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Does a Keyword Mnemonics Intervention Have an Effect on the Components of the Working Memory System?

Jessica L. Blasik

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DOES A KEYWORD MNEMONICS INTERVENTION HAVE AN EFFECT ON THE COMPONENTS OF THE WORKING MEMORY SYSTEM?

A Dissertation

Submitted to the School of Education

Duquesne University

In partial fulfillment of the requirements for the degree of Doctor of Philosophy

By

Jessica L. Blasik

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DOES A KEYWORD MNEMONICS INTERVENTION HAVE AN EFFECT ON THE COMPONENTS OF THE WORKING MEMORY SYSTEM?

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ABSTRACT

DOES A KEYWORD MNEMONICS INTERVENTION HAVE AN EFFECT ON THE COMPONENTS OF THE WORKING MEMORY SYSTEM?

By

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May 2011

Dissertation supervised by: Jeffrey A. Miller, Ph.D.

Working memory is a memory system described as a person’s ability to simultaneously store, manipulate, and process information over a brief period of time (Baddeley & Hitch, 1974); it is the active processing of information in the here and now. As working memory moves to the forefront of research studies, it becomes apparent that there is a paucity of research addressing ecologically valid interventions which can be conducted in the classroom and interventions’ direct impact on the working memory system. This paper addresses the development and research regarding the working memory system, demonstrating a current gap in the available research. It then examines the effects of Keyword Mnemonics intervention on the components of fourth graders’ working memory systems by assessing each component individually both pre- and post-intervention. Pretest and posttest data from 55 fourth grade students (25 males; 30
females) was collected, with 27 participants in the intervention group and 28 participants in the control group. Results of Multivariate Analysis of Covariance (MANCOVA) reveal that there were no differences in the working memory components between the intervention group and the no-intervention control group following the intervention. Using pretest scores as covariates, group membership did not have an effect on posttest performance. These results are discussed within the context of available literature. Finally, limitations of this project and directions for future research are considered.
DEDICATION

I dedicate this dissertation to my parents, Teresa and Mick, and to my brother, Stephen, for their unwavering love and support over the years. My parents have always believed in me and embraced my educational endeavors, providing me with the encouragement to pursue my goals. My brother provided the reality check I often needed, reminding me to not take life too seriously. I also dedicate this dissertation to James Olliver. Although he came into my life toward the end of this process, I cherish the unconditional compassion and understanding he has shown while gently pushing me to finish what I started. All of you have been integral to my success and completion of this dissertation; thank you from the bottom of my heart.
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Chapter I

Introduction

Working memory is a memory system commonly believed to represent a person’s ability to simultaneously store, manipulate and process information over a brief period of time (Baddeley & Hitch, 1974). There has been a strong connection found between working memory and learning in the academic setting (Alloway, Gathercole, Willis, & Adams, 2004), such as reading comprehension and mathematics abilities (Carretti, Cornoldi, DeBeni, & Romano, 2005; Schuchardt, Maehler, & Hasselhorn 2008). In addition, research suggests that working memory is linked to a host of other mental processes such as intelligence and attentional control (Conway, Kane, Bunting, Hambrick, Wilhelm et al., 2005; Kane, Poole, Tuhuski, & Engle, 2006). The measurement of working memory in children is complicated, but measuring and understanding the early development of working memory can help researchers discover ways to potentially enhance working memory skills through various interventions thus improving potential for learning (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009).

Children in schools are faced with a wide range of challenges, including both behavioral and cognitive expectations. They are required to attend to their environment, understand it, remember it, interpret what they are experiencing, and then apply the information or skills to new situations. This comes naturally to many children, but not to all children. Some children struggle to learn what their environment presents and often times these children become frustrated with school. Of these children who struggle to learn, some fail to benefit from academic interventions, leaving adults who work with these children looking for innovative solutions that address learning difficulties that are
resistant to remediation. Working memory plays a critical role in a child’s ability to integrate information from his/her environment thus influencing the learning taking place. This creates an opportunity to reach children who require a different type of intervention, perhaps an intervention that taps a psychological process known as working memory.

Many interventions have been suggested to improve working memory functioning (Dehn, 2008), but there is little empirical support on how this happens at a neuropsychological level. Interventions are typically measured by the intervention’s affect on an individual’s ability to carry out an academic task. The same interventions are rarely studied as they relate to the specific processes which underlie the overall academic task. For example, researchers have investigated mnemonics interventions and extensively documented the potential for the positive outcomes associated with a mnemonics intervention (Verhaeghen, Marcoen, & Goossens, 1992). However, there is a lack of research that has examined the executive functions, which are at the foundation of these general abilities that are affected by such an intervention.

In order to utilize an appropriate intervention and to develop hypotheses to establish a relationship between working memory and other cognitive abilities, current models of working memory will be examined and expanded upon. Implications of the model of choice will then be applied to the following study. This information will be used to develop working memory assessment battery amenable to busy schedules in schools in order to measure the components of working memory. In addition, this brief working memory battery will also be used to assess the specific effects of a keyword mnemonics intervention strategy used with fourth grade students.
Significance of the Problem

Working memory is a rich topic of study in psychology, as it has correlates with learning (Schuchardt, Maehler, & Hasselhorn, 2008), academic achievement (Swanson, 1994), attention deficits such as those found in children with ADHD (Barkley, 1997), and various other abilities involving everyday activities (Werheid, et al, 2002). The ability to temporarily store and manipulate information in working memory is highly related to higher cognitive functions, such as focusing and sustaining attention in the face of distractions, which are skills that are essential to benefitting from a learning environment (Gevins & Smith, 2000). The construct of working memory has a pervasive effect on the overall functioning of a person, with specific relationships to learning and skills related to memory across multiple settings. The ability to enhance working memory through intervention would imply that improvements could be made in other areas affected by working memory with a goal of improving cognitive functioning across related academic areas and enhancing strategy use in multiple contexts (Dehn, 2008).

