swanson, Zheng, & Jerman, 2009).

The most prominent model of working memory is the one proposed by Baddeley (1999). Baddeley's model details three major components: the central executive component, the phonological loop, and the visuospatial sketchpad. The central executive is the core system responsible for coordinating the overall working memory system. Two other 'slave' systems, the phonological loop and the visuospatial sketchpad, assist the central executive. These 'slave' systems allow the central executive to deposit some of its short-term storage functions, consequently freeing up the central executive to perform more cognitively demanding tasks (Baddeley, 1999). Overall, the central executive "directs attention, guides the flow of information, coordinates the execution of two or more tasks at once, and interacts with long-term memory" (Beck et al., 2010, p. 825). The phonological loop and the visuospatial sketchpad hold information for a very brief and specific period. The phonological loop involves storing phonological input and is used for rehearsing verbal input when needed. Similarly, the visuospatial sketchpad stores and rehearses nonverbal input (Beck et al., 2010; Savage et al., 2007).

Reading and Reading Comprehension

To date, educators have gained a great deal of insight about the way students learn to read and about the most effective instructional strategies recommended to assist students during the reading process. For example, the Florida Center for Reading Research (2012) noted that, "Core elements of scientifically based reading programs include intensive and systematic instruction in the following: Phonemic Awareness, Phonics, Fluency, Vocabulary, and Comprehension Strategies" (Kosnovich, 2005, p. 18). More precisely, Phonemic Awareness is the ability to hear, identify, and manipulate the individual sounds in words. Phonics denotes understanding of the alphabetic principle and knowing the relationship between phonemes and graphemes. Vocabulary pertains to the meanings and pronunciation of words used in language. Fluency is the ability to read accurately and quickly and with proper intonation. Lastly, comprehension pertains to understanding and remembering information acquired when reading (Florida Center for Reading Research, 2012).

Students who are provided with intensive and systematic instruction in phonemic awareness and the alphabetic principle, fluency in word recognition, developing and understanding of words/reading for meaning, and building comprehension typically demonstrate better reading achievement when compared to their counterparts (Denton, Vaughn, & Fletcher, 2003; Foorman & Torgesen, 2001). Explicit, intensive, scaffolded instruction in reading has made a difference in students reading achievement, especially children at risk for reading failure. During explicit instruction, the teacher serves as a model; he or she clearly teaches skills and concepts, and carefully sequences instruction for students. The teacher closely interacts with the student to guide and support skill development through teaching and practicing the skills required for the reading task. More specifically, the teacher directly assists the student with the process needed to complete the task correctly. Learning to read is not an incidental learning process, but requires explicit instruction, as many students will not learn without this assistance (Denton et al., 2003; Foorman & Torgesen, 2001).

Reading instruction equips students with skills to decode and recognize words. However, in addition to having these skills, the purpose of reading is to understand and gain information from the text. This is reading comprehension. In order to understand and gain information from text, “words need to be recognized and their meanings accessed, relevant background knowledge needs to be activated, and inferences must be generated as information is integrated during the course of reading” (Nation & Angell, 2006, p. 77).

A majority of students will learn to read despite the traditional methods used to provide instruction. However, approximately 20% of these students will be unable to master the task of reading without special assistance. During the latter part of elementary school when students transition from learning to read to reading to learn, these 20% of students will likely miss out on information presented in text. As they progress in their academic careers, about 10-15% of students with reading difficulties will eventually drop out of high school (LD Online, 2013).

Working Memory and Reading Comprehension

What is the relationship between working memory and reading comprehension? How do both constructs influence each other? The central executive in Baddeley’s theoretical model of working memory is conceptualized to be the attention and inhibitory process a reader gives to a task when reading for comprehension and understanding. It is a parallel cognitive process requisite for information processing performed during reading. Additionally, students with reading disabilities exhibit processing deficits in the phonological loop, verbal working memory, word list recall, and story detail recall. These tasks are assumed by researchers to all use verbal rehearsal strategies (Savage et al., 2007). Because of this, it is likely that without intact working memory skills a reader may have difficulty gleaning the necessary information to comprehend text (Cain, Oakhill, & Bryant, 2004; Nation et al., 1999; Seigneuric et al., 2000).

Despite all the information gained about the way students learn to read and about the most effective instructional strategies that may be used to assist students during the reading process, deficits in reading remain one of the most prevalent obstacles in education. Often children who are not reading commensurate to their peers have a difficult time closing the gap. One posited explanation for the continued obstacles in reading is that some learners have deficits in metacognition. Some researchers (Jacobs & Paris, 1987; Kuhn, 2000) refer to metacognition as thinking about thinking. It focuses on self-regulated thinking, which is how individuals apply the knowledge that they have to specific activities (Jacobs & Paris, 1987). Metacognition materializes early in life and follows a developmental course. There is the suggestion that by age three and four, children become aware of their own knowledge and realize that others may think differently than they do. As this self-regulated thinking (i.e., metacognition) develops, it may become increasingly useful and effective for tasks such as reading (Kuhn, 2000).

Another possible hypothesis for the continued obstacles in reading is that some learners have deficits in working memory (Dahlin, 2011). Nation and Angell (2006) noted that when reading, information often has to be retained in the mind and then integrated with the new information read. This likely relies heavily upon the process of working memory. Thus, poor comprehension may relate to poor working memory. Readers with deficits in comprehension have difficulty tuning out irrelevant information; this restricts and overloads the working memory process (Henderson & Pimperton, 2008). Studies have shown that working memory, specifically the phonological loop and central executive, is essential for retaining verbal information during reading (Cain, Oakhill, & Bryant, 2004; de Jong, 2006). If these findings are valid, it is likely that using the aforementioned instructional strategies alone may not provide the most gain when attempting to improve students' reading achievement. Accordingly, one may expect that providing intensive, systematic training in strategies for improving working memory should lead to gains in overall reading achievement. Using Cogmed in conjunction with the reading interventions provided by the EIP may provide additional gains when attempting to improve students' reading achievement.

Research Questions & Hypotheses

I posed three research questions relating to whether or not adaptive training in working memory strategies would improve performance in the post-test measures for the participants. Research question one evaluated whether or not adaptive training in working memory strategies produced significant improvements in working memory performance. Research question two examined the effect of adaptive training in working memory strategies on reading comprehension achievement. Finally, research question three examined the effect of adaptive training in working memory strategies on reading fluency achievement. Three corresponding hypotheses were generated.

Research Question 1

Does intensive and systematic training in working memory strategies produce improvements in the experimental group's working memory performance as measured by the working memory scores recorded by Cogmed? The corresponding null (H_0) and alternative (H_1) hypotheses were:

H_0: There is no change in the working memory performance for students' in the experimental group (i.e., $\mu = 0$).

H_1: There is a change in the working memory performance for students' in the experimental group (i.e., $\mu \neq 0$).

It is expected that working memory training will result in increased working memory performance in the experimental group.

The improvement in working memory capabilities was measured by the working memory scores recorded by Cogmed. The students' performance was recorded after each day's training had been completed. Prior research findings have demonstrated that providing intensive, systematic training in working memory offers gains in participants working memory performance after completing several weeks of training. The training promoted the students' self-awareness and taught participants to develop compensatory strategies to overcome deficits in their working memory capacities (Beck et al., 2010; Holmes, Gathercole, Dunning, 2009; Westerberg et al., 2007).

Research Question 2

Does intensive and systematic training in working memory strategies significantly improve the reading comprehension scores of participants in the experimental group by comparison to the control group as measured by post-test reading comprehension scores from the DRA (controlling for pre-test levels)? The corresponding null (H_0) and alternative (H_1) hypotheses were:

H_0: Controlling for pre-test reading comprehension scores, the post-test reading comprehension scores are equal for the control and experimental groups (i.e., $\mu_{exper} = \mu_{control}$).

H_1: Controlling for pre-test reading comprehension scores, the post-test reading comprehension scores are not equal for the control and experimental groups (i.e., $\mu_{exper} \neq \mu_{control}$).

It is hypothesized that the experimental group will have higher average post-test reading comprehension scores (controlling for pre-test scores) compared to the control group.

Research studies have shown that providing intensive, systematic training in working memory and explicit reading instruction to less-skilled readers often improved the reading achievement of these students to levels of their counterparts (Cain, Oakhill, & Bryant, 2004; de Jong, 2006; Denton, Vaughn, & Fletcher, 2003; Eilers & Pinkley, 2006; Foorman & Torgesen, 2001; Savage, Lavers, & Pillay, 2007).

Research Question 3

Does intensive and systematic training in working memory strategies significantly improve the reading fluency scores of participants in the experimental group when compared to the control group as measured by post-test reading fluency scores from the DIBELS-ORF (controlling for pre-test levels)? The corresponding null (H_0) and alternative (H_1) hypotheses were:

H_0: Controlling for pre-test reading fluency scores, the post-test reading fluency scores are equal for the control and experimental groups (i.e., $\mu_{exper} = \mu_{control}$).

H_1: Controlling for pre-test reading fluency scores, the post-test reading fluency scores are not equal for the control and experimental groups (i.e., $\mu_{exper} \neq \mu_{control}$).

It is expected that the experimental group will have higher average post-test reading fluency scores (controlling for pre-test scores) compared to the control group.

Reading fluency is the ability to automatically and fluently read. It does not require conscious attention to the decoding and identification of words (Hibert & Fisher, 2005). Studies have shown that there is a theoretical relationship between reading fluency and reading comprehension. According to the National Reading Panel (2013), reading fluency is a critical component that facilitates reading comprehension. Students are more likely to glean information from text and remember what was read if they are able to read efficiently, with accuracy, and with proper expression (National Reading Panel, 2013). Once a reader is automatically able to decode words, they can then devote their attention to comprehending text (Hiebert & Fisher, 2005).

Assumptions

It was assumed in the present study that adaptive training in working memory strategies with the Cogmed program would result in better working memory performance. It was also assumed that increases in the post-test reading measures could be attributed to the Cogmed training. The post-test reading measures were not previously administered and did not result in exposure bias. Finally, it was assumed that the participants in the study were students who received services from the Early Intervention Program and school personnel followed all standardized procedures for administering the post-test measures.

Limitations

Some potential extraneous variables that may have limited the results of this study are fidelity, experimental mortality, and population validity. Because the investigator was not in the elementary school every day, it was difficult to assure that the Tier 2 reading instruction was provided with consistency and fidelity as prescribed by the intervention used. Moreover, families move, or change schools in the district, and parents could elect to discontinue participation or rescind permission to use data gathered during the study. Additionally, the students in the control group were students who participated in the Tier 2 (i.e., Reading Horizons) program from the 2015 school year while the students in the experimental group were students from the 2016 school year. This may be a potential confounding variable because it was difficult for the researcher to be certain that the students in the control group were instructed similarly and at the same pace as the students from the 2016 school year. Each of these factors was a potential threat to the internal validity of the study.

One potential threat to external validity was the use of a convenience sample in the study. Using a convenience sample may make it difficult to generalize to the larger school population. Also, the study excluded rural and urban populations and alternative regions of the country. This may likely impact the generalizability of the study, since it is focused on a suburban setting in Fayette County, GA.

Definition of Key Terms

Adaptive working memory training: training continually challenges the user through a staircase method that adjusts on a trial-by-trial basis (Cogmed, 2013a).

Central executive: Is responsible for functions such as retrieval of information from long-term storage, it regulates information in working memory, it provides control for attention capacities while encoding and retrieving, and it allows for shifting between tasks.

Episodic buffer: Is responsible for storing novel stimuli. This serves as an interface between working memory (specifically the phonological loop and the visuospatial sketchpad) and long-term memory.

Phonological loop: Involves storing phonological input and is used for rehearsing verbal input when needed.

Reading comprehension: Pertains to understanding and remembering information acquired when reading (Florida Center for Reading Research, 2012).

Reading fluency: The ability to read accurately and quickly and with proper intonation (Florida Center for Reading Research, 2012).

Visuospatial sketchpad: Stores and rehearses nonverbal input (i.e., visual and spatial information).

Working memory: A dynamic process that encompasses the ability to briefly store information while simultaneously processing other cognitively challenging tasks.

Summary

The preceding chapter outlined the significance of the current study which examines the effects of adaptive training in working memory strategies on reading performance. More precisely, would this training provide significant improvement in students' reading achievement beyond those associated with the typical reading intervention and instruction? The theoretical relationship between working memory and reading was described. The study hypothesizes that working memory training will result in increased working memory performance in the experimental group, the experimental group will have higher average post-test reading comprehension scores (controlling for pre-test scores) compared to the control group, and the experimental group will have higher average post-test reading fluency scores (controlling for pre-test scores) compared to the control group. Assumptions and limitations were also reviewed.

CHAPTER II

LITERATURE REVIEW

In this chapter, I will review the literature relevant to working memory. The scholarly literature was gathered and reviewed over the course of two years prior to the commencement of the study. This chapter provides information pertaining to the definition, historical background, models, development, and assessment of working memory. Moreover, the chapter explores the relationship between working memory and intelligence, childhood disorders associated with working memory, and interventions used to improve working memory. Finally, the summary provides a review of the major points discussed in the literature review.

Working Memory

Memory is our ability to encode, store, retain and subsequently recall information and past experiences. It may be thought of as the use of past experience to affect or influence current behavior.

> Memory is a key feature of human intelligence in many aspects and represented in nearly all day-to-day function, be they intellectual, academic, social, vocational, or recreational. Memory makes us who we are and preserves our identity. Without the ability to recall our own personal history, we would be in a near state of confusion and constant dilemma. Memory allows us to acquire skills and knowledge, to perform our jobs, and to recognize and respond appropriately to our loved ones. (Reynolds & Voress, 2007, p. 1).

There are different aspects of memory. These include short-term memory, long-term memory, and working memory. Even though these three aspects of memory all work in conjunction, they are distinct and separate abilities. Short-term memory is the ability to encode, maintain, and manipulate information in one's immediate awareness, while long-term memory is the ability to store, consolidate, and retrieve information over periods of time (Flanagan, Ortiz, Alfonso, 2013). What is working memory? As with many constructs in cognitive psychology, many researchers studying working memory differ in their definition of the construct. A general conception of working memory is a dynamic process that encompasses the ability to store information briefly while simultaneously processing other cognitively challenging tasks (Alloway, 2009; Beck et al., 2010; Savage et al., 2007). Working memory capacities are essential for the successful completion of many cognitive tasks, such as reading and comprehending the content outlined within this document. An example of an everyday working memory task is holding a person's address in mind while listening to directions for how to get there. Working memory should not be considered synonymous with related construct of short-term memory. These constructs are not the same. Unlike working memory, short-term memory does not require simultaneous storage and manipulation. Short-term memory only encompasses the temporary storage of information. This information is believed to be held passively and is not manipulated or transformed (Swanson, Zheng, & Jerman, 2009; Savage et al., 2007).

Working memory and short-term memory (STM) share a relationship; however, working memory is distinguishable from STM. Working memory is typically assessed using complex memory tasks that tests temporary memory storage and substantial processing activities (Gathercole et al., 2006). During the process of working memory, the individual extracts, loads, and maintains information for online use. Concurrently, the information that is not being used is removed and relevant information is manipulated and stored in accordance with task demands (Hedden & Yoon, 2006).

Historical Background

Memory is often regarded as the foundation of cognitive functioning. Complex cognitive tasks require the use of several aspects of memory. For example, recalling past experiences, encoding of new information, and distinguishing important from trivial information. Many facets of cognition intertwine with memory and it plays an integral role in all higher order cognitive processes (Reynolds & Voress, 2007)

Memory has been the focus of many research studies for several centuries. Many of these studies have focused on separating attention from memory and distinguishing immediate from short-term memory. Memory problems are often apparent in children diagnosed with learning difficulties, depression, fetal alcohol syndrome, children who were exposed to crack cocaine, and having low birth weight. The extent of these memory problems often varies and typically persists into adulthood (Reynolds & Voress, 2007).

Dating back to the beginning of the 20th century, an examination of memory typically required the individual to answer questions about the current date, news, and to recite letters and words as a means of assessing the functioning of one's memory (Reynolds & Voress, 2007). It is now evident that a variety of neurological and psychological disorders adversely impact memory; consequently, more elaborate ways are necessary for the assessment of memory capacities (Reynolds & Voress, 2007). After World War II, many soldiers who suffered head injuries also demonstrated deficits in their memory capacity. In 1945, the Wechsler Memory Scale (Wechsler, 1945) was developed after a need for a standardized battery of tests became apparent. The Wechsler Memory Scale was easy to administer and allowed practitioners to quantify the degree of deficit in a patient. Around this time, other memory tests developed were the Rey Auditory Verbal Learning Test (Rey, 1941), the Rey-Osterrieth Complex Figure Design (Osterrieth, 1944), and the Benton Visual Retention Test (Benton, 1946). However, comprehensive memory batteries were not developed until the 1990s, for example, the Wide Range Assessment of Memory and Learning (Sheslow & Adams, 1990) and the Test of Memory and Learning (Reynolds & Voress, 2007).

Difficulties in working memory often go undetected in the academic environment or misunderstood as poor behavior or lack of motivation on the student's part. Currently, researchers have paid more attention to studying the impact of working memory on children's learning. As previously noted, many more assessment tools are now available to measure a student's working memory performance (Elliot et al., 2010). In addition to developing assessment tools, cognitive psychologists have closely studied the process of working memory and have suggested some theories/models of working memory. The following section will discuss three of the most prominent models.

Models

The Atkinson and Shiffrin (1968) model of working memory is considered to be one of the traditional views of human memory. It accounted for basic structures of working memory, which are encoding, maintenance, and retrieval. In this traditional view of working memory, the structural components through which information is transferred are separate. The structural components are the sensory register, the short-term store, and the long-term store (Atkinson & Shiffrin, 1968; Miyake & Shah, 1999). Information flows through the system similar to a computer, with an input, process, and output. First, information is detected by the sense organs and enters the sensory register then if attended to the information enters into short-term memory. The short-term store is the individual's working memory. Next, the information from short-term memory is transferred or encoded into long-term memory only if the information is rehearsed. If the information is not rehearsed, it is then forgotten through the process of decay. The long-term store is a permanent repository for information that has been copied from the short-term store. The sensory register holds information for approximately ¼ to ½ of a second, it stores all sensory information, and there are different sensory registers for each sense. The short-term memory store holds information for approximately 15-30 seconds, it is capable of storing seven items, and information is encoded mainly through auditory input. Finally, in the long-term store information does not decay, it is permanent. It is capable of holding unlimited amounts of information and information is encoded either through auditory or visual input (Atkinson & Shiffrin, 1968; Miyake & Shah, 1999; McLeod, 2007).

The Atkinson and Shiffrin model (1968) is influential because it prompted a lot of research into memory. This subsequent research has provided evidence to support the distinction between short-term memory and long-term memory. Specifically, there is evidence to show how information is encoded, how long information is maintained, and the storage capacity of short and long-term memory (McLeod, 2007). However, some researchers have criticized the model as oversimplified. For example, McLeod (2007) and Miyake & Shah (1999) noted that it is now known that short-term and long-term memory does not operate in a single, uniform fashion. As detailed below in the model proposed by Baddeley and Hitch (1974), working memory consist of several components that work separately and in conjunction with each other. Moreover, even though it might assist in transferring information, rehearsal is not essential to store information into long-term memory. Information that is stored in long-term memory is not stored as an individual unit and because the model mainly focuses on the structure of memory and not the process of memory, it is considered to be a passive or one-way linear model (Miyake & Shah, 1999; Baddeley, 2000; McLeod, 2007). Overtime as the research in the area of working memory progressed, other models such as the multicomponent model (Baddeley & Hitch, 1974), the embedded-process model (Cowan, 1999), and the dual-component model (Unsworth & Engle, 2007) replaced the Atkinson and Shiffrin (1968) model.

Multi-Component Model

Historically, the multicomponent model has been the most influential of the working memory systems. This model divides the system into domain specific buffers and a domain independent component. These specific buffers are the phonological loop and visuospatial sketchpad, while the central executive/attentional control is the domain independent component (McCabe et al., 2010).