Certain interventions and strategies have been well established as improving memory, such as mnemonic devices (Verhaeghen, Marcoen, & Goossens, 1992). Mnemonic interventions involve utilizing a systematic strategy approach to learning new, unfamiliar information. Mnemonics interventions have an empirically supported place in learning enhancement, but their impact on working memory and its components is not known. Research suggests that mnemonics work (Verhaeghen et al.), but does not go into detail regarding what is happening internally. Studies have repeatedly shown that using mnemonic devices helps improve functioning at an academic level. Currently, the literature does not examine the effects of mnemonic interventions beyond the fact that
improvement is shown in areas associated with academic achievement; there is no evidence related to the working memory system or executive functions affected by such an intervention.

A specific type of mnemonic intervention is Keyword Mnemonics. Keyword mnemonics engage both visual and auditory modes of learning as this intervention consists of both words that sound the same in addition to a picture. Dehn (2008) reports that keyword mnemonics are a compensatory intervention approach that supplement basic working memory skills. However, this is not empirically based; it is uncertain whether the components of working memory are actually changed at a neuropsychological level. Examining a working memory intervention is an opportunity in the respect that this approach to understanding learning problems may begin to unveil the root of learning problems and provide information on how to address learning differences in creative ways. Understanding learning problems at the neuropsychological level can help children develop basic mental processes, which make possible the ensuing academic skills needed to experience success in school.

There are studies that suggest using specialized interventions to tap specific executive functions will improve that particular executive function, but may not generalize to other areas of executive functioning (e.g. Dahlin, Neely, Larson, Backman, & Nyberg, 2008). There is no evidence related to the systems or executive functions of working memory affected by a general intervention. Although keyword mnemonics are suggested as a working memory intervention (e.g. Dehn, 2008), there are currently no studies that use working memory as a dependent variable to be measured before and after such an intervention. Gaining an understanding of the internal processes associated with a
keyword mnemonics intervention would provide insight to which working memory components are affected by an intervention that claims to improve working memory related skills.

**Theoretical Basis of Working Memory**

Understanding working memory from a theoretical perspective is important, as this helps to give structure to the complicated psychological construct. Although original models of working memory proposed singular, unitary depictions, research has begun to generally support a multi-componential description of the construct (Baddeley & Hitch, 1974; Baddeley, 2000; Cowan, 1995; Miyake, Friedman, Emerson, Witski, & Howter, 2000). Multi-component theories of working memory purport that working memory is a structure which incorporates several processes that contribute to the ability to carry out cognitive tasks. Perhaps the most widely used and empirically based multi-component working memory model is that of Baddeley and Hitch (1974), later revised by Baddeley in 2000. The four components are: the central executive, phonological loop, visuo-spatial sketchpad and the episodic buffer. Additionally, researchers have further fractionating the system, delineating the central executive into three distinct but related executive functions (Miyake et al.).

According to the original multi-component theory (Baddeley & Hitch, 1974), there are three basic mechanisms at work: the central executive and two slave systems, the visuo-spatial sketchpad and the phonological loop. In “a reformulation of the theoretical framework”, Baddeley proposed a fourth component to his theory of working memory: the episodic buffer (Baddeley, 2000, p. 417). The central executive is considered flexible and is responsible for managing a variety of processes and executive
functions such as decision making and controlling attention (Baddeley, 1996; 2000; Miyake et al., 2000). The central executive also is responsible for integrating incoming information in order to process it and delegate subsequent processes. The central executive controls attention so that the information can be stored in the corresponding systems (Baddeley, 2000). The central executive’s role in the working memory process is overarching and critical to a person’s working memory ability.

The slave systems provide the central executive with information to monitor, are specific in nature, and have specialized functions (Baddeley, 1996; Gathercole & Pickering, 2000). The phonological loop is responsible for short-term verbal storage, is vulnerable to decay and interference, and is necessary for language development. Information in the phonological loop is temporarily stored as sub-vocalizations and may be presented either verbally, words and sounds, or visually, such as written words which are representations of sounds (Baddeley, 1996). This has implications for the phonological loop’s involvement in language and reading abilities (Schuchardt, Maehler, & Hasselhorn, 2008). The visuo-spatial sketch pad has short term storage of visually presented material and is believed to have a parallel function to the phonological loop, but is less well understood and less often studied compared with the phonological loop (Baddeley, 1996). This specialized process helps a person recall the different features of visual information to form a comprehensive understanding of visual information (Hamilton, Coates, & Heffernan, 2003). The two slave systems are managed by the overarching central executive component; both slave systems provide the central executive with sensory information to be organized.
The episodic buffer holds semantic and abstract pieces of information, and has the capability of incorporating information from various sources: auditory-, visual- and semantically- stored information. It is controlled by the central executive and is responsible for integrating input from a variety of sources where information may then be manipulated or modified (Baddeley, 2000). Information is integrated across space and time as it is managed in the working memory system. Within the episodic buffer, information is integrated and linked to meaningful memories and sensory input (Baddeley). Having the ability to retrieve information in multiple modes and from a variety of sources is functional because information is constantly being observed in multiple modalities. The central executive plays a role in the episodic buffer’s ability to sort through incoming information. The central executive directs the episodic buffer, as well as the two slave systems, which makes it responsible for executive functioning tasks and creates an active system of working memory.

As a continuation of the specification of an overarching framework of the working memory as an integrated system, the central executive has been studied in more detail and fractionated further. The central executive is viewed as having both a common executive function mechanism as well as components that are partially dissociable, where both unity and diversity of the executive functions are necessary to their performance (Miyake et al., 2000). In 2000, Miyake and colleagues studied how the cognitive processes are controlled and coordinated during complex working memory tasks. Using confirmatory factor analysis, they found that although the executive functions derived are correlated with each other, they are unmistakably separable. The functional domains of
shifting, inhibition, and updating were the three constructs they investigated as the central executive component of Baddeley’s (2000) working memory model.

Baddeley’s theory explains working memory such that the central executive is responsible for manipulating information and controlling attention while Miyake and colleagues break the central executive into three functional domains: inhibition, shifting, and updating. The three factor fractionation explanation of the central executive, consisting of shifting, inhibition, and updating, has recently dominated the working memory executive function research (Friedman et al., 2008). The first domain of central executive is the executive function of inhibition. Inhibition is defined as the ability to override dominant or automatic responses in order to complete the task at hand; the “deliberate, controlled suppression of prepotent responses” (Miyake et al. 2000, p. 58). This is a cognitive task in which a person is able to consciously and purposely alter his or her thought process in order to respond in a way that is different than what would automatically be produced. Inhibition is associated with an individual’s ability to maintain attention in the face of distracting stimuli and has been correlated with attention related abilities (Barkley, 1997).

Shifting, the second domain of the central executive, is the ability to flexibly switch back and forth between tasks or mental sets, without integrating them together (Miyake et al., 2000). As with inhibition, there are other types of shifting studied, and it is important to note that the switching taking place here is cognitive, rather than switching visual attention to various stimuli by making voluntary eye movement. This distinction is made because of where this cognitive process takes place in the brain, the frontal lobes, in contrast to the voluntary eye movement involved in visual attention
which takes place in the parietal lobes and midbrain (Miyake et al.). The ability to cognitively switch mental sets is significant as it relates to tasks where previous information must be disregarded in order to carry out the present task, such as shifting activities or lessons in class.

The third domain of the central executive is updating, which is the ability to actively monitor incoming information while appropriately replacing old, no longer relevant information with new, relevant information (Miyake et al., 2000). This particular executive function is dynamic and involves the monitoring of incoming information for the relevance of the task at hand and the appropriate revision of that information. The term updating is occasionally used synonymously with the term working memory in literature, but in this instance, updating is a fractionation of the working memory system’s central executive component, responsible for the revision of incoming information, rather than the storage or retrieval of other information. This is associated with academic tasks, specifically reading comprehension (Carretti, Cornoldi, DeBeni, & Romano, 2005).

Differentiating inhibition, shifting and updating has been the focus of research studies; researchers have explored the executive function’s differences, while still incorporating inhibition, shifting, and updating into the same overarching construct (Miyake et al., 2000; Mantyla et al, 2007). This model has deepened the understanding of the working memory construct. By associating executive functions with working memory and understanding how they work both independently and synergistically, there is the potential to isolate specific processes in memory and learning. This integrative framework allows for the study of each component individually, as well as how each
individual process contributes to the overarching system utilized in cognitively demanding working memory tasks (Miyake et al., 2000). Although determining relationships between neuropsychological functions and academic skills is exciting and promising, it is not enough. Building upon the current literature to further understand which specific executive functions are associated with progress can help determine how to best improve an individual’s academic performance.

**Critical Analysis of Current Literature**

Not only is there a paucity of working memory intervention research in the current literature, but there is also often a focus on adults resulting in a lack of information regarding children. Studying brain functions in children adds to the complexities of measuring constructs due children’s differing development and ability levels (Garon et al., 2008). While attending to these challenges, researchers have attempted to design methods of measuring the specific working memory and executive functioning skills in young children in practical and useful ways. With a theoretical foundation, such as Baddeley’s (2000) model of working memory as well as Miyake and colleagues’ fractionation of the central executive (2000), assessments have the potential to be fruitful in the information provided.

Many of the working memory assessments have been correlated with cognitive abilities and intelligence (Conway, Kane, Bunting, Hambrick, Wilhelm et al., 2005), academic achievement and learning (Schuchardt et al., 2008; Swanson, 1994), attention deficits such as those found in children with ADHD (Barkley, 1997; Heitz & Engle, 2007; Kane, Poole, Tuhulski, & Engle, 2006), reading comprehension (Carretti et al., 2005; de Jonge & de Jonge, 1996), and other cognitive functions (Ashcroft & Kirk,
This is in addition to working memory’s relation to various other tasks involved everyday activities which are essential to benefitting from a learning environment (Gevins & Smith, 2000). With increasing research devoted to measuring working memory and executive functions in children, the understanding of what these constructs mean in relation to learning and academic abilities has paved the way for using specific cognitive skills as an approach to intervention, as these are currently untapped resources.