Some 40 years ago, Baddeley and Hitch (1974) suggested the theory of a multicomponent working memory model. Baddeley and Hitch (1974) were the first to propose the two functions of storage and processing (i.e., maintenance and manipulation) within the working memory system. The most prominent understanding of working memory is that it is a system of multiple parts that coordinates the temporary storage and manipulation of information in a host of domains. The Baddeley and Hitch (1974) model details one conceptualization of the domain-general model of working memory. In the multicomponent model, the central executive is responsible for managing resources and keeping track of information processing across domains. In regulating functions, the central executive retrieves information from long-term memory and controls attention. Information is stored by two domain-specific slave systems. These are the phonological loop and the visuospatial sketchpad. The phonological loop is responsible for brief storage of verbal information; the visuospatial sketchpad temporarily maintains and directs visual and spatial information (Baddeley & Hitch, 1974).

As aforementioned, Baddeley's (1974; 1999) multicomponent model details three major components: the central executive component, the phonological loop, and the visuospatial sketchpad. The central executive is the core system responsible for coordinating the overall working memory system. Two other 'slave' systems, the phonological loop and the visuospatial sketchpad, assist the central executive. These 'slave' systems allow the central executive to deposit some of its short-term storage functions, consequently freeing up the central executive to perform more cognitively demanding tasks (Baddeley, 1999). Overall, the central executive "directs attention, guides the flow of information, coordinates the execution of two or more tasks at once, and interacts with long-term memory" (Beck et al., 2010, p. 825). The phonological loop and the visuospatial sketchpad hold information for a very brief and specific period. The phonological loop involves storing phonological input and used for rehearsing verbal input when needed. Similarly, the visuospatial sketchpad stores and rehearses visual stimuli (Beck et al., 2010; Savage et al., 2007).

The phonological loop is probably the least complex and most studied component of working memory. Within the phonological loop, there is a phonological store and an articulatory rehearsal process. The phonological store can maintain memory traces for a few seconds and the articulatory rehearsal process is compared to sub-vocal speech. In Baddeley's model, the purpose of the phonological loop is to facilitate the acquisition of language. The phonological loop holds sentence information while it is analyzed and comprehended. Individuals that have a deficit in the phonological loop typically encounter difficulty acquiring vocabulary skills in a new language even though their verbal long-term memory is intact (Baddeley & Hitch, 1994). This suggests that the phonological loop may play an important role in the acquisition of language skills. The phonological loop supports language acquisition by storing temporary representations of new phoneme sequences and the articulatory system fosters learning via rehearsal (Baddeley & Hitch, 1994; Baddeley 2003).

The function of the visuospatial sketchpad is to hold and manipulate visual and spatial information (Baddeley, 2003). Similar to the phonological loop, the visuospatial sketchpad is limited in its capabilities. The visual working memory system is typically limited to three or four images. Because of this, individuals are susceptible to change blindness, a phenomenon wherein characteristics of images change in some way and an individual does not notice. Within the visuospatial sketchpad, objects compete for storage capacity (Baddeley, 2003). The visuospatial sketchpad is not as widely studied as the phonological loop. Logie and Pearson (1997) showed that similar to its counterpart, the visuospatial sketchpad encompasses a passive store and an active rehearsal system. These are the visual cache and the inner scribe, respectively. The visual cache is the visual storage component while the inner scribe is the active retrieval and rehearsal process (Logie & Pearson, 1997).

Working memory is broad and flexible in nature. In addition to the phonological loop and visuospatial sketchpad, Baddeley's (1974) model also includes the central executive. The central executive is responsible for functions such as retrieval of information from long-term storage, it regulates information in working memory, it provides control for attention capacities while encoding and retrieving, and it allows for shifting between tasks. In Baddeley's model, the phonological loop and the visuospatial sketchpad facilitates storage of information, while the central executive facilitates processing demands (Gathercole et al., 2006). Over the years, other theorists (Berninger et al., 2010; Miyake et al., 2000) have also added other executive functions, besides the supervisory attentional control, to Baddeley's model. These executive functions include inhibition, mental set shifting, self-monitoring, and updating. Because working memory is the ability to maintain information despite distraction, poor executive functioning will likely contribute to poor working memory functions (Berninger et al., 2010).

Baddeley and Hitch's (1974) model of working memory has since been revised to include the episodic buffer. The episodic buffer is responsible for storing novel stimuli (see Figure 1 below). This serves as an interface between working memory (specifically the phonological loop and the visuospatial sketchpad) and long-term memory (Alloway et al., 2009; Baddeley, 2006; Carretti et al., 2007). It is responsible for "binding information across informational domains and memory subsystems into integrated chunks" (Alloway et al., 2006, p. 1698).

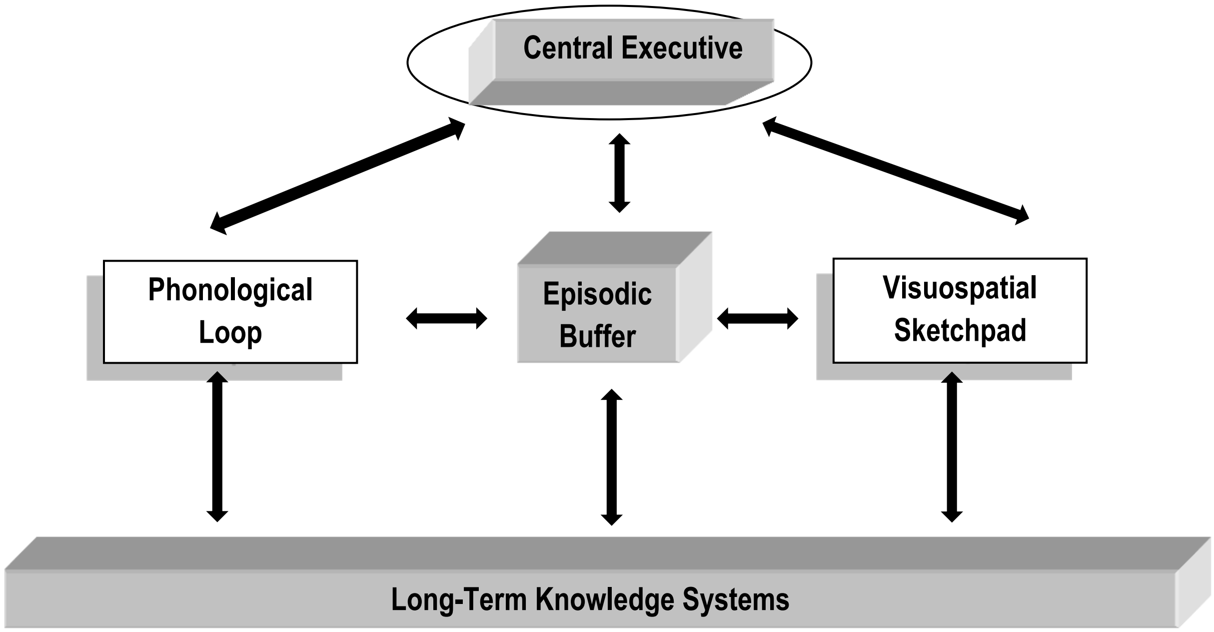

Figure 1. The multi-component model of working memory. Adapted from Repovs & Baddley, 2006. Reprinted with permission in Repovs & Baddley (2006).

The multicomponent model of working memory has been widely studied and referenced in populations that included children, adults, neuropsychological patients, and neuroimaging studies (Prabhakaran et al., 2000; Alloway et al., 2006; 2009; Wagner et al., 2013). Research in the area of neuroimaging has shown that working memory is controlled by frontal and posterior cortical regions depending on the task and type of information that is being maintained. Posterior cortical regions are responsible for maintaining the specific type of information while the prefrontal areas specialize in integrating the various types of information in working memory. Verbal information is processed in the left temporal lobes and visuospatial stimuli are processed in the right parietal, occipital, and premotor cortices (Prabhakaran et al., 2000).

Researchers (Masoura, 2006; Savage et al., 2007) who have studied the relationship between working memory and reading has noted that the central executive in Baddeley's theoretical model of working memory is conceptualized to be the attention and inhibitory process a reader gives to a task when reading for comprehension and understanding. It is a parallel cognitive process requisite for information processing performed during reading. Additionally, students with reading disabilities exhibit processing deficits in the phonological loop, verbal working memory, word list recall, story detail recall, visual spatial sketchpad, and the central executive. They often have difficulty with vocabulary acquisition, learning new words, reading, text comprehension, communication, spontaneous speed, and expressive language (Masoura, 2006; Savage et al., 2007). These tasks are assumed by researchers to all use verbal rehearsal strategies (Savage et al., 2007). Because of this, it is likely that without intact working memory skills a reader may have difficulty gleaning the necessary information to comprehend text (Cain, Oakhill, & Bryant, 2004; Nation et al., 1999; Seigneuric et al., 2000). Studies have shown that working memory, specifically the phonological loop and central executive, is essential for retaining verbal information during reading (Cain, Oakhill, & Bryant, 2004; de Jong, 2006).

The specific mechanisms that underlie and facilitate working memory have been debated. Other theoretical explanations have been offered to account for the relationship between working memory, long-term memory, attention, and language processing (Chein & Fiez, 2010). Two of the alternative models are the Dual-Component Model (Unsworth & Engle, 2006) and the Embedded-Process Model (Cowan, 1999).

Dual-Component Model

Unsworth and Engle (2007) also suggested another model of working memory called the dual-component model. In this model, to complete a working memory task information is retrieved from long-term memory and brought into short-term memory.

The participant has to switch attention between short and long-term memory. Engle and colleagues (1999) also suggested that working memory is a domain-general construct. By their accounts, working memory is limited by controlled attention. It is the ability to allot attentional resources even when distracted or interrupted. What is similar to the Baddeley & Hitch (1974) model is the central element that coordinates the continuing processing and storage of information in the slave systems. In the Unsworth and Engle model, this central element is the controlled attention component, while in Baddeley & Hitch's model, this is referred to as the central executive. Even though both models have domain-specific storage components, what is unique to each model is the relationship between these storage components and cognitive abilities. In the dual-component model, the controlled attention component is the only aspect that predicts learning. However, in the multicomponent model, relationships have been demonstrated between the central executive, the verbal and visuospatial domains, and learning.

Embedded-Process Model

Cowan (1999) conceptualizes working memory as a component of long-term memory. In his embedded-process model of working memory, Cowan purports that working memory is what is activated during the processing of long-term memories. In the embedded-process model of working memory, "the capacity of the focus of attention is limited to four chunks of information, and all other items in working memory reside within, and must be retrieved from, the activated portion of long-term memory" (Rose et al., 2010, p. 472). The basic components of the embedded-process model are encoding, maintenance, and retrieval of the information. Encoding of information is affected by attention that is activated by executive function or environmental stimuli. Information is maintained through verbal rehearsal, visualization, and mental searching. When items are brought into the focus of attention, it is then retrieved from the activated memory or long-term storage. The working memory system is limited by the individual's ability to quickly activate and hold the information as the focus of attention (Cowan, 1999).

Development

Working memory is a component of executive function. Executive function may be conceptualized as those cognitive capacities needed to direct behavior toward achieving a goal (Jacob & Parkinson, 2015). As a subcomponent of the executive function system, working memory assist in prioritizing and sequencing behavior, inhibiting familiar responses, maintaining relevant information in mind, resisting distractions, switching from one task to the next, making decisions, and problem solving (Jacob & Parkinson, 2015). Working memory appears to be heritable and its capacity does not appear to be affected by parental educational level or socio-economic status. However, there is some evidence to suggest that working memory performance may increase through strategies and intensive training (Alloway et al., 2009; Dahlin, 2011; Mastropieri et al., 2005).

At birth, the fundamental areas of the frontal lobes are already developed. However, the additional systems, which include learning, memory, emotion, cognition, language, and attention, continue to develop throughout adolescence and into adulthood. These changes are evident in a child's cognitive abilities during childhood and adolescence. Significant changes in the prefrontal cortex are noted between the ages of 3 and 9 and then again in the early 20s. An increased secretion of gonadal hormones, synaptic pruning, and myelination of neural mechanisms result in more efficient information processing (Romine & Reynolds, 2005).

Research in the area of neuroimaging has shown that working memory is controlled by frontal and posterior cortical regions depending on the task and type of information that is being processed. Posterior cortical regions are responsible for maintaining the specific type of information while the prefrontal areas specialize in integrating the various types of information in working memory (Prabhakaran et al., 2000). The development of different regions of the brain has been related to different components of working memory. Short-term memory (which is related to the phonological loop) is believed to be related to the left temporal parietal region and the frontal lobes are related to the executive system of working memory (Swanson, 2008).

The different functions of the frontal lobes develop in a multistage process. These functions all develop in different ways and at different times. Significant development seems to occur between ages 6 and 8, 9 and 12, and then again between adolescence and the early 20s. During the ages of 5 and 10 a series of changes occur that are evident in a child's attentional, executive, and self-reflexive processes. Also, during this period of time the child is able to demonstrate recognition memory, concept formation, set-shifting, and basic planning skills. By age 12 the child is typically able to control their attention span and their performance on verbal working memory tests matures (Romine & Reynolds, 2005). This is demonstrated on improvements in performance of tasks assessing memory span and memory for spatial locations (Luna et al., 2004). There is an extended period of skill development in the frontal lobes beyond age 12. The skills most affected are planning, visual working memory, the coordination of working memory and inhibition, verbal fluency, and motor sequencing. Moreover, major gains are noted in the organization of memory and the efficiency of working memory performance, planning, and problem-solving abilities (Romine & Reynolds, 2005).

The developmental progression of working memory that is evident through adolescence may be attributed to brain maturation processes that foster efficient neuronal transmission and integrated brain function. As noted before, synaptic pruning and myelination enhances the precision and proliferation of information processing (Luna et al., 2004; Romine & Reynolds, 2005). Information is widely integrated and distributed, which is necessary for the alteration of behavior. This wide circuitry allows for efficient collaboration and access of cognitive resources (Luna et al., 2004). An increase in storage capabilities (i.e., long-term retrieval) and controlled attention fosters the development of working memory in young children (Swanson, 2008).

Luna and colleagues (2004) characterized the maturation of cognition into adulthood and provided an understanding of its link to brain maturation. The researchers studied development of three cognitive processes (i.e., processing speed, inhibitory control, and spatial working memory). Processing speed allows for effective control of behavior, response inhibition allows for the focusing on goal-directed planning, while working memory allows for response selection, preparation, and maintenance of goals until needed for use. They noted that these three specific core cognitive processes all support the development of problem solving and reasoning abilities. These abilities continue to develop during adolescence (Luna et al., 2004).

Moreover, processing speed, voluntary response suppression, and working memory, appear to mature at different points during adolescence. Even though all three, for the most part, mature independently, they work cooperatively in assisting development in the other cognitive abilities (Luna et al., 2004). It was further noted that the development of processing speed and response inhibition are not affected by the development of working memory; however, working memory's development is influenced by developmental improvements in both processing speed and response inhibition. It is likely that efficient processing speed will allow for effectively encoding into working memory while growth in inhibition may reduce the load on working memory because only the necessary information is maintained and manipulated (Luna et al., 2004).

McCabe and colleagues (2010) examined the developmental progression of working memory into adulthood. They noted that aging results in deficits in working memory performance and higher-level cognition. The common thread in theories of working memory performance is attentional processing. Declines in attentional processing have had significant effects on higher-level cognitive tasks, such as working memory (McCabe et al., 2010). During childhood, the central executive is particularly important especially when acquiring language, literacy, and mathematics skills. This is so because the central executive is responsible for attentional process, simultaneous storage, and processing of ongoing information. When deficits in the central executive persist into adulthood, it typically materializes as poor performance on language processing and comprehension assessments (Gathercole & Pickering, 2001).

Assessment

Clinical and experimental psychologists have long assessed memory capacity in their clients. A majority of intelligence batteries include brief assessments of memory functions. The assessment of memory functions during school age years are vital in order to accommodate for difficulties--if any--that may be associated with poor academic achievement (Reynolds & Voress, 2007). Measuring and understanding the limitations of working memory performance will likely aid in the identification of learning support and remediation, that may be beneficial when working with such students (Gathercole & Pickering, 2001). Research has established a relationship between children's working memory performance and their academic achievement across their academic careers. Complex memory span tasks that requires significant amount of processing and storage are highly predictive of the student's academic attainment (Alloway et al., 2005).

There is a preponderance of evidence to show that working memory capabilities vary from individual to individual and each person's unique working memory performance will determine the acquisition of new skills and their ability to execute complex cognitive tasks (Gathercole & Pickering, 2001). The steady improvement in and development of working memory during childhood is astounding. This increase is noted on performance of complex working memory span tasks. These tasks assess working memory performance by requiring maintenance, recall, and simultaneous processing of information. It was suggested that the developmental improvement noted in working memory may be accounted for by the discovery of new strategies and changes in the manner a strategy is used (Camos and Barrouillet, 2011).

Working memory performance are also assessed briefly or extensively by cognitive batteries, memory batteries, and rating scales. Some of the instruments that assess working memory are the Woodcock-Johnson IV Cognitive (WJ IV COG) (Schrank, McGrew, & Mather, 2014), the Wechsler Intelligence Scale for Children – Fifth Edition (WISC-V) (Wechsler, 2015), the Stanford-Binet Intelligence Scales, Fifth Edition (SB5) (Roid, 2003), the Wide Range Assessment of Memory and Learning Second Edition (WRAML2) (Sheslow & Adams, 2003), and the Behavior Rating Inventory of Executive Function (BRIEF) (Gioia et al. 2000).

Working Memory and Intelligence

Working memory plays an important role in cognitive functions. There is a crucial connection between working memory, learning, achievement, and intelligence during childhood. Differences in working memory skills have been shown to be related to several areas of cognitive functions, such as language comprehension, mathematics, reasoning, and complex learning (Swanson, 2008). Because working memory strongly correlates to higher order, cognitive functions, it has been referred to as 'the hub of cognition' (Swanson, 2008).

Working memory and general intelligence are distinct but related constructs. As noted above, a majority of intelligence batteries include brief assessments of memory functions. These assessments contribute to the overall general intelligence score. Typically, the working memory tasks used on these intelligence batteries require auditory, visuospatial, and controlled executive functioning. Examples of some of the tasks used to assess working memory performance are recall numbers forward and backward and recalling numbers or letters in ascending order or alphabetical order (Mather & Wendling, 2014; Raiford & Holdnack, 2014).

Even though working memory and short-term memory are distinctive processes, they are highly related. Working memory and short-term memory both seem to share properties of the same construct. Working memory also shares a relationship with fluid intelligence. The controlled attention found in the central executive strongly correlates with measures of fluid intelligence (Swanson, 2008). The executive system of working memory that uses controlled attention to facilitate problem solving likely acts as the crucial working memory factor for fluid intelligence tasks (Oberauer et al., 2003). In younger and older children, working memory and short-term memory are distinguishable on tasks. Despite sharing a correlation, short-term memory and working memory operate as separate entities and independently predict performance on tasks of fluid and crystalized intelligence (Swanson, 2008).

As noted by Swanson (2008), working memory strongly correlates with higher order, cognitive functions, one of which is reading. Next, the relationship between working memory and learning to read will be discussed.

Working Memory and Learning to Read

To date, educators have gained a great deal of insight about the way students learn to read and about the most effective instructional strategies recommended to assist students during the reading process. For example, the Florida Center for Reading Research (2012) noted that, “Core elements of scientifically based reading programs include intensive and systematic instruction in the following: Phonemic Awareness, Phonics, Fluency, Vocabulary, and Comprehension Strategies” (Florida

Center for Reading Research, 2012, p. 18). More precisely, phonemic awareness is the ability to hear, identify, and manipulate the individual sounds in words. Phonics denotes understanding of the alphabetic principle and knowing the relationship between phonemes and graphemes. Vocabulary pertains to the meanings and pronunciation of words used in language. Fluency is the ability to read accurately and quickly and with proper intonation. Lastly, comprehension pertains to understanding and remembering information acquired when reading (Florida Center for Reading Research, 2012).

Students who are provided with intensive and systematic instruction in phonemic awareness and the alphabetic principle, fluency in word recognition, developing and understanding of words/reading for meaning, and building comprehension typically demonstrate better reading achievement when compared to their counterparts (Foorman & Torgesen, 2001; Denton, Vaughn, & Fletcher, 2003). Explicit, intensive, scaffolded instruction in reading has made a difference in students' reading achievement, especially children at risk for reading failure. During explicit instruction, the teacher serves as a model; he or she clearly teaches skills and concepts, and carefully sequences instruction for students. The teacher closely interacts with the student to guide and support skill development through teaching and practicing the skills required for the reading task. More specifically, the teacher directly assists the student with the process needed to complete the task correctly. Learning to read is not an incidental learning process, but requires explicit instruction, as many students will not learn without this assistance (Denton et al., 2003; Foorman & Torgesen, 2001).

Reading instruction equips students with skills to decode and recognize words. However, in addition to having these skills, the purpose of reading is to understand and gain information from the text. This is reading comprehension. In order to understand and gain information from text, “words need to be recognized and their meanings accessed, relevant background knowledge needs to be activated, and inferences must be generated as information is integrated during the course of reading” (Nation & Angell, 2006, p. 77).

A majority of students will learn to read despite the traditional methods used to provide instruction. However, approximately 20% of these students will be unable to master the task of reading without special assistance. During the latter part of elementary school when students transition from learning to read to reading to learn, these 20% of students will likely miss out on information presented in text. As they progress in their academic careers, about 10-15% of students with reading difficulties will eventually drop out of high school (LD Online, 2013).

Working Memory and Reading Comprehension

It is rarely challenged that deficits in working memory during childhood are related to academic difficulties. Poor working memory is linked to difficulties focusing, remembering and completing classroom instructions, planning and organizing information, solving problems, and monitoring progress during complex tasks (Elliot et al., 2010). Working memory is essential in several complex-thinking tasks, such as problem solving, reasoning, and language comprehension. Working memory is especially important in language comprehension because comprehension requires sequential processing of symbols that have been produced and learned over a period of time. Working memory plays a crucial role in a reader's ability to store and integrate incoming information from the stream of successive words in a text (Just & Carpenter, 1992).

Deficits in reading are usually characterized by difficulties with fluent word recognition, decoding, and spelling. Moreover, they are often related to deficits in the phonological component of language. More specifically, difficulties are noted in detecting, blending, and manipulating individual sounds of speech (Beneventi et al., 2010).

Researchers have consistently demonstrated a relationship between working memory and reading ability. Moreover, it is well established that students who have deficits in reading also perform poorly on working memory tasks when compared to same-aged peers (Gathercole et al., 2006). In 2001 Evans and colleagues examined the relationship Cattell-Horn-Carroll (CHC) specialized cognitive clusters (i.e., Phonemic Awareness and working memory) and reading achievement during childhood and adolescence. The participants, 6 to 19 years of age, completed tests of reading comprehension, phonemic awareness, and working memory. Results of multiple regression analyses demonstrated a moderate to strong relationship between reading achievement, phonemic awareness, and working memory (Evans et al., 2001). The relationship between working memory and reading comprehension suggests that working memory provides a holding area that facilitates the processing of language-based stimuli while the words are simultaneously decoded. As the child ages the process of reading becomes more automatized and the speed of mental processing increases, consequently more efficient functioning during complex cognitive tasks occurs and the child requires less working memory space (Dufva et al., 2001; Evans et al., 2001; Fry & Hale, 2001).

Despite all the information gained about the way students learn to read and about the most effective instructional strategies that may be used to assist students during the reading process, deficits in reading remain one of the most prevalent obstacles in education. Oftentimes, children who are not reading commensurate with their peers have a difficult time closing the gap. A possible hypothesis for the continued obstacles in reading is that some learners have deficits in working memory (Dahlin, 2011). Difficulties in working memory often go undetected in the academic environment or at times may be perceived as poor behavior or lack of motivation on the student's part (Elliot et al., 2010).

The construct of working memory is now recognized more in current knowledge and in education. Researchers have paid more attention to studying the impact of working memory on children's learning. Many assessment tools are now available to measure student's working memory skill (Elliot et al., 2010). Nation and Angell (2006) noted that when reading, information often has to be retained in the mind and then integrated with the new information read. This likely relies heavily upon the process of working memory. Thus, poor comprehension may relate to poor working memory. Readers with deficits in comprehension have difficulty tuning out irrelevant information; this restricts and overloads the working memory process (Henderson & Pimperton, 2008). Studies have shown that working memory, specifically the phonological loop and central executive, is essential for retaining verbal information during reading (Beneventi et al., 2010; Cain, Oakhill, & Bryant, 2004; de Jong, 2006; Gathercole et al., 2006; Just & Carpenter, 1992; Savage et al., 2007; Swanson et al., 2006).

Because the process of reading involves the simultaneous processing of phonological and visual stimuli and the continuous storage and retrieval of information, proficiency in working memory and how it relates to proficiency in reading is best captured by Baddeley's multicomponent model (1986). Working memory may be perceived as a "limited central executive system that interacts with a set of two storage systems used for the temporary storage of different classes of information" (Swanson et al., 2006, p. 252). These two storage systems are the speech-based phonological loop and the visuospatial sketchpad. Both of these storage systems are in direct contact with the central executive. The central executive in this model is largely responsible for coordinating information and using its resources to increase the amount of information that is stored in the two subsystems (Swanson et al., 2006).

The central executive in Baddeley’s theoretical model of working memory is conceptualized to be the attention and inhibitory process a reader gives to a task when reading for comprehension and understanding. It is a parallel cognitive process requisite for information processing performed during reading. Additionally, students with reading disabilities exhibit processing deficits in the phonological loop, verbal working memory, word list recall, and story detail recall. These tasks are assumed by researchers to all use verbal rehearsal strategies (Savage et al., 2007). Because of this, it is likely that without intact working memory skills a reader may have difficulty gleaning the necessary information to comprehend text (Cain, Oakhill, & Bryant, 2004; Nation et al., 1999; Seigneuric et al., 2000).

It is likely that deficits in working memory adversely impact all aspects of academic achievement. Poor working memory negatively affects the ability to maintain information retrieved from long-term storage and then integrate that information with current inputs. Often times, during classroom instruction students are expected to engage in learning activities that places heavy demands on working memory. Consequently, these students often fail at completing a task due to poor working memory function. Working memory is required for the normal incremental process of acquiring knowledge and skills (Gathercole et al., 2006).

Students with poor working memory capacities encounter difficulty with following complex instructions, forgetting information, performing tasks that require significant storage and processing, and performing tasks that have a hierarchical structure. Often times, the students will lose their place and typically will abandon the tasks before completion. Because of this, it is likely that students with low working memory will have difficulties performing structured learning tasks, which are typical of the classroom environment. They will frequently miss opportunities to learn and progress in complex academic skills (Gathercole et al., 2006).

Working memory performance is quite different from individual to individual and shares a close relationship with learning abilities during childhood. A majority of the studies to date which pertain to working memory often focus on deficits in individuals with disabilities in reading, math, language, and attention (Alloway et al., 2009). Students that suffer deficits in working memory performance also experience failures in learning activities that place heavy demands on the working memory system. For example, they often forget multi-step instructions, keeping place while reading, and they often experience difficulty with any learning activity that requires simultaneous processing and storage (Alloway et al., 2009).

Despite knowing this information, reading development remains a complex process, which involves working memory. "Functional magnetic resonance imaging (fMRI) studies have shown that a distributed network of regions in the prefrontal cortex and the temporo-parietal cortex are associated with working memory in both adults and children" (Beneventi et al., 2010, p. 51). Beneventi and colleagues in 2010 conducted a study where children with reading deficits were assessed on working memory demands. The children with working memory deficits showed significant impairment in performance. The fMRI studies showed activation in the cortical networks that include the prefrontal cortex, the cingulate gyrus, the parietal lobe, and the cerebellum when solving working memory tasks. Children who performed within normal limits on reading tasks showed significantly more activation in these cortical regions when compared to their disabled counterparts. These areas are associated with continuous memory updating and temporal order memory (Beneventi et al., 2010). These findings provide support for the role of working memory in the reading process. Because of this, working memory deficits should be considered when assessing for and providing interventions for reading difficulties. Consequently, the researchers recommended that the learning environment in the classroom should minimize the load on working memory (Beneventi et al., 2010).

Swanson and colleagues (2006) also conducted a study demonstrating that working memory does underlie performance in reading. In their study, they noted that children who experience poor reading comprehension also suffer deficits in working memory. With these children, the executive processing activity that plays a crucial role in working memory while reading is updating. Updating is the monitoring, coding, and revising of information for the task. Updating requires the control of attention and maintaining information in the face of interference (Swanson et al., 2006).

Finally, in 2006 Gathercole and colleagues conducted a study that examined the extent to which deficits in working memory are associated with problems in reading and mathematics. This study noted that skills in working memory are significantly related to difficulties in reading ability. Working memory skill alone can predict how well students will achieve in reading. Working memory provides the learner with a resource that allows him or her to integrate information retrieved from long-term storage and then integrate that information with current inputs. A student with poor working memory capabilities will likely have trouble executing this important cognitive ability. Because the working memory system may be viewed as a bottleneck for learning and acquiring knowledge, deficits in working memory likely will result in learning difficulties (Gathercole et al., 2006).

As is common knowledge, the ability to decode words is an area of difficulty often experienced by students who have problems reading. Additionally, the speed with which the words are decoded separates a fluent reader from a non-fluent reader. Students that encounter difficulties in reading are often slower at naming letters, numbers, and words (Semrud-Clikeman, 2005). Working memory has the ability to organize a task based on the time it was learned and is part of a system that allows the child to retrieve previously stored information. If difficulties are encountered at the beginning of the memory process, or during the working memory stage, the child likely will have problems retrieving previously learned skills (Semrud-Clikeman, 2005).

Within Baddeley and Hitch's (1974) model, the phonological loop is necessary for the development of vocabulary skills. It supports the learning of sound patterns of new words. Deficits in phonological loop function during childhood, hinders the learning of new words in either native or foreign languages. It may also result in significant difficulties in learning language, resulting in specific language impairment (Gathercole & Pickering, 2001). This evidence shows the direct and detrimental consequences of impairment in working memory on students' learning and ability to perform complex cognitive tasks (Gathercole & Pickering, 2001).

Gathercole and Pickering in 2001 investigated whether the impairments in working memory related to the failures in progressing in academic skills and whether or not the deficits are severe enough to require special education. The findings show that students who require special education services do perform poorly on measures of working memory. They particularly experience deficits in tasks that require the use of the central executive and tasks that used visuospatial patterns. During working memory, processing the central executive is used as a workspace where complex and demanding activities are stored and integrated. Such activities include listening to another speaker, decoding an unfamiliar word, holding the meaning of previously decoded text, writing information while formulating your thoughts, and performing mental arithmetic. These tasks all require processing of new or recently encountered information. These activities are all common in the classroom setting (Gathercole & Pickering, 2001). Because the process of working memory is so involved, it is not surprising that a student with limited working memory performance will encounter difficulties in the acquisition of academic skills when compared to their peers.

Working memory performance is affected by both short-term and long-term memory.   A reader must be able to efficiently retrieve the meaning of words and phrases and relate them to upcoming words and phrases. The reader "must also store the theme of the text, the representation of the situation to which it refers, the major propositions from preceding sentences, and a running, multilevel representation of the sentence that is currently being read" (Just & Carpenter, 1992, p. 122). The process of reading comprehension highlights the demands of maintenance, manipulation, and retrieval in complex information processing (Just & Carpenter, 1992).

If the findings of the aforementioned studies are considered valid, it is likely that using instructional strategies alone may not provide the most gain when attempting to improve students' reading achievement. Accordingly, one may expect that providing intensive, systematic training in strategies for improving working memory should lead to gains in overall reading comprehension achievement. Using Cogmed in conjunction with the reading interventions provided by the EIP may provide additional gains when attempting to improve students' reading achievement.

Childhood Disorders Associated with Working Memory Deficits

Reading and Learning

Working memory is one of the cognitive processes that lay the foundation for individual learning ability. Children who experience learning difficulties show impairments in their working memory performance. The central executive in Baddeley's theoretical model of working memory is conceptualized to be the attention and inhibitory process a reader gives to a task when reading for comprehension and understanding. It is a parallel cognitive process requisite for information processing performed during reading. Additionally, students with reading disabilities exhibit processing deficits in the phonological loop, verbal working memory, word list recall, story detail recall, visual spatial sketchpad, and the central executive. They often have difficulty with vocabulary acquisition, learning new words, reading, text comprehension, communication, spontaneous speed, and expressive language (Masoura, 2006; Savage et al., 2007). These tasks are assumed by researchers to all use verbal rehearsal strategies (Savage et al., 2007). Because of this, it is likely that without intact working memory skills a reader may have difficulty gleaning the necessary information to comprehend text (Cain, Oakhill, & Bryant, 2004; Nation et al., 1999; Seigneuric et al., 2000).

Nation and Angell (2006) noted that when reading, information often has to be retained in the mind and then integrated with the new information read. This likely relies heavily upon the process of working memory. Thus, poor comprehension may relate to poor working memory. Readers with deficits in comprehension have difficulty tuning out irrelevant information; this restricts and overloads the working memory process (Henderson & Pimperton, 2008). Studies have shown that working memory, specifically the phonological loop and central executive, is essential for retaining verbal information during reading (Cain, Oakhill, & Bryant, 2004; de Jong, 2006).

Elementary school children who perform below age-expected levels in reading and mathematics are often identified with working memory deficits. These students usually lag behind their peers in academic skills. Working memory has been demonstrated to share a stronger relationship with subsequent reading and mathematics performance more than intelligence quotient (IQ). Poor working memory often result in failures at simple tasks like remembering instructions and tasks that are more complex that require storing, processing, and monitoring progress during difficult tasks (Alloway et al., 2010).

Research has shown that working memory shares a close relationship and plays a vital role in language and language development (Masoura, 2006). The central executive is the key component of the working memory system. It is responsible for higher-order functioning and for coordinating the phonological loop and the visuospatial sketchpad. It also controls attention and integrates information from long-term memory into working memory. Baddeley (2000) in a revision of his working memory model added the episodic buffer, which is responsible for assisting with the integration of information from multiple sources and long-term memory.

Much interest has been shown in how children learn to speak and read. Phonological awareness has been widely studied and has been shown to have a close link with reading development. Moreover, there is evidence supporting the close relationship of phonological memory and reading achievement (Jeffries & Everatt, 2004; Masorua, 2006; Savage et al., 2007). Poor readers typically will not perform well on tasks that assess digit span, serial recall of unrelated strings of words, and the repetition of non-words. Low performance on memory tasks typically reflects an impairment of the phonological loop in working memory (Masoura, 2006).

Attention-Deficit/Hyperactivity Disorder

Executive functions are among higher cortical abilities that comprise neuropsychological functioning. Executive functions refer to the ability to maintain information for the attainment of future goals. Some of the abilities included in executive functions are attention, reasoning, planning, inhibition, set shifting, interference control, and working memory (working memory). These functions are vital to complex human behavior (Biederman et al., 2004). Working memory is an executive function process that garners the most attention when studying the academic/learning deficits in children with Attention Deficit Hyperactivity Disorder (ADHD). Working memory deficits are well established when looking at the behavioral profile of children with ADHD. It is critical to cognitive development, motor skills, academic achievement, and higher order functioning. Children with ADHD demonstrate deficits with working memory and inhibitory control (Huang-Pollock & Karalunas, 2010).

Alloway and colleagues (2010) studied the behaviors typical of working memory deficits that are associated with poor academic achievement in a child with ADHD. Oftentimes, these working memory problems go undetected and usually labeled as lack of motivation. These researchers found that children diagnosed with ADHD also exhibit behaviors that are characteristic of working memory deficits. These deficits are not sex-specific and the children perform significantly worse in academic tasks. However, early screening using standardized measures may prevent subsequent learning troubles (Alloway et al., 2010).

Deficits in behavioral inhibition and working memory are two of the processes regarded to be central to theories of ADHD. The inhibitory processes have difficulty effectively keeping out extraneous information from the working memory process. Consequently, the working memory system is unable to maintain and complete task goals without interference (Alderson et al., 2010). Research evidence is available to show that children with ADHD have deficits in the central executive, phonological loop, and visuospatial sketchpad (i.e., all three components of working memory). The greatest impairment is found in the central executive, followed by the visuospatial sketchpad, and finally the phonological loop. The deficits noted in the central executive are functionally related to the inattentive and hyperactive behaviors characteristic of ADHD. Deficits in behavioral inhibition are considered a product of poor working memory because the information first has to be processed and evaluated through the working memory system (Alderson et al., 2010).

Poor behavioral inhibition is a byproduct of ADHD. Because of this, there are secondary deficiencies noted in working memory. Children who suffer from ADHD often exhibit the following behaviors that are detrimental to efficient working memory: they have less control over internal information, they are easily influenced by immediate events; they have greater difficulty retrieving, holding, and manipulating information on-line; they have difficulty anticipating and preparing for incoming information, only information that is current is regarded and previous information is not integrated; and their ability to persist in goal-directed behavior is diminished because of greater interference by internal and external stimuli (Barkley, 1997). Additional working memory deficits associated with ADHD are an inability to imitate lengthy sequences of goal-directed behavior because these sequences have to be held in mind and correctly executed; difficulty with the sense of time; information that is retrieved from long-term memory is usually disorganized; execution of tasks is disorganized; and information is not integrated during the process (Barkley, 1997).

For children suffering from ADHD, tasks that assess response inhibition are often positively associated with measures of working memory. This is so because the child is required to wait to respond while keeping information in mind (Barkley, 1997). Short and long-term memories have not been implicated in children that suffer from ADHD. It is when increasingly complex information is required to be stored and manipulated, difficulties are apparent for children suffering from ADHD. Such children also lack the strategies required for organizing and effectively storing material necessary for efficient working memory capabilities (Barkley, 1997). "The incapacity to hold information in mind in those with ADHD creates a disability in imitating complex and lengthy behavioral sequences performed by others that may be novel to the individual" (Barkley, 1997, p. 78). Children who suffer from ADHD have great difficulty performing tasks based on internally represented information when compared to their peers (Barkley, 1997).

Academic under-achievement is one of the prominent concerns for children that suffer from ADHD. Approximately 30% of children who suffer from ADHD have failed a grade, about half of them received academic tutoring, they are likely to complete less schooling and/or drop out of school, and they have a lower socioeconomic status. Difficulties in reading are often comorbid with other diagnoses such as anxiety, depression, and Attention-Deficit Hyperactivity Disorder (ADHD). Approximately 20-50% of children who struggle with reading achievement also suffer from ADHD. The neuropsychology of a reading disability encompasses the complex processing of information. When evaluating a child's reading skills, it is vital to understand how the child processes language, how they interpret what is heard, how the information is organized, the speed with which the information is processed, the child's attention span, ability to maintain and manipulate information, and the child's ability to self-monitor as they read (Semrud-Clikeman, 2005).

Because of the detrimental outcomes of ADHD on children's lives, it is important to study and understand how children with ADHD learn. Huang-Pollock and Karalunas (2010) examined the attentional and working memory resources of children suffering from ADHD. These resources are extremely important to learning and academic success. The study sought to determine how children with ADHD develop automaticity for complex cognitive skills and how working memory load affects the cognitive skill acquisition. The results of the study showed that children with ADHD are impaired in their development of automaticity for complex cognitive processes. The severity of the impairment directly correlates with the working memory load that is needed for the task. This demonstrates that a student's effort alone is not sufficient when performing working memory tasks; automaticity is also required. Reducing working memory load during learning in addition to training the working memory processes will likely aid the acquisition of skills (Huang-Pollock & Karalunas, 2010).

In addition to the over-activity, inattention, and impulsiveness (the behaviors characteristic of ADHD) there is increasing evidence that children with ADHD also demonstrate behaviors that are typical of working memory deficits while in the classroom. These children often find it difficult to remember complex instructions due to lack of attention and they find it difficult to not interrupt as instructions are provided (Alloway et al., 2010).

Autism Spectrum Disorder

The role of memory in the cognitive function of individuals with autism is unclear. Some children seem to have strong rote memory skills while others seem to have severe deficits in their memory capacity (Williams et al., 2005). Working memory may be assessed using relatively simple tasks or tasks that are more complex, as in problem solving. Individuals with autism who also suffer working memory deficits show problems with behavioral regulation, cognitive flexibility, abstract reasoning, and difficulty with focusing and maintaining attention (Williams et al., 2005).

Individuals with high-functioning autism tend to perform significantly worse than their peers on working memory tasks that require planning and problem solving skills. It has been suggested that because of the working memory component in these tasks, individuals with autism perform worse than their peers (Williams, et al., 2005). An additional explanation offered is that these individuals have trouble retaining information in the articulatory loop and visuospatial sketchpad well enough to aid in problem solving. Others have posited that these individuals perform poorly because there is a deficiency in working memory as a whole system (Williams et al., 2005).