There has been much research on the capacity and measurement of working memory and associated executive functions, but there is still a scarcity of research targeting how working memory performance can be improved (Carretti et al., 2007). Studies suggest that working memory capacity is limited; although the limit is not exact, this should not imply that working memory cannot be enhanced or improved with effective interventions. Working memory interventions aim to remediate or compensate the construct in a way that improves the efficiency of information processing, storage, and retrieval (Dehn, 2008). Intervening at the level of executive functioning can potentially have implications in relation to any and all of the areas associated with working memory, including academic abilities and achievement.

Although there is some research which suggests that executive functions and working memory abilities are genetic and stable over a lifetime, similar to intelligence (Conway et al., 2005; Friedman et al., 2006; Friedman et al., 2008), there has been other research which suggests that these skills are, in fact, malleable and can be improved through intervention (e.g. Klingberg et. al, 2005; Verhaeghen et al., 2004). One critical aspect of the differing views in this instance is whether working memory is examined in terms of capacity or effectiveness. Working memory capacity is believed to be innate and
less amenable to change, whereas working memory efficiency can be enhanced through intervention and strategy use (Dehn, 2008).

As working memory develops, so do the strategies which children utilize (Bjorklund, Dukes, & Brown, 2009; Cowan, Saults & Morey, 2006). Researchers (Lehmann & Hasselhorn, 2007) found that during elementary school, two developmental changes in strategy use were taking place: labeling and cumulative rehearsal. Labeling was defined as saying each word only once when the word was presented; cumulative rehearsal was the actual practicing of saying at least two words sequentially. Labeling decreased around the beginning of third grade and cumulative rehearsal increased, replacing labeling by the end of third grade, indicating a progressive increase in strategy use.

In addition, children increasingly tended to integrate activity of the visuo-spatial and phonological working memory components to help remember information from the environment. As they mature, so does their ability to integrate information from these two systems. This suggests that the individual slave systems do not only improve over time, but also the two systems interact more effectively with the central executive which allows for increased working memory ability (Hamilton, Coates, & Heffernan, 2003). Interventions, such as keyword mnemonics, target this skill: the integration of auditory and visual stimuli to help enhance the likelihood of remembering new information.

Posner and Rothbart (2005) state that neural networks “are shaped by genes, but can also be influenced by specific experiences such as educational interventions” (p. 102). However, much of the research which does exist is mainly in adults (Buschkuehl, Jaeggi, Hutchison, Perrig-Chiello, & Dapp et al., 2009; Verhaeghen et. al., 2004), people
with traumatic brain injuries (Cicerone, Levin, Malec, Struss, & Whyte, 2006; Duval, Coyette, & Seron), and/or those with other significant deficits such as ADHD (Conners, Rosenquist, Arnett, Moore, & Hume, 2008; Klingberg et al., 2005).

**Interventions**

Typical academic interventions aim to help children at three progressive levels: skill acquisition, skill fluency, and generalization of the skill (Ardoin, Eckert, & Cole, 2008). The first level refers to teaching a child a new skill, one which they have not yet acquired. Moving to the second level, fluency represents a child’s ability to quickly and accurately execute a task. For example, reading. First, a child needs to learn the basic sounds of words and how to read words individually, and eventually develops the fluency associated with smooth reading. The final step is generalization. This refers to a child’s ability to use the information they’ve learned and apply it in novel situations. Generalization is the end goal of most interventions (Ardoin et al.). However, it is helpful to know what the intervention is effecting in order to understand how the intervention will affect other abilities and generalization of the skill.

Limited working memory and executive function intervention research does exist, and research has recently begun to study young children. Most of the research within the domain of working memory intervention has involved training participants in a specific task but has neglected to look at the application of the training to real life situations. These interventions teach a very specific skill and do not consider the application of the skill. However, even with this lack of ecological utility, studies have shown that participants can improve their working memory skills in controlled, experimental settings (Klingberg et al., 2005; Thorell et al., 2009; Verhaeghen et al., 2004). This is an exciting
finding because it provides evidence that skills at the foundation of working memory functioning can be improved.

Other, well established interventions, such as mnemonics, have gained support regarding their effectiveness in the classroom. Mnemonics are systematic ways of learning new information suggested as a compensatory working memory intervention. Keyword mnemonics involve both visual and auditory cues to enhance working memory efficiency through taught strategy use (e.g. Dehn, 2008). However, there is no literature that investigates whether working memory components are enhanced by such an intervention. Keyword mnemonics work, but the literature does not specify what are they improving. Applying what is known and understood about working memory and expanding future research in this area has many promising benefits for helping school aged children succeed academically.

**Problem Statement**

Although working memory and its associated executive functions have received significant attention and empirical support, there is still a lack of research which investigates how the components of working memory (phonological loop, visuo-spatial sketchpad, episodic buffer) and three components of the central executive (inhibition, shifting, and updating) can be improved through intervention. Research supports the positive effects of keyword mnemonics interventions (Verhaeghen at al., 1992) on working memory specifically (Dehn, 2008), but there is no evidence related to which components of working memory are affected. The implications for understanding, measuring, and improving the constructs have yet to be comprehensively examined in children.
The central executive is arguably the most critical component of Baddeley’s (2000) working memory model as it is responsible for managing, organizing, and manipulating incoming information as well as controlling attentional resources allocated to the task at hand. The central executive has been fractionated into three separate but correlated domains: inhibition, shifting, and updating (Miyake et al., 2000). These three domains thus play a vital role in an individual’s ability to carry out working memory tasks. Currently, research does not examine how these executive functions are affected by working memory interventions. The central executive is often neglected when looking at working memory improvement, with many studies focusing on the phonological loop or the visuo-spatial sketchpad separately (e.g. Schuchardt et al., 2008).