Functional neuroimaging studies conducted with individuals that exhibit normal working memory performance show that distinct domain-specific cortical networks mediate verbal working memory and spatial working memory. However, there are some overlap in the networks and neural circuitry. Consequently, it is likely that one cortical network may be impaired while the other may not result in impairment in the verbal or spatial system (Williams et al., 2005).

Interventions for Working Memory Deficits in Children

Working memory is an important component for learning and it is necessary for these difficulties to be identified and remediated. Even though it is not difficult to identify children with working memory deficits, what is problematic is creating effective means of interventions that will maximize educational achievement (Elliot et al., 2010). Younger children who have a diminished working memory performance often rely more on executive resources (controlled attention) when performing working memory tasks. Moreover, these children typically perform poorly in learning to read and doing mathematics and they often require additional support in the classroom setting. Consequently, low working memory skill is a risk factor for educational under-achievement (Alloway et al., 2009).

It is rarely challenged that deficits in working memory during childhood are related to academic difficulties. Poor working memory is linked to difficulties focusing, remembering and completing classroom instructions, planning and organizing information, solving problems, and monitoring progress during complex tasks (Elliot et al., 2010). Working memory skills share a positive correlation with academic progress in reading, mathematics, and language comprehension. Because of this, it is important to find ways to improve working memory difficulties so that students are able to gain the most from academic instruction. To achieve this, researchers (Alloway et al., 2009; Dahlin, 2011) have attempted to directly increase student's working memory performance with the hope that the training would generalize to educational performance. Alternatively, others have attempted to alter the learning environment in a manner that would reduce processing demands and use effective learning strategies with the hope of reducing memory overload (Elliot et al., 2010).

Many of the studies in the literature regarding working memory fall in two categories. The first category details whether or not enhancing long-term memory will produce improvements in working memory performance. Most working memory models agree that working memory and long-term memory work together. Individuals who are able to engage better strategies for maintaining information is typically able to extend their working memory performance (Carretti et al., 2007). The second category pertains to studies that aim to measure the effects of working memory training and whether it produces positive effects on higher order cognition (transfer effects) (Carretti et al., 2007). To successfully execute a complex task, working memory resources are required. However, it has been demonstrated that with practice, performance drastically improves and it eventually becomes automatic (Huang-Pollock & Karalunas, 2010). Following is a review of the relevant literature and the effectiveness of each category.

Strategy Training

Mnemonic strategy instruction has been proven effective for helping students who encounter difficulties learning novel information. Mastropieri et al. (2005) showed that with the use of visual and auditory cues, mnemonic strategies aid in linking new information with prior knowledge allowing for the information to be more concrete and accessible. This process allows information to be easily retrieved from storage. Mnemonic strategies that use systematic encoding procedures and direct retrieval links to information just learned are the most effective. Other effective mnemonic strategies are those that associate images, pictures, or verbal phrases. Students that function within normal limits independently use mnemonic strategies; however, this is not the case for students who encounter difficulties with learning. When students with learning difficulties are exposed to mnemonic strategies, they significantly improve in their learning performance (Mastropieri et al., 2005).

Because they are versatile and can be altered to fit any learning situation, mnemonic strategies are successful when used with students with learning difficulties. When creating a mnemonic strategy, the student should identify the important information, generate a keyword for the unfamiliar word, generate a picture in which the keyword is interacting with the answer, and then picture using the strategy until the information is learned (Mastropieri et al., 2005). It is important to prioritize the information to be learned when constructing a mnemonic strategy. The key pieces of information should be selected and associated before developing the strategy. The following guidelines are recommended when developing mnemonic strategies: prioritize content to be learned; select content to be learned that is novel to the students; create keywords that are acoustically similar, familiar, and concrete; create interactive illustrations of the keywords and the information that is to be remembered; introduce the strategies to students, providing numerous opportunities to practice; finally students should be taught how to use the strategies on their own (Mastropieri et al., 2005).

Mnemonic strategies have proven to be effective with students with learning difficulties. When students utilize mnemonic strategies, they remember almost two-times the amount of information when compared to their counterparts. It should also be noted that students without learning difficulties when exposed to mnemonic strategy instruction also benefit. Mnemonic strategy instruction has proven to be highly effective in remembering academic content (Mastropieri et al., 2005).

Most working memory models agree that working memory and long-term memory work together. Individuals who are able to engage better strategies for maintaining information are typically able to extend their working memory performance (Carretti et al., 2007). Researchers Ericsson and Delaney (1999) have demonstrated that the use of mnemonic strategies enhances working memory performance. Those skilled in memorizing efficiently store relevant information into long-term memory and are able to access that information quickly via cues when needed. Individuals skilled in memorizing and efficiently storing and retrieving information likely rely on prior knowledge to encode and store the items into groups. They then associate the encoded items with a retrieval cue that later triggers retrieval from long-term memory. Lastly, with more and more experience at encoding, storing, and retrieving information they are able to become more proficient in the process, consequently needing less time to do so (Carretti et al., 2007).

In 2007, Carretti and colleagues conducted a study to examine the effects of strategic training on working memory. More specifically, they analyzed the performance of younger and older adults to determine the effects on a memory task after receiving strategic training. In the study, 120 participants were randomly assigned to a training group or control group. Participants were required to process lists of words and maintain the last word of each list. Each participant in the experimental group was trained to use an imagery based strategy in the context of long-term memory recall (i.e., create an image for each word). As a result of learning this strategy, the participants demonstrated that they were able to use this strategy to recall information during the working memory process. The trained group significantly improved their ability to immediately recall information when pre-test and post-test data were compared (Carretti et al., 2007).

Cognitive Training

Direct training in cognitive processes and the ability to transfer the effects of this training to higher cognitive processes has gained much interest over the past few years. Specifically, direct training in working memory strategies via the use of a computer has been of interest. Working memory is now recognized more in current knowledge and in education. Researchers have paid more attention to studying the impact of working memory on children's learning (Elliot et al., 2010; Dahlin, 2011).

Thorell and colleagues (2009) investigated the effects of a training program that utilized visuospatial working memory tasks. Sixty-five preschool children were randomly assigned to a training group or a control group. The training was computerized and lasted 8 weeks. The children in the experimental group played games specifically designed to improve visuospatial working memory. The training group was provided with continuous feedback from the researcher during the training. The results of the study showed that working memory training was successful in improving working memory performance in spatial and verbal domains and attentional control. The effect size for the comparison between the working memory group and the control groups was large ($d = 1.15$). Because of the significant effects noted from the working memory training on the children's working memory performance, it is likely that this type of training if provided early to children that suffer working memory deficits will make a significant difference. Early intervention is crucial when using cognitive interventions to remediate cognitive deficits (Thorell et al., 2009).

In 2014, Rose and colleagues sought to investigate the effects of working memory training within a regular school setting on school-related achievement. Two hundred and eighty two third grade students were randomly assigned to an experimental group or a control group. The students were pre and post-tested on measure of working memory and academic achievement (i.e., math and reading). Students in the experimental group completed an intensive computerized program during routine classroom instructional time. The training was 20-30 minutes per day, five days per week, for 4 weeks. The students in the control group experienced regular instruction. The results of the study showed that the children in the experimental group did improve in the working memory performance from the initial session to the last session. However, there was no evidence that the working memory training generalized to academic performance (Rose et al., 2014).

Jacob and Parkinson (2015) recently conducted a meta-analysis to review the empirical evidence regarding the association between executive function and achievement in reading and mathematics. The four subcomponents of executive function are working memory, attention control, attention shifting, and response inhibition. The results of the meta-analytic techniques demonstrated that there was a moderate association between executive functions and achievement in reading and mathematics. The association was not affected by the student's age or subcomponent of executive function. Moreover, the review showed that even though there was an association between executive function and achievement, there was no evidence that the association is causal. There was evidence to show that using interventions that are designed to impact executive functions do have a positive change on measures of executive functions. However, there was no compelling evidence to show that an increase in executive functions positively impacts academic achievement (Jacob & Parkinson, 2015).

Cortese et al., (2015) reviewed fifteen randomized controlled trials to determine the effects of cognitive training on symptoms of Attention-Deficit/Hyperactivity Disorder (ADHD), academic skills, and neuropsychological deficits in children ages three to eighteen. Fifteen trials were included in the study. Six of the trials focused on working memory training, four looked at attention training, two studies combined attention and working memory training, two pertained to inhibition and working memory training, and one trial looked at executive function training. All of the trainings in the trials included an adaptive component, where task difficulty increased from session to session. After reviewing all of the studies, the findings provided little support for cognitive training as a treatment for ADHD. However, there was stronger evidence for the benefits of cognitive training on working memory. Improvements were noted in visual and verbal working memory but these improvements did not extend to academic achievement (Cortese et al., 2015).

Finally, Dahlin (2011) examined the relationship between working memory and reading achievement in students with special needs. The goal of the study was to determine to what extent the students' working memory could be trained and whether this training will bring benefits to their reading achievement. Fifty-seven students, ages 9 to 12 years, who were either diagnosed with Attention-Deficit/Hyperactivity Disorder

(ADHD) or a specific learning disability participated in the study. The students were either placed in the treatment group or the control group. Both groups completed pre-test assessments in nonverbal reasoning, working memory, and reading. The treatment group received computerized working memory training, daily, for five weeks (30-40 minutes) while the control group only received the standard Special Education instruction. The working memory training contained visuospatial and verbal working memory tasks. The level of difficulty was adapted to the child's ability on a trial-by-trial basis. The software was guided and feedback on performance was provided immediately. Each child's performance was recorded daily by the computer software. It was found that when compared to the control group, the experimental group did show improvement in their working memory performance and in their reading comprehension performance. A substantial effect size (d = .91) in the reading comprehension performance was found, suggesting the importance of working memory performance in the process of reading (Dahlin, 2011). Dahlin's (2011) research serves as the foundation for the present study of the effectiveness of intensive working memory training when used with other interventions.

As is evident by the aforementioned studies, outcome studies have been mixed in their findings. The purpose of this study is to evaluate the effectiveness of Cogmed training (i.e., a computerized training program) when used with other interventions. Cogmed is an evidenced-based intervention designed to improve working memory. Cogmed may be used with children and adults ages four to seventy years and over (Cogmed, 2013a). Conceptually, working memory is a necessary cognitive function that aids in learning and performance of most complex tasks. Working memory performance is a dynamic process that encompasses the ability to store information briefly while simultaneously processing other cognitively challenging tasks (Alloway, 2009; Beck et al., 2010; Savage, Lavers, & Pillay, 2007). Cogmed training uses a web-based computerized system and can be accessed in various locations. Cogmed training has been demonstrated to be a complementary intervention and likely will produce the greatest benefit when combined with other sources of interventions (Cogmed, 2013a). Research has shown that adaptive training in working memory has led to gains in word reading, reading comprehension, mathematical ability, and improved attention (Beck et al., 2010; Dahlin, 2011; Holmes et al., 2009).

Since its inception, many researchers have demonstrated the efficacy of Cogmed through rigorous investigations of its treatment protocols and methods (Beck et al., 2010; Dahlin, 2011; Holmes & Gathercole, 2013). The publishers of Cogmed noted that:

> Cogmed users train intensively for 30 to 40 minutes, 5 days a week, for 8 weeks. It is during this sustained training period that the user engages in 8 out of 12 visuospatial and verbal exercises per day that continually adjust in difficultly based on user performance. Although it is the adaptivity and intensity of the training that is believed to underlie the training effect, support from a trained Cogmed Coach ensures compliance with the Cogmed protocol, fidelity to the training plan, and assessment of working memory with non-trained tasks (i.e., sound measurement of working memory gains). (Cogmed, 2013b, p. 9)

The working memory training provided by Cogmed is designed to be adaptive, supported by a coach, and intensive. More specifically, the training continually challenges the user through a staircase method that adjusts on a trial-by-trial basis. The Cogmed coach provides support and feedback and ensures fidelity of the intervention. Lastly, to demonstrate improvements individuals are assessed using non-trained assessments of working memory. These non-trained tests differ in configurations, presentations, and response modes. For example, a trained visuospatial working memory task may be presented as a 4x4 grid on the computer screen, the stimuli light up, and the trainee uses the mouse to respond. While a non-trained visuospatial working memory task may be presented as blocks on a board, with an irregular pattern, and the trainee responds using his or her hands (Cogmed, 2013a).

A meta-analysis of published Cogmed studies (Cogmed, 2013b) provided statistics for improvements after receiving adaptive training in working memory tasks. When research participants were assessed using visuospatial working memory and verbal working memory tasks improvements were noted. More precisely, there was a 26% improvement in visual-spatial working memory and a 23% improvement in verbal working memory from baseline to post-test. Additionally, the average effect sizes were 0.98 and 0.77 for visuospatial and verbal working memory respectively. These published studies provide research evidence for Cogmed and its ability to notably improve working memory (Cogmed, 2013b).

Cogmed training holds great potential as an intervention for improving working memory. However, outcome studies have been mixed in their findings. The purpose of this study is to evaluate the effectiveness of Cogmed training when used with other interventions.

Summary

Memory is our ability to encode, store, retain and subsequently recall information and past experiences. It may be thought of as the use of past experience to affect or influence current behavior. What is working memory? As with many constructs in cognitive psychology, many researchers studying working memory differ in their definition of the construct. A general conception of working memory is that it is a dynamic process that encompasses the ability to briefly store information while simultaneously processing other cognitively challenging tasks (Alloway, 2009; Beck et al., 2010; Savage et al., 2007). Working memory capacities are essential for the successful completion of many cognitive tasks, such as reading and comprehending the content outlined within this document.

Memory has been the focus of many research studies for several centuries. Many of these studies have focused on separating attention from memory and distinguishing immediate from short-term memory. Memory problems are often apparent in children diagnosed with learning difficulties, depression, fetal alcohol syndrome, children exposed to crack cocaine, having low birth weight, and those born to mothers addicted to drugs. The extent of these memory problems often varies and typically persists into adulthood (Reynolds & Voress, 2007). Dating back to the beginning of the 20th century, an examination of memory typically required the individual to answer questions about the current date, news, and to recite letters and words as a means of assessing the functioning of one's memory.

Over the decades, several models of working memory have been proposed. Three of the theoretical approaches pertaining to working memory often cited in the literature are the multicomponent model, the embedded-process model, and the dual-component model. Historically, the multicomponent model has been the most influential of the working memory systems. This model divides the system into domain specific buffers and a domain independent component. These specific buffers are the phonological loop and visuospatial sketchpad while the central executive/attentional control is the domain independent component (McCabe et al., 2010). Unsworth and Engle (2007) have also suggested another model of working memory called the dual-component model. In this model, to complete a working memory task information is retrieved from long-term memory and brought into short-term memory. The participant has to switch attention between short and long-term memory. Lastly, Cowan (1999) conceptualizes working memory as a component of long-term memory. In his embedded-process model of working memory, Cowan purports that working memory is what is activated during the process of long-term memory. In the embedded-process model of working memory, "the capacity of the focus of attention is limited to four chunks of information, and all other items in working memory reside within, and must be retrieved from, the activated portion of long-term memory" (Rose et al., 2010, p. 472).

Working memory pertains to the maintenance of short-term information that is relevant to present goals. Presently, the origins of working memory are unknown. However, it appears to be heritable. Working memory performance does not appear to be affected by parental educational level or socio-economic status. There is substantial evidence to show that working memory performance may be increased via intensive training (Alloway et al., 2009). There is a preponderance of evidence to show that working memory capabilities vary from individual to individual and each person's unique working memory performance will determine the acquisition of new skills and their ability to execute complex cognitive tasks (Gathercole & Pickering, 2001). The steady improvement in and development of working memory during childhood is astounding. This increase may be noted on performance on complex working memory span tasks. These tasks assess working memory performance by requiring maintenance, recall, and simultaneous processing of information. It has been suggested that the developmental improvement noted in working memory may be accounted for by the discovery of new strategies and changes in the manner a strategy is used (Camos & Barrouillet, 2011).

Working memory is central when attempting to understand cognitive functions. Playing an important role at the cognitive basis for intelligence is working memory. Measures of working memory, learning, achievement, and intelligence show that there is a crucial connection between working memory and learning during childhood. Academic measures of fluid and crystallized intelligence (i.e., reading and mathematics) require significant use of working memory capacities. Differences in working memory skills have been shown to be related to several areas of cognitive functions, such as language comprehension, mathematics, reasoning, and complex learning. Because working memory is strongly correlated to higher order cognitive functions, it has been referred to as ‘the hub of cognition’ (Swanson, 2008).

It is rarely challenged that deficits in working memory during childhood are related to academic difficulties. Poor working memory is linked to difficulties focusing, remembering and completing classroom instructions, planning and organizing information, solving problems, and monitoring progress during complex tasks (Elliot et al., 2010). Researchers have consistently demonstrated a relationship between working memory and reading ability (Cain, Oakhill, & Bryant, 2004; Dahlin, 2011; de Jong, 2006; Henderson & Pimperton, 2008; Nation and Angell, 2006). Moreover, it is well established that students who have deficits in reading also perform poorly on working memory tasks when compared to same-aged peers (Gathercole et al., 2006).

Deficits in working memory often correlate with many disorders in childhood.

Working memory is one of the cognitive processes that lay the foundation for individual learning ability. Children who experience difficulties with learning show impairments in their working memory performance. It has been demonstrated that these children show impairment in the phonological loop, visuospatial sketchpad, and the central executive. They often have difficulty with vocabulary acquisition, learning new words, reading, text comprehension, communication, spontaneous speed, and expressive language (Masoura, 2006). Moreover, working memory is an executive function process that garners the most attention when studying the academic/learning deficits in children with Attention-Deficit/Hyperactivity Disorder (ADHD). Working memory deficits are well established when looking at the behavioral profile of children with ADHD. It is critical to cognitive development, motor skills, academic achievement, and higher order functioning. Children with ADHD demonstrate deficits with working memory and inhibitory control (Huang-Pollock & Karalunas, 2010). However, the role of memory in the cognitive function of individuals with autism is unclear. Some children seem to have strong rote memory skills while others seem to have severe deficits in their memory capacity (Williams et al., 2005). The working memory performance of children on the autism spectrum may be assessed using relatively simple tasks or tasks that are more complex, as in problem solving. Individuals with autism who also suffer working memory deficits show problems with behavioral regulation, cognitive flexibility, abstract reasoning, and difficulty with focusing and maintaining attention (Williams et al., 2005).

A majority of the studies in the literature regarding working memory fall in two categories. These are strategy training and cognitive training. Mnemonic strategy instruction has demonstrated to be effective for helping students who encounter difficulties learning novel information. With the use of visual and auditory cues mnemonic strategies aids in linking new information with prior knowledge allowing the information to be more concrete and accessible. This process allows information to be easily retrieved from storage. Mnemonic strategies that use systematic encoding procedures and direct retrieval links to information just learned are the most effective. Other effective mnemonic strategies are those that associate together image, pictures, or verbal phrases (Mastropieri et al., (2005). Direct training in cognitive processes and the ability to transfer the effects of this training to higher cognitive processes have gained much interest over the past few years. Specifically, direct training in working memory strategies via the use of a computer has been of interest. Working memory is now recognized more in current knowledge and in education. Researchers have paid more attention to studying the impact of working memory on children's learning (Dahlin, 2011; Elliot et al., 2010).

The proposed study will assess the effective of adaptive training on working memory and reading achievement via the use of Cogmed. Cogmed is an evidenced-based intervention designed to improve working memory. It may be used with children and adults ages four to 70 years and over (Cogmed, 2013a). Cogmed training uses a web-based computerized system and can be accessed in various locations. The training has been demonstrated to be a complementary intervention and will likely produce the greatest benefit when combined with other sources of interventions (Cogmed, 2013a). Research has shown that adaptive training in working memory has led to gains in word reading, reading comprehension, mathematical ability, and improved attention (Beck et al., 2010; Dahlin, 2011; Holmes et al., 2009). Since its inception, many researchers have demonstrated the efficacy of Cogmed through rigorous investigations of its treatment protocols and methods (Beck et al., 2010; Dahlin, 2011; Holmes & Gathercole, 2013).

Chapter 3 provides the research design, methodology, and ethical considerations for the study.

CHAPTER III

METHODOLOGY

The following sections will review the specific methods used for this study. They will include a design of the study and the related research design diagrams, the population from which the study is derived, the sample of subjects in this study, assignment procedures that will be used, and the instruments that will be used to gather the data.