The purpose of the current study is to examine the effects of a keyword mnemonic strategy intervention on the working memory components of elementary aged school children. More specifically, this study will look at the effects of a keyword mnemonic intervention on the working memory system, including the fractionated domains of the central executive, of fourth grade students. Change will be measured by a battery assessment of the individual components of working memory based on Baddeley’s (2000) model and Miyake et al.’s (2000) fractionation of the central executive.

**Research Questions and Hypotheses**

It has been determined that the components of working memory (phonological loop, visuo-spatial sketchpad, episodic buffer) and three domains of the central executive (inhibition, shifting, and updating) are highly associated with a variety of cognitive abilities and academic skills (Carretti et al., 2005; Conway et al., 2005; Kane et al., 2006; Schuchardt et al., 2008). Interventions have been suggested to improve working memory,
such as keyword mnemonics (Dehn, 2008). However, there is currently no literature addressing how a keyword mnemonics intervention affects the individual components of working memory and domains of the central executive. The following research questions aim to address this gap in the current literature.

Research Question:

1. What is the effect of a keyword mnemonics intervention on the non-executive components of working memory when compared to a no treatment control group?

   Hypothesis 1: Children who receive the keyword mnemonics intervention will perform better on a phonological loop task than a no treatment control group.

   Hypothesis 2: Children who receive the keyword mnemonics intervention will perform better on a visuo-spatial sketchpad task than a no treatment control group.

   Hypothesis 3: Children who receive the keyword mnemonics intervention will perform better on an episodic buffer task than a no treatment control group.

2. What is the effect of a keyword mnemonics intervention on the accuracy of central executive domains of inhibition, shifting, and updating performance when compared to a no treatment control group?

   Hypothesis 4: Children who receive the keyword mnemonics intervention will exhibit an increase in accuracy on an inhibition performance task as compared to a no treatment control group.
Hypothesis 5: Children who receive the keyword mnemonics intervention will exhibit an increase in accuracy on a shifting performance task as compared to a no treatment control group.

Hypothesis 6: Children who receive the keyword mnemonics intervention will exhibit an increase in accuracy on an updating performance task as compared to a no treatment control group.

3. What is the effect of a keyword mnemonics intervention on the response time of central executive domains of inhibition, shifting, and updating performance when compared to a no treatment control group?

Hypothesis 7: Children who receive the keyword mnemonics intervention will exhibit a decrease in response time on an inhibition performance task as compared to a no treatment control group.

Hypothesis 8: Children who receive the keyword mnemonics intervention will exhibit a decrease in response time on a shifting performance task as compared to a no treatment control group.

Hypothesis 9: Children who receive the keyword mnemonics intervention will exhibit a decrease in response time on an updating performance task as compared to a no treatment control group.
Chapter II

Literature Review

For the purpose of understanding how working memory affects learning, the following literature review will provide information necessary to making informed decisions regarding the current study. The construct of working memory and models of associated abilities (Baddeley & Hitch, 1974; Cowan, 1995; Miyake, Friedman, Emerson, Witski, & Howter, 2000) are discussed, as well as working memory implications, development, assessment, and interventions. Working memory assessment has a variety of tasks and tests associated with the measurement of the construct, setting the foundation for discussion about which tasks measure working memory or what components of working memory (Engle et al., 1999). There are interventions that have been found to improve working memory skills that have not been examined as they impact the components of working memory.

Working Memory

Working memory is a memory system commonly described as a person’s ability to simultaneously store, manipulate and process information over a brief period of time (Baddeley & Hitch, 1974; Baddeley, 2000). Working memory is more than simply remembering information; it involves active manipulation or processing of information. Although the name suggests otherwise, working memory does not imply memory per se’; instead, it involves executive functions such as attentional control and vigilance to incoming information. Since the introduction of the multi-component construct of working memory in 1974 (Baddeley & Hitch), working memory has been the focus of numerous studies, gained empirical support, and has been continuously linked to the
process of learning. There is a strong connection between working memory and learning (Alloway, Gathercole, Willis, & Adams, 2004), which has initiated a shift from a focus on adults to a focus on younger children in recent years (Garon, Bryson, & Smith, 2008). The measurement of working memory in children is complicated, but understanding the early development of working memory can help researchers discover ways to potentially enhance working memory skills through various interventions thus improving potential for learning (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009).

**Working Memory Theory**

Understanding working memory from a theoretical perspective is important, as this helps to give structure to the complicated psychological construct. The different theoretical approaches vary in preciseness of components and how they attempt to explain working memory. Studies that focus on how executive functions work to coordinate and control complex cognitive tasks originate with brain injured patients, mainly adults with frontal lobe injuries, who exhibited deficits in higher order tasks (e.g. Baddeley, 2000; Miyake et al., 2000). It has been understood that executive tasks such as problem solving, reasoning, planning, organizing, and the control and regulation of attention take place in the frontal lobes; working memory falls in this area as well. Over the years, various models have been developed, studied, and have gained empirical support in theorists’ attempts to explain the working memory system (Miyake et al.).