Research Design

This study utilized a quasi-experimental, repeated measures design. Data for this study were collected through the use of the Cogmed working memory assessments, the Developmental Reading Assessment (DRA), the Dynamic Indicators of Basic Early Literacy Skills – Oral Reading Fluency (DIBELS-ORF), and school records. More specifically, the data showed the students' working memory scores recorded by Cogmed. The students' performance was recorded after each day's training had been completed (Cogmed, 2013). Reading comprehension scores provided by the DRA and reading fluency scores were provided by the DIBELS-ORF. The students' sex, grade level, and free and reduced lunch status were taken from school records. The data were anonymously coded and then analyzed using a series of one-sample *t*-tests and two analyses of covariance (ANCOVA).

The independent variable for the present study was the standardized training program in working memory strategies using the Cogmed system. The participants were matched with students from the previous school year that participated in the same Tier 2 reading intervention program. The expected treatment condition was implemented for 8 weeks. The dependent variables were reading comprehension, reading fluency, and working memory performance. The covariate was the initial working memory score recorded by Cogmed and the repeated measures were the reading comprehension and reading fluency probes.

In the present study, the investigator and the EIP teachers were involved in the administration and management of the Cogmed training program. The Cogmed training method consisted of 40 online sessions, each 25 minutes long. Each session consisted of a selection of various tasks that target different aspects of working memory. The training was provided online at the elementary school. The standard program was 8 weeks long with five sessions every week. The EIP teachers were responsible for logging the students into and out of the program each day.

Cogmed users trained intensively for 25 to 30 minutes, 5 days a week, for 8 weeks. It was during this sustained training period that the user engaged in 8 out of 12 visuospatial and verbal exercises per day that continually adjusted in difficultly based on user performance. Although it is the adaptivity and intensity of the training that is believed to underlie the training effect, support from a trained Cogmed Coach ensured compliance with the Cogmed protocol, fidelity to the training plan, and assessment of working memory with non-trained tasks (i.e., sound measurement of working memory gains) (Cogmed, 2013b).

Once the Cogmed training was completed the Index Improvement score and Cogmed Progress Indicator (CPI) Improvement scores were provided. The Index Improvement was a measure of training progress on the trained exercises that the students did on a daily basis. It measured how much each student improved over the baseline. On average, students move about 27 index improvement points by the end of the program. The CPI provided information pertaining to the students training progress on working memory related abilities. The CPI tasks are non-trained tasks and therefore should reflect training effects on abilities, since the students did not practice these tasks daily. There were three CPI tasks (i.e., Shape Up, Listen Up, and Add Up) and typically students improve on at least 1 to 2 CPI measures. Effects of the Cogmed training typically manifest four weeks after training is complete (Cogmed, 2013).

Population

The sample for the study came from a suburban school district in Georgia with a population of approximately 20,301 students. Based upon an estimate of district students in second and third grade receiving EIP services in reading, the population consisted of approximately 434 students. Review of student records and the consent of parents/guardians provided accurate estimates.

The total population of students in the school district is 5.3% Asian, 25.3% African American, 9.7% Hispanic, 0.5% Native American/Alaskan Native, 53.7% Caucasian, 0.2% Pacific Islander, and 5.4% are Multiracial (Fayette County Board of Education [FCBOE], 2013). When placed into subgroups, 8% were classified as a student with a disability, 3% were limited English proficient, and 22% were eligible for free/reduced meals (Governor's Office of Student Achievement, 2011). According to the Georgia Department of Education [GADOE], (2012), 1,760 students enrolled in Special Education. Of these 1,760 students, 56.8% graduated from high school and there was a 2.6% dropout rate.

Sample

A convenience sample was employed in this study. The data obtained from the DRA, DIBELS-ORF, sex, grade, and free and reduced lunch status were collected on students in second and third grade. The average age of the second and third grade students were 7 and 8 years old. Males and females were included in the study. There were no restrictions based on sex. Sex, grade level, and free and reduced lunch status were used to select and describe the sample.

Sex

Research has suggested that the prevalence rates for reading difficulties tend to be higher for males than females. The ratio for male to female may vary depending on the methods used to determine level of difficulty; however, a greater number of males are typically reported (Hawke, Olson, Willcut, Wadsworth, & DeFries, 2009). Each student's sex was available in the demographic information maintained within the school records.

Grade Level

It has been suggested that providing explicit training in memory strategies by the third grade tends to have a more salient effect on students' reading comprehension performance rather than waiting until the students are older (Kolić-Vehovec & Bajšanski, 2006). Each student's grade level was available in the demographic information maintained within the school records.

Free and Reduced Lunch Status

Kirby and Hogan (2008) noted that there is a modest but reliable association between parental levels of income/education and children's reading achievement.

Information about students' free and reduced lunch status will be collected from school records. This variable was used to control for potential confounds in the primary analysis.

Information obtained from the second and third grade students of the participating elementary school were analyzed. In the study, second and third grade students of the experimental group, that were already receiving the standard Tier 2 reading intervention, also received explicit working memory training using the Cogmed program. The desired students also participated in the After School Reading and Math (ARM program) five days per week.

The specific assessments related to reading, sex, grade, and free and reduced lunch status were analyzed for the students selected for participation from grades two and three. Students who suffered from epilepsy, anxiety, and/or depression were excluded from the study. Student-level data were obtained from minors; however, all data reviewed were confidential. Parental consent to participate in the study were sought prior to the commencement of the study.

Sample Size

The sample size was chosen based on the availability of students receiving Tier 2 reading intervention in the elementary school.

Sample Selection

The study employed a quasi-experimental design, as the participants were matched with students from the previous school year that had participated in the same Tier 2 reading intervention program. When 50 participants were obtained, the investigator randomly assigned numeric ID codes to the experimental group and the control group and then attempted to create matched-pairs. Matched-pairs were based on sex, grade level, and free and reduced lunch status.

The Assistant Principal at the participating school generated a spreadsheet of second and third grade students who participated in the ARM program and who also received reading EIP support during the school day. The spreadsheet also included each student's sex, grade level, free and reduced lunch status, benchmark DRA, and benchmark DIBELS-ORF scores. Each student on the list was also assigned a numeric code that was linked to his or her identifying information. The Assistant Principal mailed the research packet that contains a letter fully describing the study and its purpose, the consent form, and a stamped, self-addressed return envelope to the parents of each student on the list. Once consent was granted, the Assistant Principal generated another spreadsheet with the students' targeted information and their unique numeric ID code in lieu of names. This spreadsheet was given to the investigator. The Assistant Principal kept a separate spreadsheet that linked the numeric ID codes to the students' identifying information. This was done to maintain confidentiality of the students.

A follow-up post card was mailed to each respondent 14 days after the mailing of the packet. This post card thanked respondents who have completed and returned the consent form and served as a reminder to those who had not. Non-respondents were reminded that participation was strictly voluntary.

When 50 participants had been obtained, the investigator created matched-pairs and then randomly assigned numeric ID codes to the experimental group and the control group. Matched-pairs were based on sex, grade level, and free and reduced lunch status. The investigator provided the Assistant Principal a list of numeric ID codes that are members of the experimental group and the control group. The Assistant Principal informed the EIP teachers of which students belonged to which group. The EIP teachers assisted the students of the experimental group each day with logging on and off of the Cogmed program.

Instruments

Reading comprehension was measured using the reading comprehension score obtained from the Developmental Reading Assessment (DRA). This variable was selected in order to establish a baseline for skill development as well as gains in each student's reading comprehension over time. The DRA as the instrument used by the school district for monitoring student progress and making educationally based decisions. The DRA provided an accurate assessment of individual students' reading comprehension ability. It was administered in a one-on-one setting and guided the teacher in pinpointing each student's area of need. Before beginning, the teacher selected the text that seemed appropriate for the student and then the teacher introduced the text. The student read the complete text aloud, while the teacher took a running record of oral reading. The student then retold either the story or the information read to demonstrate comprehension. After the assessment, the teacher added up all the scores for accuracy, fluency rate, phrasing, and retelling. The reliability and validity of the DRA was reported as moderate to high. Reliability scores ranged from .50 to .80 while validity scores ranged from .60 to .80 (Pearson, 2012).

The students' reading fluency scores were derived from the Dynamic Indicators of Basic Early Literacy Skills – Oral Reading Fluency (DIBELS-ORF) probes. This variable was selected to establish skill level as well as gains in each student's reading fluency over time. The DIBELS-ORF is a standardized, individually administered test of accuracy and fluency with connected text. It is intended for most children from mid first grade to third grade. The passages and administration procedures are designed to identify children who may need additional instructional support and monitor progress toward instructional goals. Students read a passage aloud for one minute. Words omitted, substituted, and hesitations of more than three seconds are scored as errors. Words self-corrected within three seconds were scored as accurate. The number of correct words per minute from the passage was the oral reading fluency rate. DIBELS-ORF includes both benchmark passages used as screening assessments and alternate forms for monitoring progress. The reliability and validity of the DIBELS-ORF were high. The reliability of the DIBELS-ORF ranged from .92 to .97 while the validity coefficients ranged from .52 to .91 (UO DIBELS Data System, 2013).

The working memory scores recorded by Cogmed were used to measure working memory. The students' performance was recorded after each day's training had been completed (Cogmed, 2013). Cogmed is an evidenced-based intervention designed to improve working memory. It may be used with children and adults ages four to 70 years and over (Cogmed, 2013a). Cogmed training uses a web-based computerized system and can be accessed in various locations. The training has been demonstrated to be a complementary intervention and will likely produce the greatest benefit when combined with other sources of interventions (Cogmed, 2013a). Cogmed users trained intensively for 30 to 40 minutes, 5 days a week, for 8 weeks. It was during this sustained training period that the user engaged in 8 out of 12 visuospatial and verbal exercises per day that continually adjusted in difficultly based on user performance (Cogmed, 2013b).

The working memory training provided by Cogmed is designed to be adaptive, supported by a coach, and intensive. More specifically, the training continually challenged the user through a staircase method that adjusted on a trial-by-trial basis. The Cogmed coach provided support and feedback and ensured fidelity of the intervention. Lastly, to demonstrate improvements individuals were assessed using non-trained assessments of working memory. These non-trained tests differed in configurations, presentations, and response modes. For example, a trained visuospatial working memory task may be presented as a 4x4 grid on the computer screen, the stimuli light up, and the trainee uses the mouse to respond. While a non-trained visuospatial working memory task may have been presented as blocks on a board, with an irregular pattern, and the trainee responded using their hands (Cogmed, 2013a).

The Tier 2 reading intervention was Reading Horizons. Reading Horizons is the standard protocol Tier 2 reading intervention used by the school district. Reading Horizons is a phonics program that may be used with children and adults. It provides instruction in 42 sounds, five phonetic rules, and a two-step decoding system. Instruction in the Reading Horizons method develops the students' phonemic awareness, phonics, fluency, vocabulary, and comprehension. The program is taught by the Early Intervention Program teacher and is used as a supplement to the school's core reading program. The goal of Reading Horizons is to teach students the phonic elements, consequently becoming fluent readers and spellers. The students are also provided instruction in spelling, vocabulary, grammar, sentence structure, and dictionary skills. Reading Horizons provide instruction that is explicit, systematic, and it follows a logical sequence. Skills are taught in small units, they build cumulatively, and these skills are reviewed frequently. Immediate corrective feedback is provided to the students. The instruction is highly interactive, multi-sensory, and detailed (Reading Horizons, 2014

Independent Variable

The independent variable for the present study was the standardized training program in working memory strategies using the Cogmed system. The participants were matched with students from the previous school year that participated in the same Tier 2 reading intervention program. The treatment condition was implemented for 8 weeks. Because the control group consisted of students that participated in the Tier 2 reading intervention program from the previous school year, no additional interventions were implemented with this group of students.

Dependent Variables

The dependent variables were reading comprehension, reading fluency, and working memory performance.

The following table summarizes the latent and observed variables, information source, and the validity and reliability of each variable:

Table 1

Latent Variables, Observed Variables, Information Source, Validity, and Reliability.

Latent Variable	**Observed Variable**	**Instrument/Source**	**Validity**	**Reliability**
Working Memory	Working Memory Score	Cogmed	--	--
Reading Comprehension	Reading Comprehension Score	Developmental Reading Assessment (DRA)	0.6 – 0.8	0.5 – 0.8
Reading Fluency	Reading Fluency Score	Dynamic Indicators of Basic Early Literacy Skills – Oral Reading Fluency (DIBELS-ORF)	0.52 – 0.91	0.92 – 0.97
Sex	Male/Female	School Records	Excellent	Excellent
Grade Level	2nd and 3rd	School Records	Excellent	Excellent
Free & Reduced Lunch	Free & Reduced Lunch, Partial Free & Reduced, No Free & Reduced Lunch	School Records	Excellent	Excellent

Table 2 summarizes a meta-analysis of data from published Cogmed studies. The data represents statistics for improvements after receiving adaptive training in working memory tasks. When research participants were assessed using visuospatial working memory and verbal working memory tasks improvements were noted. More precisely, there was a 26% improvement in visual-spatial working memory and a 23% improvement in verbal working memory from baseline to post-test. Additionally, the average effect sizes were 0.98 and 0.77 for visuospatial and verbal working memory respectively. These published studies provide research evidence for Cogmed and its ability to notably improve working memory (Cogmed, 2013b).

Table 2

Treatment Percentage Improved and Effect Size

Type of working memory	Average Treatment Improvement (%)	Average Effect Size Post-Test (d)	Individuals in Adaptive Training	Individuals in Non-Adaptive Training
Visual-Spatial working memory	26	0.98	249	204
Verbal working memory	23	0.77	264	210

Statistical Analyses

The following research questions were investigated in this study and the associated statistical analyses will be discussed. A series of one-sample *t*-tests were used to answer questions regarding whether or not the intensive training in working memory strategies produce improvements in the experimental group's working memory performance. Two analyses of covariance (ANCOVA) were used to answer questions regarding whether or not the intensive training in working memory strategies, in addition to Tier 2 reading intervention, showed improvement in reading comprehension and reading fluency scores.

The one-sample *t*-test is used to determine whether a sample comes from a population with a specific mean. This population mean is not always known, but is sometimes hypothesized. Analysis of covariance (ANCOVA) is a general linear model which blends analysis of variance (ANOVA) and regression. ANCOVA evaluates whether population means of a dependent variable are equal across levels of a categorical independent variable often called a treatment. The procedure controls for the effects of other continuous variables that are not of primary interest, known as covariates. ANCOVA is used in experimental studies when researchers want to remove the effects of some antecedent variable. For example, pretest scores are used as covariates in pretest – posttest experimental designs. ANCOVA can be used to increase the ability to find a significant difference between groups when one exists by reducing the within-group error variance (i.e., statistical power). An ANCOVA may also be used to adjust for preexisting differences in nonequivalent groups. This aims to correct for initial group differences that exists on the dependent variable among the groups. In this situation, participants cannot be made equal through random assignment, so the covariates are used to adjust scores and make participants more similar than without the covariates (Hanna & Dempster, 2012).

I posed three research questions relating to whether or not adaptive training in working memory strategies would improve performance in the dependent variables for the participants. Research question one evaluated whether or not adaptive training in working memory strategies produced significant improvements in working memory performance. Research question two examined the effect of adaptive training in working memory strategies on reading comprehension achievement. Finally, research question three examined the effect of adaptive training in working memory strategies on reading fluency achievement. Three corresponding hypotheses were generated.

Research Questions and Hypotheses

Research Question 1

Does intensive and systematic training in working memory strategies produce improvements in the experimental group's working memory performance as measured by the working memory scores recorded by Cogmed? It was expected that the students in the experimental group who received intensive and systematic training in working memory strategies will show improvement in their working memory capabilities from week to week. This improvement in working memory capabilities were measured by the working memory scores recorded by Cogmed. The students' performance was recorded after each day's training had been completed.

Because the Cogmed program provides improvement scores for trained and non-trained working memory tasks, a series of one-sample *t*-tests will be used to determine any significant differences between the sample mean and the population mean. The following assumptions regarding the data in the one-sample *t*-tests were made: the dependent variable was measured at the interval or ratio level (i.e., continuous), the data were independent (i.e., not correlated/related), there were no significant outliers, and the dependent variable was approximately normally distributed. The appropriateness of these assumptions was examined using the following steps: examine data, analyze descriptive statistics, examine charts & histograms, and run one-sample *t*-tests.

Research Question 2

Does intensive and systematic training in working memory strategies significantly improve the reading comprehension scores of participants in the experimental group by comparison to the control group as measured by post-test reading comprehension scores from the DRA (controlling for pre-test levels)? It was hypothesized that students who received intensive and systematic training in working memory strategies in addition to the Tier 2 reading intervention will show improvement in their reading comprehension score.

Because the sample was selected from an after school program and there were preexisting differences, the ANCOVA was used. The after school program consisted of students with mixed reading levels. By using the ANCOVA, the researcher was able to control for differences in the reading pre-test scores (i.e., pre-test DRA and pre-test DIBELS-ORF). The ANCOVA also determined group differences in the dependent variable (i.e., post-test scores) while controlling for the covariate (i.e., pre-test scores). The independent variable was the systematic training in working memory strategies. The covariate was the pre-test reading comprehension score. The dependent variable was the post-test reading comprehension score. The following assumptions regarding the data in the ANCOVA were made: the independent variables were categorical, the dependent variable was measured at the interval/ratio level, the differences between each session had approximately equal variances, the residual scores followed an approximately normal distribution, there was independence of the covariate and treatment effect, and there was homogeneity of regression slopes. The appropriateness of these assumptions were examined using the following steps: examine data, analyze descriptive statistics, examine charts & histograms, check the normality & standard deviation for all scores, and run ANCOVA – analyze descriptive statistics; homogeneity of variance; estimate of effect size; observed power.

Research Question 3

Does intensive and systematic training in working memory strategies significantly improve the reading fluency scores of participants in the experimental group when compared to the control group as measured by post-test reading fluency scores from the DIBELS-ORF (controlling for pre-test levels)? It was expected that the students in the experimental group will achieve higher reading fluency scores after participating in Cogmed.

Similar to research question two, an ANCOVA was used to determine group differences in the dependent variable (i.e., post-test scores) while controlling for the covariate (i.e., pre-test scores). The independent variable was the systematic training in working memory strategies. The covariate was the pre-test reading fluency score. The dependent variable was the post-test reading fluency score. The following assumptions regarding the data in the ANCOVA were made: the independent variables were categorical, the dependent variable was measured at the interval/ratio level, the differences between each session have approximately equal variances, the residual scores followed an approximately normal distribution, there was independence of the covariate and treatment effect, and there was homogeneity of regression slopes.

The appropriateness of these assumptions will be examined using the following steps: examine data, analyze descriptive statistics, examine charts & histograms, check the normality & standard deviation for all scores, and run ANCOVA – analyze descriptive statistics; homogeneity of variance; estimate of effect size; observed power. Figure 2 describes the path used to complete the current statistical analyses.