Theories used to explain the construct of working memory have taken two different approaches: unitary models, which suggest that working memory is a singular function (Engle, Tuhulski, Laughlin, & Conway, 1999; Kane & Engle, 2003), and multi-componential models (Baddeley, 2000; Miyake, Friedman, Emerson, Witzki, Howerter,
& Wager, 1999), which suggest there is a fractionation of working memory where multiple processes act together to form a working memory system. However, over the past five years, research has begun to generally support a multi-componential description of the construct (Conway et al., 2005).

Models of Working Memory

In the early stages of working memory theory, a central executive, or Supervisory Attentional System proposed by Norman and Shallice in 1986, was believed to be unitary in nature, with no delineation of specific functions within the system to account for differing tasks (Miyake et al., 2000). Early theories of Engle and colleagues (1999) purport that working memory consists of a unitary functioning system, in which attention is the control component, or central executive, and has a domain-general function. Researchers (Kane et al., 2004) began to advocate for a domain-general model of working memory and attributed the domain specific functions to storage and rehearsal, moving towards a multi-componential model. Findings of this study suggest that there is an overarching domain-general process being utilized in working memory, which implies that there is no distinction between verbal and spatial working memory capacity (Kane et al., 2004). Domain- general skills, such as paying attention, allow for cognitive control across domains (Conway et al. 2005) However, domain-specific skills were also found to facilitate storage of novel information in different modes, suggesting that there is also some division of responsibility (Kane et al.).

There has been a shift from the unitary view of working memory to multi-component theories (Baddeley & Hitch, 1974; Cowan, 1995; Miyake et al., 2000). Multi-component theories of working memory purport that working memory is a structure that
incorporates several processes that contribute to the ability to carry out cognitively demanding tasks. The Embedded Process Model of Cowan (1995) suggests that working memory is a sub-component of long term memory whereas Baddeley (2000) describes working memory as its own memory system. Baddeley’s model has four components: the central executive, phonological loop, visuo-spatial sketchpad and the episodic buffer. This four component model of working memory has gained the most empirical support, with some researchers further fractionating the central executive into distinct but related executive functions (Miyake et al.).

**Embedded Process Model**

In the Embedded Processes Model explanation of working memory, there are three levels of attention accounting for the working memory process, which connects working memory to long term memory. Oberauer (2002) suggests a model involving three concentric circles, representing the specificity of attention as three functionally distinct regions. Information first enters through a temporary sensory store and then goes on to one of three levels: the long term store, activated or short term memory, or the focus of attention (Cowan, 1995; Oberauer, 2002). The temporary sensory store involves senses, such as sight for visual stimuli and sounds for auditory stimuli, and is passed on one of the levels according to the novelty of the stimuli; very relevant or novel information will be moved to the focus of attention.

The central executive is responsible for bringing information into conscious awareness and assessing its novelty (Cowan, 1995). When the information is important or novel, the central executive directs the focus of attention to the incoming stimuli. When the stimuli are no longer new, the central executive begins to habituate and no longer
provides attention to it. If attention is not allocated, the stimuli do not proceed to the sensory store and thus do not enter any level of memory. As stimuli enter the sensory store, one of three levels is activated according to how significant the information is; information in each level is only activated in accordance with its necessity to complete a task (Cowan).

The long-term memory store represents information that is readily accessible and stored, but not activated. This store has essentially unlimited space and is not subject to decay over periods of time. The activated or short term memory accounts for information that is being processed from the long term memory store; it is accessing the stored information for current use. The activated memory has a limited capacity, holding information available for use in ongoing cognitive tasks, and can be victim to interference or decay (Oberauer, 2002; 2005). This means that some new information may cause other pieces of information to be forgotten or un-activated. Both visual and auditory information can lose their strength over a short time interval, which can prohibit information from being integrated in long term memory (Oberauer). The third level in this model is the focus of attention, which is directly controlled by the central executive. Bringing any piece of information from working memory, either for manipulation or recall, involves bringing the single item into the focus of attention. Oberauer argues that the activated memory store can hold several pieces of semantically related information, or chunks, but only one item can be the focus of attention at any given time (Oberauer, 2002).
Baddeley’s Model of Working Memory

Perhaps the most widely used and empirically based multi-component working memory model is that of Baddeley and Hitch (1974). In 1974, Allen Baddeley and Graham Hitch devised a three component theory of working memory (Baddeley & Hitch). According to their original multi-component theory, there are three basic mechanisms at work: the central executive and two slave systems, the visuo-spatial sketchpad and the phonological loop. The central executive is considered flexible and is responsible for managing a variety of processes and executive functions such as decision making and controlling attention (Baddeley, 1996) and is believed to take place in the frontal and prefrontal cortex (Osaka & Osaka, 2007).

The central executive is the decision making center in the working memory model and is believed to be comprised of a number of divisible processes (Baddeley, 2002; Miyake et al, 2000). It is responsible for receiving information and then processing it accordingly. The central executive also is responsible for integrating incoming information in order to process it and delegate subsequent tasks. The central executive does not have storage capacity; instead it controls attention so that the information can be stored in the corresponding systems (Baddeley, 2000). The central executive’s role in the working memory process is overarching and is critical to a person’s working memory functioning.