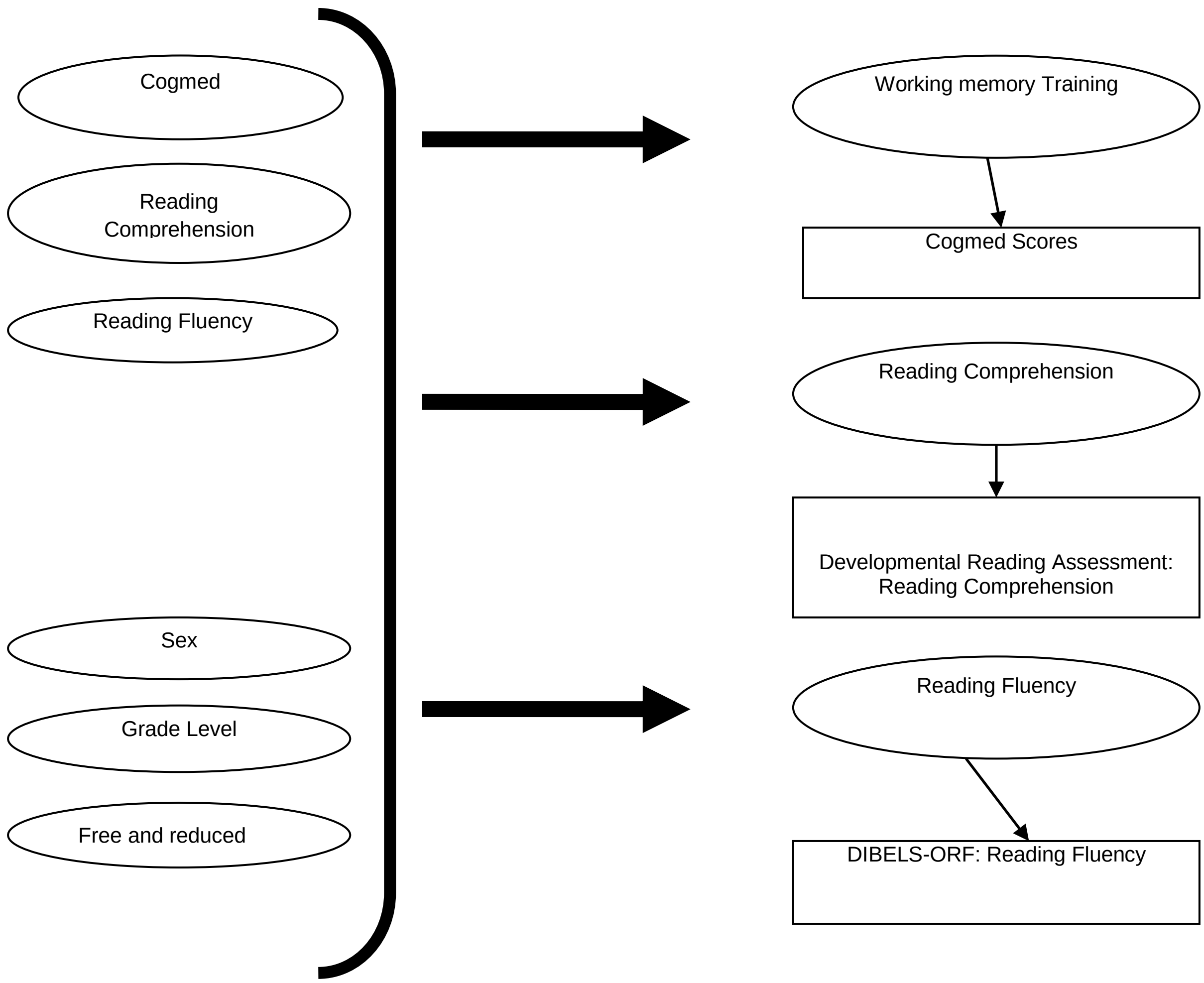

Figure 2. Research design diagram of the working memory training project

All research questions and hypotheses are summarized in Table 3 below.

Table 3

Research Questions, Hypotheses, Variables, Statistical Analyses, and Statistical Assumptions for Intensive Training in Working Memory Strategies Project

Research Questions	Hypotheses	Variables	Statistic	Assumptions
1. Does the treatment produce improvements in the experimental group's working memory performance as measured by the working memory scores recorded by Cogmed from beginning to end?	Experimental group will score higher than control group.	working memory scores recorded by Cogmed	One-sample *t*-Test	1) Interval or Ratio data 2) No significant outliers 3) Approximately normally distributed
2. Does intensive and systematic training in working memory strategies significantly improve the reading comprehension scores of participants in the experimental group when compared to the control group as measured by post-test reading comprehension scores from the DRA?	Experimental group will score higher than control group.	DRA Reading Comprehension	Analysis of Covariance	1) The independent variables should be categorical 2) The dependent variable should be measured at the interval/ratio level 3) The differences between each session have approximately equal variances 4) The residual scores should follow an approximately normal distribution 5) Independence of the covariate and treatment effect 6) Homogeneity of regression slopes
3. Does intensive and systematic training in working memory strategies significantly improve the reading fluency scores of participants in the experimental group when compared to the control group as measured by post-test reading fluency scores from the DIBELS-ORF?	Experimental group will score higher than control group.	DIBELS Oral Reading Fluency	Analysis of Covariance	1) The independent variables should be categorical 2) The dependent variable should be measured at the interval/ratio level

	3) The differences between each session have approximately equal variances 4) The residual scores should follow an approximately normal distribution 5) Independence of the covariate and treatment effect 6) Homogeneity of regression slopes

Timeline

Please see Table 4 for a description of the tasks associated with the current study. Also, see Appendix A, B, and C for the permission forms that were presented to the parents and students.

Table 4

Working Memory Training and Effects on Reading Task Table

#	Name	Description	Begin	End	Person(s)
1	Project Idea	Based on administrative meetings, there is a need for a reduction of students going on for additional reading comprehension support in Tier 3 and consequently receiving a referral for Special Education services.	8-2013	4-2016	Investigator, Elementary Principals, Reading Curriculum Coordinator, Tier 2 Reading Teachers, 2nd and 3rd Grade Teachers
1 (A)	Prospectus Meeting	Meet with Committee to determine appropriateness of project/study	7-2014	7-2014	Prospectus Committee and Investigator
1 (B)	DRB/IRB	Finalize and obtain approval through DRB/IRB	8-2014	8-2014	Investigator and Chair

1 (C)	3 Chapter Defense	Defend 3 chapters (Introduction, Lit. Review, and Methodology)	10-2015	10-2015	Investigator and Dissertation Committee
2	Refine Study Design	Review approaches to improve reading comprehension. Identify curriculum materials used for reading comprehension and working memory strategies. Identify instruments to measure reading comprehension and working memory strategies.	10-2015	10-2015	Investigator, Elementary Principals, Reading Curriculum Coordinator, Tier 2 Reading Teachers, 2nd and 3rd Grade Teachers
3	Obtain Materials	Obtain the Developmental Reading Assessment (DRA), Dynamic Indicators of Basic Early Literacy Skills – Oral Reading Fluency (DIBELS-ORF), Cogmed, and the consent form to present to parents of the 2nd-3rd grade students. Review school records for sex, grade, free & reduced lunch status.	11-2015	11-2015	Investigator and Principal(s)
4	Data Collection	Collect the student information of those for whom consent has been received.	12-2015	12-2015	Investigator
5	Treatment Implementation	Provide participants with the purpose of the study and begin Cogmed.	1-2016	4-2016	Investigator, EIP Teachers
6	Scoring	Score the DRA, DIBELS-ORF, and obtain Cogmed results. Enter the scores into the school project database, which includes basic student demographic information.	4-2015	4-2016	Investigator, EIP Teachers
7	Evaluation of Results	Review all pertinent data from the results of the DRA, DIBELS-ORF, and Cogmed.	5-2016	5-2016	Investigator
7 (A)	Chapters 4 & 5	Completion of final dissertation chapters	5-2016	5-2016	Investigator and Chair
7 (B)	Defense	Defend Dissertation	8-2016	8-2016	Investigator and Committee
7 (C)	Submission	Submit Final Dissertation	9-2016	9-2016	Investigator

9	Report Presentation	Obtain de-identified student data from the school system database. Check data. Examine data to see if it meets the assumptions for analysis to be used. Run the analysis. Interpret analysis results. Write the report.	9-2016	9-2016	Investigator, Elementary Principals, Reading Curriculum Coordinator, Tier 2 Reading Teachers, 2nd and 3rd Grade Teachers

Threats to Validity

Research is often conducted to determine if a cause-and-effect relationship exist. Internal validity allows the researcher to determine cause-and-effect relationships. It allows one to conclude that changes in the independent variable caused the observed changes in the dependent variable. Just as important as a cause-and-effect relationship is the generalizability of a study's findings. External validity is the extent to which the results of a study can be generalized to other situations and individuals (Hanna & Dempster, 2012). The validity of a study may be compromised or influenced by variables known as extraneous variables. Extraneous variables are variables that may compete with the independent variable when explaining the outcome of a study. Some potential extraneous variables that may limit the results of this study are fidelity, experimental mortality, and population validity (Hanna & Dempster, 2012).

Treatment integrity (fidelity) is the sine qua non of response to intervention. It is vital to ensure that the information obtained from all the assessments accurately represents the students' progress (Kovaleski, 2007). Some potential extraneous variables that may have limited the results of this study are fidelity, experimental mortality, and population validity. Because the investigator was not in the elementary school every day, it was difficult to assure that the Tier 2 reading instruction was provided with consistency and fidelity as prescribed by the intervention used. Moreover, families move, or change schools in the district, and parents could elect to discontinue participation or rescind permission to use data gathered during the study. Each of these factors was a potential threat to the internal validity of the study.

One potential threat to external validity was the use of a convenience sample in the study. Using a convenience sample may make it difficult to generalize to the larger school population. Also, the study excluded rural and urban populations and alternative regions of the country. This may likely impact the generalizability of the study, since it is focused on a suburban setting in Fayette County, GA.

Summary

This proposed study examined the effects of intensive and systematic training in working memory strategies on reading performance. More precisely, did this training provide significant improvement in students' reading achievement beyond those associated with the typical reading intervention and instruction? In the study, second and third grade students, already receiving the standard Tier 2 reading intervention, also received explicit working memory training using the Cogmed program. Cogmed is a promising evidenced-based, computerized training program hypothesized to train working memory by improving attention and increasing working memory performance (Cogmed, 2013a). The Early Intervention Program (EIP) in the elementary school chosen for participation in the current study utilized common district-wide Tier 2 interventions.

A pre and post-test were administered to determine working memory, reading comprehension, and reading fluency performance. Because a treatment was implemented and a pre-test and post-test measure was used, an ANCOVA was utilized to get an estimate of effect size and observed power. Assumptions of the ANCOVA, were checked to ensure that accurate statistical analyses were utilized. It was expected that students who received intensive and systematic training in working memory strategies will show improvement in their working memory, reading comprehension, and reading fluency scores.

CHAPTER IV

RESULTS

In this study, the investigator sought to test the effect of adaptive training on working memory and reading achievement via the use of Cogmed. This study utilized a quasi-experimental, repeated measures design. Data for this study were collected through the use of the Cogmed working memory assessments, the Developmental Reading Assessment (DRA), the Dynamic Indicators of Basic Early Literacy Skills – Oral Reading Fluency (DIBELS-ORF), and school records. The independent variable was intensive training in working memory strategies, the covariate was the students' reading scores on the pre-test measures, and the dependent variable was students' reading scores on the post-tests. Working memory scores were completed as a function of participation in the prescribed Cogmed program. Reading comprehension was measured using the DRA and reading fluency was measured by using the DIBELS-ORF. The students' sex, grade level, and free and reduced lunch status were taken from school records and used to match students participating in either the experimental or control group. The data were anonymously coded and then analyzed using a series of one-sample *t*-tests and analyses of covariance (ANCOVA).

The investigator posed three research questions relating to whether or not adaptive training in working memory strategies would improve performance in the dependent variables for the participants. Research question one evaluated whether or not adaptive training in working memory strategies produced significant improvements in working memory performance. Research question two examined the effect of adaptive training in working memory strategies on reading comprehension achievement. Finally, research question three examined the effect of adaptive training in working memory strategies on reading fluency achievement. Three corresponding hypotheses were generated.

Does intensive and systematic training in working memory strategies produce improvements in the experimental group's working memory performance as measured by the working memory scores recorded by Cogmed? The corresponding null (H_0) and alternative (H_1) hypotheses were:

> H_0: There is no change in the working memory performance for students in the experimental group (i.e., $\mu = 0$).
>
> H_1: There is a change in the working memory performance for students in the experimental group (i.e., $\mu \neq 0$).

I expected working memory training to result in increased working memory performance in the experimental group.

Does intensive and systematic training in working memory strategies significantly improve the reading comprehension scores of participants in the experimental group by comparison to the control group as measured by post-test reading comprehension scores from the DRA (controlling for pre-test reading comprehension levels)? The corresponding null (H_0) and alternative (H_1) hypotheses were:

> H_0: Controlling for pre-test reading comprehension scores, the post-test reading comprehension scores are equal for the control and experimental groups (i.e., $\mu_{exper} = \mu_{control}$).
>
> H_1: Controlling for pre-test reading comprehension scores, the post-test reading comprehension scores are not equal for the control and experimental groups

(i.e., $\mu_{exper} \neq \mu_{control}$).

I expected the experimental group to have higher average post-test reading comprehension scores (controlling for pre-test scores) compared to the control group.

Does intensive and systematic training in working memory strategies significantly improve the reading fluency scores of participants in the experimental group when compared to the control group as measured by post-test reading fluency scores from the DIBELS-ORF (controlling for pre-test reading fluency levels)? The corresponding null (H_0) and alternative (H_1) hypotheses were:

H_0: Controlling for pre-test reading fluency scores, the post-test reading fluency scores are equal for the control and experimental groups (i.e., $\mu_{exper} = \mu_{control}$).

H_1: Controlling for pre-test reading fluency scores, the post-test reading fluency scores are not equal for the control and experimental groups (i.e., $\mu_{exper} \neq \mu_{control}$).

I expect the experimental group to have higher average post-test reading fluency scores (controlling for pre-test scores) compared to the control group.

This chapter details the data collection procedures utilized for the study and the demographic characteristics of the sample. Procedures for screening the data are described and the assumptions for the one-sample *t*-tests and ANCOVA are evaluated. Finally, the results of the statistical analyses used to test each hypothesis are reported. The Statistical Package for Social Sciences – Version 23 (SPSS 23) was used to generate the results.

Data Collection

Data were collected for 36 students. Eighteen students participated in the Cogmed intervention and the Reading Horizons program between January 2016 and April 2016. The other 18 students participated in only the Reading Horizons program between January 2015 and April 2015. Reading Horizons is a phonics program that may be used with children and adults. It provides instruction in 42 sounds, five phonetic rules, and a two-step decoding system. Instruction in the Reading Horizons method develops the students' phonemic awareness, phonics, fluency, vocabulary, and comprehension. The goal of Reading Horizons is to teach students the phonic elements, consequently becoming fluent readers and spellers. The students are also provided instruction in spelling, vocabulary, grammar, sentence structure, and dictionary skills (Reading Horizons, 2014). The sample consisted of 18 males and 18 females. Their ages ranged from seven to eight years. The post-test DRA and DIBELS-ORF scores for the experimental group were collected one to two weeks after the Cogmed training was completed.

Characteristics of the Sample

A convenience sample was employed in this study. The data obtained from the DRA, DIBELS-ORF, sex, grade, and free and reduced lunch status were collected on students in second and third grade. The average age of the second and third grade students are 7 and 8 years old. Males and females were included in the study. There were no restrictions based on sex. Sex, grade level, and free and reduced lunch status were used to match students participating in either the experimental or control group.

Table 5 provides the descriptive summary of the demographic information of the students who participated in the current study.

Table 5

Descriptive Statistics – Demographic Characteristics

Variable	Control	Experimental
N	18	18
Sex		
Male (N)	10	10
Female (N)	8	8
Male (%)	55.6	55.6
Female (%)	44.4	44.4
Grade		
2 (N)	10	10
3 (N)	8	8
2 (%)	55.6	55.6
3 (%)	44.4	44.4
Free/Reduce Lunch		
Yes (N)	4	8
No (N)	14	10
Yes (%)	22.2	44.4
No (%)	77.8	55.6

Descriptive Statistics

Table 6 provides the descriptive summary of the dependent variables for both the experimental group and the control group. The dependent variables for the control group are reading comprehension and reading fluency. The dependent variables for the experimental group are reading comprehension, reading fluency, and the Cogmed progress indicator scores (i.e., the working memory scores).

Table 6

Descriptive Statistics – Dependent Variables

	N	Variable	Mean	SD	Median	Min	Max
Control	18	Pre-DRA	13.72	7.42	14.00	1.00	24.00
		Post-DRA	18.33	7.10	18.00	8.00	28.00
		Pre-ORF	48.83	15.08	50.00	24.00	81.00
		Post-ORF	75.17	18.66	75.00	40.00	112.00
Experimental	18	Index Improved	13.78	5.92	13.50	4.00	25.00
		Shape Up	20.67	23.57	18.00	0	89.00
		Listen Up	48.22	54.77	30.50	0	204.00
		Add Up	3.39	7.06	0	0	23.00
		Pre-DRA	16.89	8.92	12.00	6.00	38.00
		Post-DRA	21.89	8.88	18.00	10.00	40.00
		Pre-ORF	41.56	18.69	39.00	16.00	96.00
		Post-ORF	53.83	19.41	52.00	19.00	91.00

Independent samples *t*-tests were used to screen for significant differences between the two groups on the pre-DRA and pre-DIBELS-ORF scores. Results showed there were no statistically significant differences between the control group and the experimental group on the pre-test scores ($p > .05$ for both). The Levene's test was used to verify the homogeneity of variance assumption. For the pre-DRA, the underlying assumption of homogeneity of variance for the independent samples *t*-test was met as evidenced by the statistically non-significant Levene's test; $F(1, 34) = 1.075$, $p = .307$. Similarly, the underlying assumption of homogeneity of variance for the pre-DIBELS-ORF was met as evidenced by the statistically non-significant Levene's test; $F(1, 34) = .214$, $p = .647$. The results of the independent samples *t*-tests are reported in Table 7.

Table 7

Independent t-Tests Summary

Variable	Mean	95% CI Lower	95% CI Upper	SD	*t*-value	*df*	*p*-value
Pre-DRA	13.72	-2.39	8.72	7.41	1.15	34	0.255
Pre-ORF	48.83	-18.78	4.22	15.08	-1.28	34	0.207

Pearson *r* correlations coefficients were used to describe the strength of associations among the variables collected in the current study. All of the pre- and post-test measures (i.e., DRA and DIBELS-ORF) showed strong, positive, statistically significant relationships. More specifically, higher pre-test scores were associated with higher post-test scores. Table 8 and Table 9 provide the correlations among the variables for the control and experimental groups, respectively.

Table 8

Correlations (Pearson's r) – Control Group

Variable	1	2	3	4	5	6	7
1. Male	1.00						
2. Free/Reduced Lunch	0.60	1.00					
3. Grade 3	-0.13	0.06	1.00				
4. Pre-DRA	0.08	0.17	0.87*	1.00			
5. Post-DRA	0.05	0.09	0.86*	0.95*	1.00		
6. Pre-ORF	0.25	-0.01	-0.04	0.20	0.22	1.00	
7. Post-ORF	0.33	0.17	-0.25	0.08	0.12	0.67*	1.00

Note: *p<.05. Reference, or dummy, coding was used for the gender, free reduced lunch, and grade variables.

Table 9

Correlations (Pearson's r) – Experimental Group

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Male	1.00										
2. Free/Reduced Lunch	0.33	1.00									
3. Grade 3	-0.13	0.33	1.00								
4. Pre-DRA	-0.22	0.09	0.86*	1.00							
5. Post-DRA	-0.25	-0.01	0.82*	0.96*	1.00						
6. Pre-ORF	-0.26	-0.05	0.63*	0.88*	0.85*	1.00					
7. Post-ORF	-0.18	-0.42	0.45	0.70*	0.80*	0.70*	1.00				
8. Index Improved	-0.18	-0.47*	-0.14	-0.28	-0.14	-0.16	-0.12	1.00			
9. Shape-Up	-0.04	0.16	0.21	0.13	0.14	0.04	-0.02	0.03	1.00		
10. Listen-Up	-0.34	0.05	0.14	0.20	0.17	0.17	-0.09	0.02	0.53*	1.00	
11. Add-Up	-0.30	-0.07	0.23	0.40	0.40	0.38	0.29	-0.31	0.36	0.56*	1.00

Note: *p<.05. Reference, or dummy, coding was used for the gender, free reduced lunch, and grade variables.

Analysis of the Assumptions

Because the Cogmed program provides improvement scores for trained and non-trained working memory tasks, a series of one-sample *t*-tests were used to determine any significant differences between the sample mean and the population mean. The following assumptions regarding the data in the one-sample *t*-tests were made: the dependent variable was measured at the interval or ratio level (i.e., continuous), the data were independent (i.e., not correlated/related), there were no significant outliers, and the dependent variable was approximately normally distributed. The appropriateness of these assumptions was examined using the following steps: examine data, analyze descriptive statistics, and examine charts.

An analysis of covariance (ANCOVA) was used to determine group differences in the dependent variable (i.e., post-test scores) while controlling for the covariate (i.e., pre-test scores). The following assumptions regarding the data in the ANCOVA were made: the independent variables are categorical, the dependent variable are measured at the interval/ratio level, the differences between each session have approximately equal variances, the residuals should be equally distributed along the regression line, for each group the relationship between the dependent variable and the covariate is linear, the residual scores follow an approximately normal distribution, there is independence of the covariate and treatment effect, and there is homogeneity of regression slopes. The data in the current study were randomly and independently sampled and the dependent variables were measured on a continuous scale. Consequently, the assumption of independence and scale of measurement were met.

Normality

Normality assumes that the residual scores follow an approximately normal distribution. This assumption was tested via examination of the unstandardized residuals. The Shapiro-Wilk test was used to verify this assumption. The results of the Shapiro-Wilk are considered to be significant when $p < .05$. For research question two, the underlying assumption of normality was met as evidenced by the statistically non-significant Shapiro-Wilk test ($SW = .947$, $df = 36$, $p = .087$) and skewness (.393) and kurtosis (.768). Similarly, the underlying assumption of normality for research question three was met as evidenced by the statistically non-significant Shapiro-Wilk test (*SW* = .986, *df* = 36, *p* = .915) and skewness (.393) and kurtosis (.768). Table 10 provides a summary of the results of the Shapiro-Wilk tests.

Table 10

Tests for Normality – Shapiro-Wilk

Variable	*Statistic*	*p*
Post-DRA	.947	.087
Post-ORF	.986	.915

Homoscedasticity

Homoscedasticity assumes that the residuals are equally distributed right along the regression line. It is expected that the residuals will be equally distributed in relation to the predictor variables. Hence, a linear pattern should not be detected in the scatterplot (Hanna & Dempster, 2012; McCormick et al., 2015). To check this assumption, scatterplots of the variables (dependent and predictors) were generated to determine if the residuals are equally distributed. See Figure 3 for research question two analysis and Figure 4 for research question three analysis. The scatterplots indicated reasonable consistency of spread through the distributions. Accordingly, this suggested that homoscedasticity assumption was not violated.

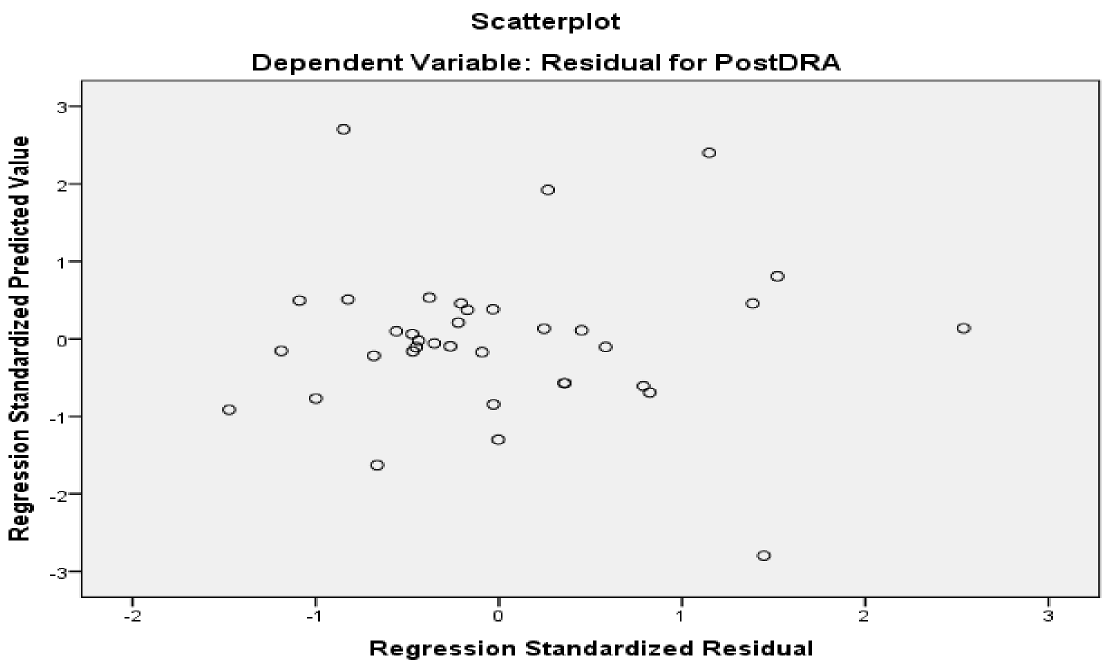

Figure 3. Residual scatterplot to assess homoscedasticity among residuals (reading comprehension)

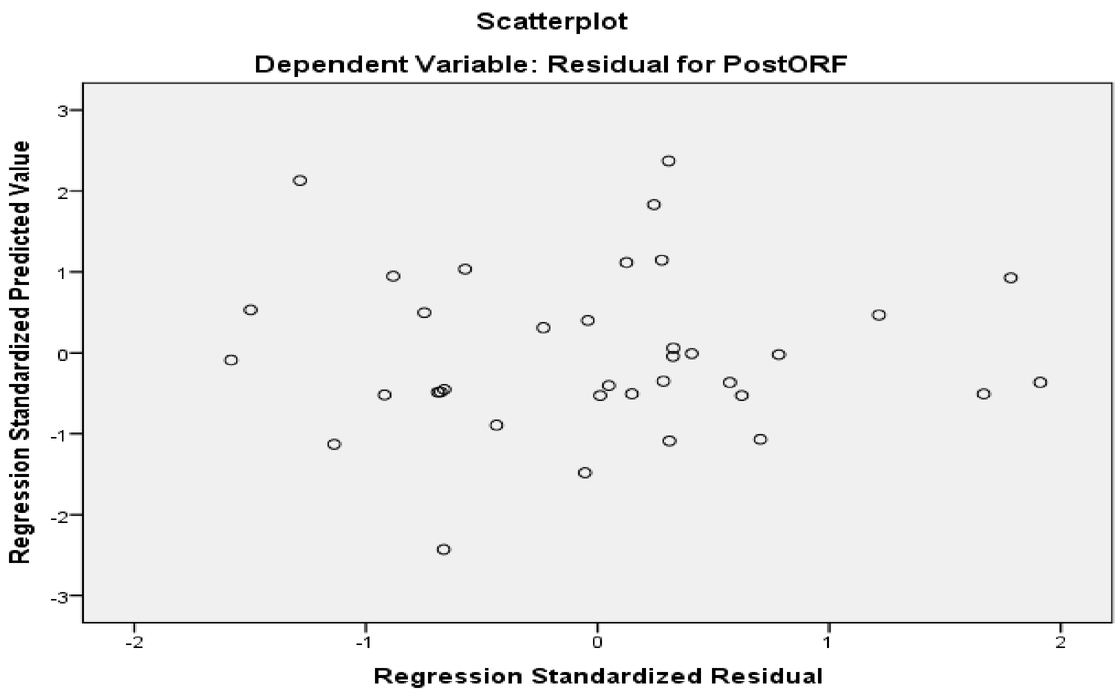

Figure 4. Residual scatterplot to assess homoscedasticity among residuals (reading fluency)

Linearity

Linearity assumes that for each group, the relationship between the dependent variable and the covariate is linear. It also assumes that the covariate value is correlated with the outcome variable value. By checking this assumption, one is able to determine if there's an interaction between the covariate and the experimental manipulation (i.e., the treatment). To check this assumption, scatterplots of the variables (dependent variable was post-test scores and the covariate was pre-test scores) were generated to determine if linear relationships were present. See Figure 5 for research question two analysis and Figure 6 for research question three analysis. The scatterplots show that the variables used for research question two and research question three followed a general linear fashion. Accordingly, this suggested that linear relationships were present and the linearity assumption was not violated.

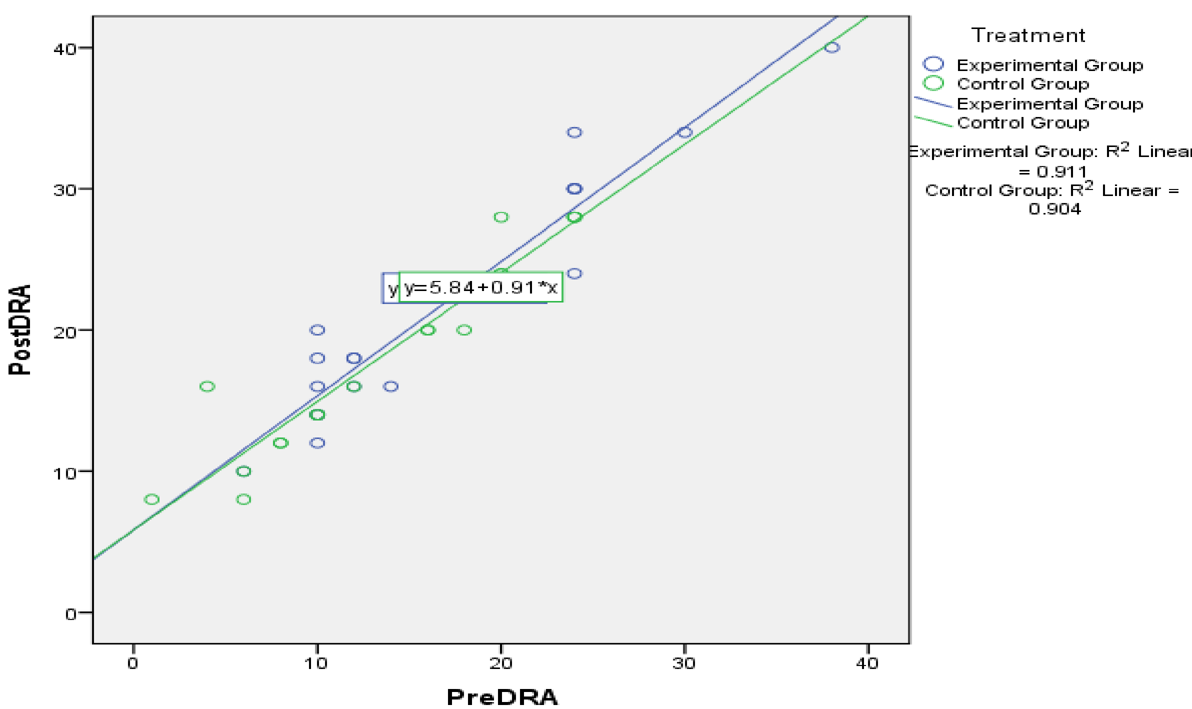

Figure 5. Scatterplots to assess linearity of the covariate and the dependent variable (reading comprehension)

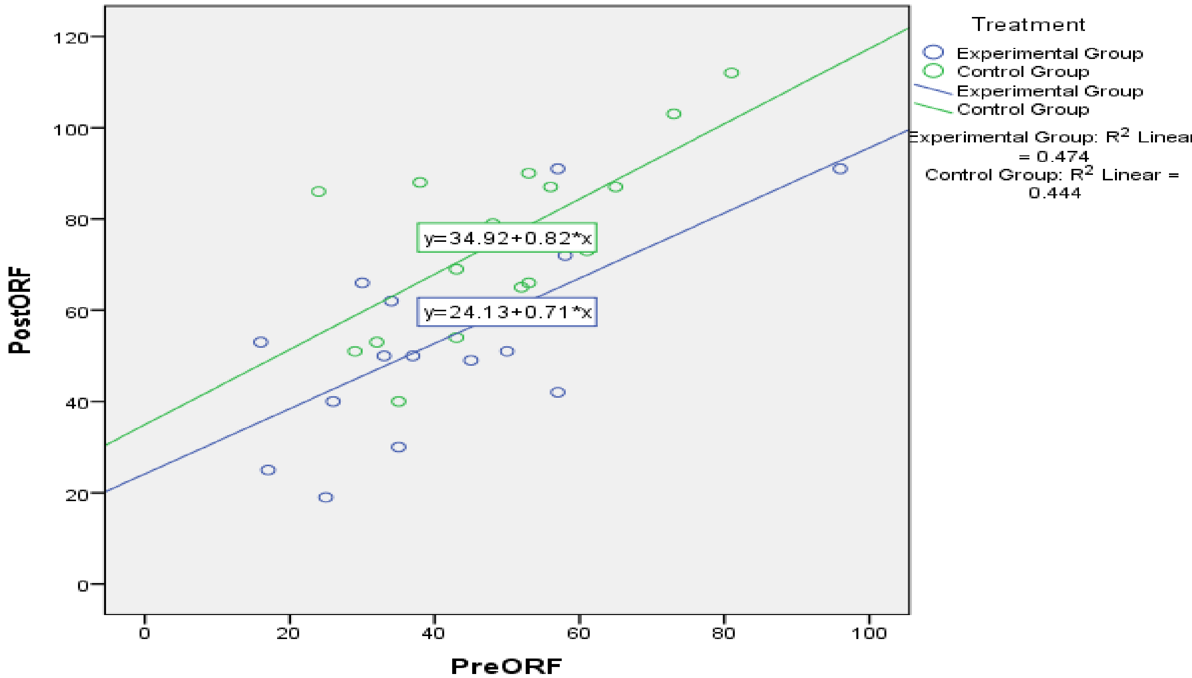

Figure 6. Scatterplots to assess linearity of the covariate and the dependent variable (reading fluency)

Homogeneity of Error Variance

Homogeneity of variance assumes that each level of the between-group variable should have approximately equal error (or residual) variances. If the significance value is .05 or greater, then one can conclude that the variances of the groups are similar and the results can be interpreted (Hanna & Dempster, 2012; McCormick et al., 2 015). The Levene's test was used to verify this assumption. For research question two, the underlying assumption of homogeneity of variance for the one-way ANCOVA was met as evidenced by the statistically non-significant Levene's test; $F(1, 34) = 1.818$, $p = .186$. Similarly, the underlying assumption of homogeneity of variance for research question three was met as evidenced by the statistically non-significant Levene's test; $F(1, 34) = .014$, $p = .908$. Table 11 provides a summary of the results of the Levene's tests.

Table 11

Levene's Test of Equality of Error Variances – Outcome Measures

Variable	*F*	*df1*	*df2*	*P*
Post-DRA	1.81	1	34	.186
Post-ORF	.014	1	34	.908

Homogeneity of Regression Slope

The homogeneity of regression (slope) evaluates the interaction between the covariate (pre-test score) and the independent variable (treatment) in the prediction of the dependent variable (post-test score). A significant interaction between the covariate and the independent variable suggests that the difference on the dependent variable among groups vary as a function of the covariate. If the interaction is significant, the results from the ANCOVA are less meaningful (McCormick et al., 2015). For research question two, a preliminary analysis evaluating the homogeneity-of-regression assumption indicated that the relationship between the covariate (pre-DRA) and the dependent variable (post-DRA) did not differ significantly as a function of the independent variable, $F(1, 32) = .137$, $p = .714$. Similarly, for research question three the analysis also indicated that the relationship between the covariate (pre-ORF) and the dependent variable (post-ORF) did not differ significantly as a function of the independent variable, $F(1, 32) = .134$, $p = .716$. Based on these findings, the assumption of homogeneity of regression was met.

Data Analysis

Research Question 1

Does intensive and systematic training in working memory strategies produce improvements in the experimental group's working memory performance as measured by the working memory scores recorded by Cogmed?

When the Cogmed training was completed, an Index Improvement score and Cogmed Progress Indicator (CPI) Improvement scores were provided. The Index Improvement is a measure of training progress on the trained exercises that the students did on a daily basis. It measured how much each student improved over the baseline. The CPI provides information pertaining to the students' training progress on working memory related abilities. The CPI tasks are non-trained tasks and therefore should not reflect training effects on abilities, since the students did not practice these tasks daily. There are three CPI tasks (i.e., Shape Up, Listen Up, and Add Up) and, according to the test publisher, typically students improve on at least one of the three CPI measures.

A series of one-sample *t*-tests were used to evaluate this hypothesis. A Bonferroni correction was used to adjust the alpha level to correct for increased Type I error rates. Results showed that Index Improvement, Shape Up, and Listen Up all significantly improved (i.e., average improvement scores were significantly different from zero, $p<.01$ for all). The improvement in Add Up did not reach statistical significance ($p = .06$). The results of the one-sample *t*-tests are reported in Table 12.

Table 12

One-Sample t-Tests Summary

	M	95% CI Lower	95% CI Upper	SD	*t*-value	*df*	*p*-value
		M					
Index Improvement	13.78	10.84	16.72	5.92	9.88	17	0.000
Shape Up	20.67	8.95	32.39	23.57	3.72	17	0.002
Listen Up	48.22	20.99	75.46	54.77	3.74	17	0.002
Add Up	3.39	-0.12	6.90	7.06	2.04	17	0.06

Research Question 2

Does intensive and systematic training in working memory strategies significantly improve the reading comprehension scores of participants in the experimental group when compared to the control group as measured by post-test reading comprehension scores from the DRA (controlling for pre-test scores)?

An analysis of covariance (ANCOVA) was conducted. The independent variable was intensive training in working memory strategies, the covariate was the students' reading comprehension score on the pre-test measure, and the dependent variable was the students' reading comprehension on the post-test measure. Results indicated that pre-test scores on the DRA predict performance on post-test scores on the DRA ($p < .01$). However, the groups did not significantly differ in post-test scores after controlling for pre-test, $p > .05$. See Table 13-15 for ANCOVA summary results.

Table 13

Analysis of Covariance Summary – Reading Comprehension

Source	*SS*	*df*	*MS*	*F*	*p*	*Partial* η²	*Observed Power*
Pre-test	1995.58	1	1995.58	325.7	.001	.908	1.00
Treatment	3.10	1	3.10	0.50	.481	.015	.106
Error	202.19	33	6.12				
Total	16872.00	36					

Note. R^2 = .913 ($R^2_{Adjusted}$ = .907); Computed using alpha = .05

Table 14

Estimated Marginal Means – Reading Comprehension

Group	*Mean*	*SE*	95% CI	
			Lower	Upper
Experimental	20.41	.589	19.212	21.609
Control	19.812	.589	18.613	21.010

Table 15

Pairwise Comparison Between Treatment Group – Reading Comprehension

Group	*MD*	*SE*	*p*	95% CI	
				Lower	Upper
Experimental vs. Control	.599	.841	.481	-1.112	2.310

Research Question 3

Does intensive and systematic training in working memory strategies significantly improve the reading fluency scores of participants in the experimental group when compared to the control group as measured by post-test reading fluency scores from the DIBELS-ORF (controlling for pre-test scores)?

Like research question two, an ANCOVA was conducted. The independent variable was intensive training in working memory strategies, the covariate was the students' reading fluency score on the pre-test measure, and the dependent variable was students' reading fluency on the post-test. Similar to research question two, results indicated that pre-test scores on the DIBELS-ORF predict performance on post-test scores on the DIBELS-ORF ($p < .01$). However, after controlling for pre-test scores, the control group had greater than expected post-test scores compared to the experimental group; $p < .05$. See Tables 16-18 for ANCOVA summary results.

Table 16

Analysis of Covariance Summary – Reading Fluency

Source	*SS*	*df*	*MS*	*F*	*p*	*Partial* η^2	*Observed Power*
Pretest	5632.08	1	5632.08	27.76	.000	.457	.999
Treatment	2147.34	1	2147.34	10.58	.003	.243	.885
Error	6692.91	33	202.81				
Total	166190.00	36					

$R^2 = .592$ ($R^2_{Adjusted} = .568$); Computed using alpha = .05

Table 17

Estimated Marginal Means – Reading Fluency

Group	*M*	*SE*	95% CI	
			Lower	Upper
Experimental	56.591	3.397	49.679	63.503
Control	72.409	3.397	65.497	79.321

Table 18

Pairwise Comparison Between Treatment Group – Reading Fluency

Group	*MD*	*SE*	*p*	95% CI	
				Lower	Upper
Experimental vs. Control	-15.818*	4.861	.003	-25.708	-5.927

Summary

The current study examined the effects of intensive and systematic training in working memory strategies on reading performance. A series of one-sample *t*-tests and two ANCOVAs were used to statistically determine improvements in working memory performance and treatment group differences in reading comprehension and reading fluency.

Research question one hypothesized that intensive and systematic training in working memory strategies improves students' working memory capabilities. The results of the one-sample *t*-tests supported this hypothesis by indicating that the experimental group significantly improved working memory performance for two out of the three non-trained working memory tasks. More specifically, results showed that the students in the experimental group significantly improved on the Shape Up and Listen Up tasks. The improvement in the Add Up task did not reach statistical significance.