The slave systems, which serve to provide the central executive with specific modes of information to monitor, help with the input of environmental stimuli. The phonological loop is responsible for manipulating auditory input, activating the left ventrolateral prefrontal cortex (Osaka & Osaka, 2007; Postle, 2007). The visuo-spatial
sketchpad is responsible for manipulating visual information and activates the corresponding right ventrolateral prefrontal cortex (Osaka & Osaka; Postle). It is believed that higher order cognitive processes take place in the prefrontal cortex because the executive functions involve supervisory and attentional control. This has been supported by neuroimaging studies which indicate activation in the prefrontal cortex when a person is engaged in a working memory task (Miyake et al., 2000; Osaka & Osaka). The two slave systems are managed by this overarching central executive component; both slave systems provide the central executive with sensory information to be organized.

The two slave systems are specific in nature, each having specialized functions (Baddeley, 1996; Gathercole & Pickering, 2000). The phonological loop is responsible for short-term verbal storage, is vulnerable to decay and interference, and is necessary for language development. Information in the phonological loop is temporarily stored as subvocalizations and may be presented either verbally, words and sounds, or visually, such as written words which are representations of sounds (Baddeley, 1996). When there is some disruption to the phonological loop during a working memory task, such as its capacity exceeded or rehearsal interrupted, the information may be lost. This has implications for the phonological loop’s involvement in language and reading abilities (Schuchardt, Maehler, & Hasselhorn, 2008).

It is believed that the verbal memory component is information based, rather than semantically based. This is because similar sounding phonological information can cause interference in recall but similar meaning does not have the same adverse effect on recall ability. The phonological loop has been fractionated into two different subcomponents, they are: the phonological store and the articulatory control (Baddeley, 1996). The
phonological store is responsible for temporarily storing auditory stimuli and will fade within 1-2 second (Baddeley, 2003). This is the passive subcomponent, temporarily holding information in the same way it was received. The articulatory control is active and is the sub-vocal rehearsal that people may use to remember information temporarily.

The visuo-spatial sketch pad has short term storage of visually presented material and is believed to have a parallel function to the phonological loop, but is less well understood and less often studied compared with the phonological loop (Baddeley, 1996). The visuo-spatial sketchpad can maintain up to four objects and the object’s associated features of location, shape and color. When any of the features are similar to one another, there can be overlap and thus disruption of retention. This is evidenced by studies that have presented individuals with information that has similar features and found that when there are similarities, it is more difficult for those participants to recall the information (Baddeley, 2003).

Logie (1995) delineated the visuo-spatial sketchpad into two different subcomponents, they are: the visual cache and the inner scribe. The visual cache is passively responsible for the temporary storage of form and color; whereas the inner scribe is actively responsible for spatial relations and movement for temporary storage purposes (Logie, 1995). Together, these two specialized processes help a person recall the different features of visual information. More recently, there has been additional research done in regard to the visual cache and inner scribe (Hamilton, Coates, & Heffernan, 2003). Hamilton and colleagues found that visual and spatial skills are distinct abilities that interact to form a comprehensive understanding of visual information.
The visuo-spatial sketchpad is less well understood compared to the phonological loop, but the two slave systems have similar functions within them. Both include an active component responsible for rehearsal, the articulatory control and inner scribe, and a passive storage component, the phonological store and visual cache. These two sensory dependent systems provide the central executive with information about the environment. With the three component model of working memory in place, studies of temporary memory abilities began to have a theoretical foundation and began to gain empirical support.

Baddeley and Hitch’s (1974) model of working memory created a basic framework of the construct, leaving much open for future specification and investigation. However, there were processes which were not captured under the three component model. The three component model did not explain certain emerging phenomena. For example, people with impaired short-term phonological memory were found to be able to recall multiple visually presented digits but only a single digit when digits are presented via auditory stimuli (Baddeley, 2000). Baddeley attributed this finding to a person’s ability to access memories in their long term memory store more readily in certain situations, suggesting differential pathways to memory. In addition, there was no storage component within the central executive that would be responsible for integrating information and connecting meaning to input. These contradictory findings urged Baddeley (2000) to pursue further investigation of his own model. In “a reformulation of the theoretical framework”, Baddeley proposed a fourth component to his theory of working memory: the episodic buffer (Baddeley, 2000, p. 417).
The episodic buffer holds semantic and abstract pieces of information, and has the capability of incorporating information from various sources: auditory-, visual- and semantically- stored information. It is controlled by the central executive and is responsible for integrating input from a variety of sources where information may then be manipulated or modified (Baddeley, 2000). This additional component helps to explain the storage of information which does not fit into the visuo-spatial sketchpad or phonological loop, or has some interaction with episodic long term memory (Bunting & Cowan, 2005) such as semantic meaning and time sequencing. The episodic buffer is involved in the integration of material from multiple locations and modalities (Baddeley). Environmental stimuli are integrated across space and time as are is managed in the working memory system.

Within the episodic buffer, information is integrated and linked to meaningful memories and sensory input. When there is visual similarity of presented information or semantic meaning between sentences, there is a significant impact on the immediate recall of this information. Without some component which allows for the connection to be made and interactions to take place, phenomena such as these do not fit within the original working memory framework (Baddeley, 2000). An example of the episodic buffer at work would be listening to a sentence while simultaneously linking it to meaningful information in long term memory. There is not necessarily a focus on that memory per se. Rather it is the use of that memory to supplement the auditory stimuli in order to maintain the input in the short duration of working memory.