Research question two hypothesized that intensive and systematic training in working memory strategies improves reading comprehension. Results of the ANCOVA procedure showed that the experimental working memory training group did not significantly differ from the control group with regards to post-test reading comprehension scores (controlling for pre-test). Finally, research question three hypothesized that intensive and systematic training in working memory strategies significantly improves reading fluency. Interestingly, results indicated that, controlling for pre-test, the control group with no working memory training had greater post-test reading fluency scores compared to the experimental group with working memory training.

Even though the results of the study showed significant improvements in working memory performance for the students in the experimental group, it appears that the gains did not result in better reading comprehension and reading fluency performance compared to the control group without working memory training. The implications of these findings and directions for future research will be explored in further detail in Chapter 5.

CHAPTER V

DISCUSSION

Introduction

Working memory is a dynamic process that encompasses the ability to briefly store information while simultaneously processing other cognitively challenging tasks (Alloway, 2009; Beck et al., 2010; Savage et al., 2007). Working memory capacities are essential for the successful completion of many cognitive tasks, such as reading and comprehending the content outlined within this document.

The current study assessed the effect of adaptive training on working memory and reading achievement via the use of Cogmed. Cogmed is an evidenced-based intervention designed to improve working memory. It may be used with children and adults ages four to 70 years and over (Cogmed, 2013a). The training has been demonstrated to be a complementary intervention and will likely produce the greatest benefit when combined with other sources of interventions (Cogmed, 2013a).

This study utilized a quasi-experimental, repeated measures design. The sample consisted of 36 students in a suburban school district in Georgia. These students had been identified as requiring additional reading intervention services in the Early Intervention Program. The students in the experimental group trained intensively for 30 to 40 minutes, 5 days a week, for 8 weeks. Baseline data on working memory, reading comprehension, and reading fluency were compared to post-test measures after 8 weeks of Cogmed training. Data were analyzed using a series of one-sample *t*-tests and two analyses of covariance (ANCOVA).

In this chapter the findings of the study will be summarized and delineated by each research question and hypothesis. Furthermore, implications for school psychology practice, limitations, and recommendations for future research will be discussed.

Research Questions and Hypotheses

Research Question 1

Does intensive and systematic training in working memory strategies produce improvements in the experimental group's working memory performance as measured by the working memory scores recorded by Cogmed?

It was hypothesized that intensive and systematic training in working memory strategies would significantly improve students' working memory capabilities from week to week as measured by the scores recorded by Cogmed. According to the analysis, results showed that Index Improvement, Shape Up, and Listen Up all significantly improved by comparison to baseline estimates ($p < .01$). However, the improvement in Add Up did not reach statistical significance ($p = .06$). The initial finding supported the alternative hypothesis, which stated that working memory training would result in increased working memory performance in the experimental group.

The increased working memory performance in two of the three non-trained working memory tasks is consistent with previous research. In 2009, Thorell and colleagues investigated the effects of a training program that utilized visuospatial working memory tasks. The results of the study showed that working memory training was successful in improving working memory performance in spatial and verbal domains as well as attentional control. The effect size ($d = 1.15$) for the comparison between the working memory group and the control group was large (Thorell et al., 2009).

Correspondingly, Spencer-Smith and Klingberg (2015) conducted a meta-analysis to evaluate whether training in working memory improved attention span in daily life. Eleven studies that used only the Cogmed program were included in the meta-analysis. The central finding of this meta-analysis was that working memory training did result in better performance on measures of attention span. Moreover, significant improvements were noted in children and adults who participated in the training when compared with a control program. A training effect of -0.47 (Cohen's *d*) was demonstrated. Interestingly, individuals with Attention-Deficit/Hyperactivity Disorder (ADHD) and working memory deficits showed improvements in their attention span. Moreover, the benefits of the training appeared to last for two to eight months after the training concluded (Spencer-Smith & Klingberg, 2015).

Research Question 2

Does intensive and systematic training in working memory strategies significantly improve the reading comprehension scores of participants in the experimental group by comparison to the control group as measured by post-test reading comprehension scores from the Developmental Reading Assessment (DRA) (controlling for pre-test levels)?

It was hypothesized that intensive and systematic training in working memory strategies would significantly improve the students' reading comprehension score as measured by the DRA by comparison to the control group. It was expected that students who receive intensive and systematic training in working memory strategies in addition to the Tier 2 reading intervention would show improvement in their reading comprehension. According to the analysis, pre-test scores on the DRA predicted performance on post-test scores on the DRA ($p < .01$). However, the groups did not significantly differ in post-test scores after controlling for pre-test. This finding did not support the alternative hypothesis, which stated that the experimental group will have higher average post-test reading comprehension scores (controlling for pre-test scores) compared to the control group.

Research Question 3

Does intensive and systematic training in working memory strategies significantly improve the reading fluency scores of participants in the experimental group when compared to the control group as measured by post-test reading fluency scores from the Dynamic Indicators of Basic Early Literacy Skills-Oral Reading Fluency DIBELS-ORF (controlling for pre-test levels)?

It was expected that the students in the experimental group would have achieved higher reading fluency scores after participating in Cogmed. Similar to research question two, results indicated that pre-test scores on the DIBELS-ORF predicted performance on post-test scores on the DIBELS-ORF ($p < .01$). However, after controlling for pre-test, the control group had greater than expected post-test scores compared to the experimental group. This finding did not support the alternative hypothesis, which stated that the experimental group will have higher average post-test reading fluency scores (controlling for pre-test scores) compared to the control group.

These findings seen in research question two and three are consistent with previous research. Recently, some studies showed that even though working memory training resulted in improved working memory performance, this training did not generalize to measureable improvements in academic performance (Cortese et al., 2015; Melby-Lervåg & Hulme, 2013; Rose et al., 2014). These studies noted that performance gains observed through the participation in the Cogmed program did not generalize to performance gains in reading, math, or verbal ability. A number of explanations may be considered. For example, it is possible that the gains seen in working memory performance do not result in better achievement scores because the assessments are conducted too soon after the cognitive training concluded. It might be that not enough time had passed to see any far-transfer of the training on academic performance. A second consideration might be that the cognitive training produces marginal or practice-like effects on the students' working memory performance. Participants may become familiar with the specific tasks and the mode in which the tasks are presented. Thus, there is an absence of far-transfer effects on academic achievement. It is also possible that the interventions to improve working memory have no effects on students' reading performance. A fourth consideration may be that the benefits seen in achievement after participating in the cognitive training are limited to specific groups of students (e.g., students with a learning disability or ADHD) as demonstrated in the Dahlin (2011) and the Spencer-Smith and Klingberg (2015) studies.

Children with learning disabilities are often characterized as having cognitive processing strengths and weakness (Flanagan et al., 2013). Working memory is typically one of the processing deficits identified, although other processing deficits may be present. Similar to children identified with a learning disability, children with ADHD too experience deficits in working memory. Working memory is an executive function process that garners the most attention when studying the academic/learning deficits in children with ADHD. Working memory deficits are well established when looking at the behavioral profile of children with ADHD. It is critical to cognitive development, motor skills, academic achievement, and higher order functioning (Huang-Pollock & Karalunas, 2010). Research evidence is available to show the relationship between working memory, attention, and academic achievement. Because of this, it is plausible to expect a positive relationship between working memory performance, reading, and attention tasks.

Implications

The Cogmed training seems to be beneficial in significantly improving working memory performance for the students who participated in the present study. This finding was consistent with existing research (Beck et al., 2010; Dahlin, 2011; Holmes et al., 2009; Jacob & Parkinson, 2015; Rose et al., 2014; Spencer-Smith & Klingberg, 2015; Thorell et al., 2009) that studied the effects of direct training on cognitive processes. Furthermore, this study also found that even though improvements were noted in the students' working memory performance, the gains did not result in better reading comprehension or reading fluency performance compared to the control group who did not receive the working memory training. This finding too is consistent with existing research (Cortese et al., 2015; Jacob & Parkinson, 2015; Melby-Lervåg & Hulme, 2013; Rose et al., 2014).

The research conducted by Dahlin in 2011 served as the foundation for the present study. Both studies investigated the effectiveness of intensive working memory training when used with other interventions. In both the present study and Dahlin's

(2011) study, the effects of adaptive training in working memory strategies were analyzed in the school setting. Moreover, both studies looked at the effects of this training on reading achievement for the participants. In both studies, the Cogmed program did produce significant gains in working memory performance for the experimental groups. However, Dahlin's (2011) findings also showed significant improvements in reading achievement six months post-training while no significant improvements in reading achievement were noted in the present study.

In the current study, post-test measures of reading achievement were obtained one to two weeks after the training was completed. Other researchers have noted that improvements in working memory performance have shown gains in reading achievement, but these gains are seen over time (Dahlin, 2011; Holmes & Gathercole, 2013; Spencer-Smith & Klingberg, 2015). Because achievement in reading comprehension and reading fluency were assessed one to two weeks post-training, this might provide a possible explanation for why there were no significant effects on the reading post-test measures for the experimental group. It is possible that there was not enough time between the end of the training and the post-test measures to see any effects in the reading achievement. Because previous researchers (Cain, Oakhill, & Bryant, 2004; Dahlin, 2011; de Jong, 2006; Henderson & Pimperton, 2008; Nation et al., 1999; Nation & Angell (2006); Savage et al., 2007; Seigneuric et al., 2000) have demonstrated an association between working memory performance and reading achievement, it is plausible to expect that students who experience gains in working memory performance will employ the same strategies while reading over time.

Based on the work of other researchers and the present study Cogmed training seems to hold potential as an intervention for improving working memory in children and adults. However, as noted previously, outcome studies demonstrating the benefit of working memory training on academic performance have been mixed.

Limitations of the Study

Some potential extraneous variables that may limit the results of this study are fidelity, experimental mortality, and population validity. Because the investigator was not in the elementary school every day, it was difficult to assure that the Tier 2 reading instruction was provided with consistency and fidelity as prescribed by the intervention. With regard to experimental mortality, during the course of the Cogmed training one student moved to another school in the district and six students were placed into Special Education. Consequently, only 18 students completed the Cogmed training and were included in the study. Additionally, the students in the control group were students who participated in the Tier 2 (i.e., Reading Horizons) program from the 2015 school year while the students in the experimental group were students from the 2016 school year. This may be a potential confounding variable because it is difficult for the researcher to be certain that the students in the control group were instructed similarly and at the same pace as the students from the 2016 school year.

One potential threat to external validity was the use of a convenience sample in the study. Using a convenience sample likely makes it difficult to generalize to the larger school population. Also, the study excluded rural and urban populations and alternative regions of the country. This likely impacts the generalizability of the study, since it is focused on a suburban setting in Fayette County, GA.

Recommendations for Future Research

In the present study, the intensive and adaptive training in working memory strategies did not provide significant gains in the reading achievement of students in the experimental group when compared to the control group. Additional research is needed to longitudinally follow students who participate in this type of training to determine if any gains in achievement are made in the future. Also, it may be beneficial to know if the gains in working memory performance are reliable over time. Training in strategies to improve working memory performance in the school setting should be studied with other population of students that are achieving adequately who do not require additional reading interventions, as did the students in the present study. Cogmed may not be a robust intervention for all students. Consequently, future researchers may want to identify the narrow segment of the student population that Cogmed might benefit academically. Also, using a larger sample of students likely will aid in generalizing results to the larger school population.

Summary and Conclusion

The purpose of the present study was to examine the effects of intensive and systematic training in working memory strategies on reading performance. It addressed a lingering question concerning the generalizability of this training to academic achievement. Specifically, does this training (i.e., Cogmed) provide significant improvement in students' reading achievement beyond those associated with the typical reading intervention and instruction? It was hypothesized that this training would improve working memory performance and reading achievement.

Cogmed is an evidenced-based intervention designed to improve working memory. Cogmed training uses a web-based computerized system. The training has been demonstrated to be a complementary intervention and will likely produce the greatest benefit when combined with other sources of interventions (Cogmed, 2013a). Research has shown that adaptive training in working memory has led to gains in word reading, reading comprehension, mathematical ability, and improved attention (Beck et al., 2010; Dahlin, 2011; Holmes et al., 2009). Since its inception, many researchers have demonstrated the efficacy of Cogmed through rigorous investigations of its treatment protocols and methods (Beck et al., 2010; Dahlin, 2011; Holmes & Gathercole, 2013; Spencer-Smith & Klingberg, 2015).

Consistent with contemporary theories of memory functioning, in order to collect the necessary information to comprehend the text, a reader must have intact working memory skills (Cain, Oakhill, & Bryant, 2004; Nation et al., 1999; Seigneuric et al., 2000). In the present study it was expected that by combining the Cogmed training and the academic instruction in reading received in the Tier 2 intervention program would increase the students' fluency in reading and their understanding of text.

The Cogmed training proved to be beneficial in significantly improving working memory performance for the students who participated in the study. However, no effect was seen on the students' reading achievement. Because it has been suggested that the effects of an improved working memory performance are seen over time, it is recommended that the students who participated in this study are followed to determine the long-term effects of the Cogmed training on their reading achievement.

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Appendix A

Informed Consent Letter

Dear Fayette County School District Parents/Guardians:

The elementary school where you child attends will be participating in a research study specifically related to second and third grade students who participate in the reading Early Intervention Program (EIP) and the After School Reading and Math Program (ARM). This proposed study would examine the benefits of intensive and systematic training in working memory strategies on reading performance. More precisely, this study seeks to address the question of whether this training would provide significant improvement in students' reading comprehension achievement beyond those associated with the current reading intervention and instruction? In the study, second and third grade students, already receiving the standard Tier 2 reading intervention, may also receive explicit working memory training using the Cogmed program. Cogmed is a promising evidenced-based, computerized training program hypothesized to train working memory by improving attention and increasing working memory performance.

The study will begin in the spring of 2016. Your child's participation in this study is strictly voluntary. You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators, educational agency, or Indiana University of Pennsylvania. If you choose to participate, you may withdraw at any time by notifying the Project Director or informing the EIP teacher. Upon your request to withdraw, all information pertaining to you will be destroyed. If you choose to participate, all information will be held in strict confidence and will have no bearing on the services you receive from the school district. Your child's individual performance in working memory will be confidential. The information obtained in the study may be published in scientific journals or presented at scientific meetings but your identity will be kept strictly confidential.

Reading data from second and third grade will be the targeted area of review. Information from Cogmed and its effects on reading achievement is the specific focus of the study. Cogmed is not effective for everyone. It is very important for the user to have persistence and high effort when completing their Cogmed training sessions.

The training may trigger seizures in individuals with photosensitive epilepsy. It is not recommended for those individuals. People with extreme depression or extreme anxiety will not be helped, as those disorders need to be addressed prior to participation. No other adverse side effects have been noted from the use of Cogmed. Students with epilepsy, depression, and anxiety will be excluded from the study.

Your child will be randomly assigned to an experimental group or a control group. The experimental or treatment group is the group that receives the Cogmed training. The control group is the group used to produce comparisons. The Cogmed training is deliberately withheld from the students in the control group to provide a baseline performance with which to compare the experimental or treatment group's performance. This is important to do in order to determine if significant gains in reading achievement is noted after receiving intensive training in working memory strategies. It is important to note that your child will not lose any instructional time, as the treatment is provided in the afterschool program.

All individual scores will be held in strict confidence. If interested, you will receive a written copy of the results upon completion of the study. The data will be stored along with other confidential data in a locked filing drawer at the participating elementary school, in the Assistant Principal's office. As is procedure, within the Fayette County School District, this data will be maintained and secured well beyond seven years.

Your child has been assigned a unique numeric ID code. This is done to maintain confidentiality of each student.

Please feel free to call Geneel A. McKenzie at (770) 460-3990 ext. 163 or email me at rxlr@iup.edu if you have questions or concerns about the study.

Sincerely,

Geneel A. McKenzie, M.S.
Doctoral Candidate
Lafayette Educational Center
205 Lafayette Ave
Fayetteville, GA 30214
Office: (770) 7460-3990
rxlr@iup.edu

Dr. Mark McGowan
Coordinator, School Psychology Certification Program
246 Stouffer Hall
Indiana, PA 15705
Office: (724) 357-2174
mmcgowan@iup.edu

Consent of Parent/Guardian

Numeric ID code: 01

Does your child suffer from epilepsy? Yes _______ No _______
Does your child suffer from anxiety? Yes _______ No _______
Does your child suffer from depression? Yes _______ No _______

Would you like to receive a written copy of the study's results upon completion?

Yes _______ No _______

Signature: ____

Print name: ____

Date: ____

Project Director:
Ms. Geneel A. McKenzie
Rank/Position: Doctoral Candidate
Department Affiliation: School Psychology

Dr. Mark R. McGowan
Rank/Position: Advisor
Department Affiliation: School Psychology

This project has been approved by the Indiana University of Pennsylvania Institutional Review Board for the Protection of Human Subjects (Phone: 724/357-7730).

Appendix B

Child's Informed Consent Form

My name is Mrs. McKenzie. I am a school psychologist and work in your school a few days a week. I am also a student and need to complete a research study as homework. I would like you to help me with a research study. I am going to tell you about my research study so you can decide if you want to help me or not help me with this study. It is OK for you to ask me questions about the study. My telephone number and e-mail address is listed at the bottom of this page. If you have questions and would like to discuss them with someone else, you can speak to Dr. Mark McGowan at my school. He will be able to answer your questions. I would like you to help me because you are a student in the second/third grade at Inman Elementary School.

I would like to know how you use your memory and how well you read. I will also ask your reading EIP teacher to help me figure out how your memory works and how well you are doing in your reading class. An example of a question that I might and your reading EIP teacher is: "How fast do you read or how much do you understand when you read?" Helping me with this study will take about 25 minutes of your time every day for five weeks. You will not miss any important class time because you will only be allowed to help me during the after school program. If you would like to help me, your reading EIP teacher will take you to the computer lab every day and help you sign on and off the computer. When you sign into the computer you will begin to play a memory game that is very similar to a videogame. The game will be very easy in the beginning but as you play more and more it will become more difficult. Nothing in this study will be graded.

Your parent(s) know about this and agree that it is okay for you to help me if you want to. You may find the activity fun. The things I will learn from this study will help me and others learn more about children's memory and reading skills.

No one is making you help me, and you don't have to if you don't want to. If you don't want to help me with the study nothing bad will happen to you. No one will be mad at you. If you decide later that you don't want to be part of my research study, you or your parent/guardian can tell me that by calling, emailing, or writing to me, and I will put all of the information in the garbage and not include you in my study. If you do want to be in my study, nobody will know how you did on the memory game, including me. I am asking all of the second and third graders in your EIP class to help me, so the information from you and your teacher will just be a little part of the big research study. When I finish my research study, I might talk about what I learned with other people, or write it down so other people can read it, but I will always talk about groups of kids, never about you.

If you would like to help me in my study, please print and sign your name on the signature page. If you do not want to participate please sign at the bottom of the signature page and return it.

Geneel A. McKenzie, M.S.
Doctoral Candidate
Lafayette Educational Center
205 Lafayette Ave
Fayetteville, GA 30214
Office: (770) 7460-3990
rxlr@iup.edu

Dr. Mark McGowan
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mmcgowan@iup.edu

This project has been approved by the Indiana University of Pennsylvania Institutional Review Board for the Protection of Human Subjects (Phone: 724/357-7730).

CHILD VOLUNTARY CONSENT FORM: SIGNATURE PAGE

(PLEASE RETURN THIS FORM WITH THE PARENT CONSENT FORM)

I understand the information on the form and agree to participate in this study. I understand that no one will know my individual answers. I have the right to change my mind and not participate at any time. I have an unsigned copy of this informed Consent Form to keep.

Child's Name (PLEASE PRINT)

____

Child's Signature

____

Parent/Guardian Signature

____

Date

I do not want to participate in this study.

Child's Name (PLEASE PRINT)

____

Child's Signature (PLEASE PRINT)

____

Parent/Guardian Signature

____

Date

Appendix C

Follow-Up Post Card (14 Day)

September 2015

Approximately two weeks ago you should have received a packet of information seeking your consent for your son/daughter's participation in a research study specifically related to second and third grade students who participate in the reading Early Intervention Program (EIP) and the After School Reading and Math Program (ARM).

If you have already completed and returned the consent form, thank you. If not, please do so today. Your child's participation will be appreciated.

Although your participation is solicited, it is strictly voluntary. If by some chance you did not receive the packet, or it was misplaced, please call me at (770) 460-3990 ext. 163 or email me at rxlr@iup.edu and I will immediately mail you another packet.

Sincerely,

Geneel A. McKenzie, M.S.
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