Information can be observed in only visual or only auditory stimuli independently, but can also be stored and retrieved in the opposite mode (Postle, 2007).
For example, a person may be presented with the auditory stimuli, “dog”, which could be stored in the phonological loop. But to remember “dog” the person may imagine a picture of a dog, utilizing the right hemisphere of the brain and engaging the visuo-spatial sketchpad. This modality switching can go the other way as well; a child may be given a picture of a dog which could be maintained in the visuo-spatial sketchpad, but in order to remember it he or she repeats the word “dog” in his or her head, tapping the phonological loop in the left hemisphere of the brain. Or, the person might think of a dog they know, linking “dog” to personally semantic or meaningful information in order to maintain and recall the stimuli. Therefore, as continued support of the fourth component of working memory, retrieval is not limited to the mode of input and involves an overarching, interactional component potentially utilizing more than one mode.

Having the ability to retrieve information in multiple modes and from a variety of sources is functional because information is constantly being observed in multiple modalities. It also increases the chances of remembering information when multiple modes are incorporated, making information retrieval more successful and efficient. The central executive plays a role in the episodic buffers ability to sort through incoming information and manage attentional control. The central executive directs the episodic buffer, as well as the slave systems, which makes it responsible for executive functioning tasks and creates an active system of working memory.

**The Fractionation of the Central Executive.** As a continuation of the specification of an overarching framework of the construct of working memory as an executive function task, the central executive has been studied in more detail and further fractionated. The central executive is viewed as having both a common executive
function mechanism as well as components that are partially dissociable, where both the unity and diversity of the processes are recognized (Miyake et al., 2000). In 2000, Miyake and colleagues studied how the cognitive processes are controlled and coordinated during complex working memory tasks. Using confirmatory factor analysis, they found that although the executive functions derived are correlated with each other, they are unmistakably separable. The functional domains of shifting, inhibition, and updating were the three constructs investigated as part of the central executive (Miyake et al.)

These three constructs are domains of the central executive and have some control over the regulation of attention to the environment. The central executive has the function of controlling whether information is attended to in order to access previously learned information and link it in a meaningful way to incoming information, activating the episodic buffer (Baddeley, 2000). The three domains of shifting, inhibition, and updating were found to be involved in various forms of information management (Friedman et al., 2008). Since the Miyake et al. (2000) study, there have been numerous supporting research projects that have found similar results suggesting three unique processes captured by the central executive (e.g. Hartman, Bolton, & Fehnel, 2001; Lehto, Juujarvi, Kooistra, Pulkkinen, 2003; Mantyla, Carelli, & Forman, 2007). For example, another group of researchers found that executive functions generally tend to cluster into the same three domains of shifting, inhibition, and updating (Lehto et al., 2003).

The executive function of inhibition is defined as the ability to override dominant or automatic responses in order to complete the task at hand; the “deliberate, controlled suppression of prepotent responses” (Miyake et al. 2000, p. 58). This is a cognitive task
in which a person is able to consciously and purposely alter his or her thought process in order to respond in a way that is different than what would automatically be produced. Other types of inhibition studied and discussed in literature tend to lack the deliberate and intention of responding, and although that type of inhibition correlates with the inhibition discussed here, they are theoretically different (Miyake et al., 2000).

Shifting, also referred to as set shifting or attention switching, is the ability to flexibly switch back and forth between tasks or mental sets, without integrating them together (Miyake et al., 2000). As with inhibition, there are other types of shifting studied, it is important to note that the switching taking place here is cognitive, rather than switching visual attention to various stimuli by making voluntary eye movement. This distinction is made because of where this cognitive process takes place in the brain, the frontal lobes, in contrast to the voluntary eye movement involved in visual attention which takes place in the parietal lobes and midbrain (Miyake et al.).

Cognitive based shifting involves a switching of engagement in mental set, suggesting that a person must engage one operation while disengaging the other one. Also, the person completing the switching task may have to face some interference from the previous set. When a mistake is made, not switching to the correct set, it could be due to engagement/disengagement, or due to some interference of the previous operation (Miyake et al., 2000). The process of shifting mental sets happens internally, rather than in the environment. It is the person’s responsibility to maintain the different, parallel sets in order to complete the task. Shifting is believed to take place in the frontal lobes as well, acting as an additional executive function, responsible for controlling the switching
of cognitive sets (Garon et al., 2008). This is a critical aspect of cognitive control, as it serves to engage or disengage other parts of memory and attention.

Another domain of the central executive in working memory is updating, which is the ability to actively monitor incoming information while appropriately replacing old, no longer relevant information with new, relevant information (Miyake et al., 2000). The term updating is occasionally used synonymously with the term working memory in the literature, but in this instance, updating is a fractionation of the working memory system, specifically the central executive, responsible for the revision of incoming information, rather than the storage or retrieval of other information. An example of updating is recalling the three most recent numbers in a string of constantly increasing and changing numbers. While constantly monitoring the incoming information, the person has to update a single digit each time a new digit is presented and disregard the previous numbers (Morris & Jones, 1990).

Each of these specific processes contributes to the working memory system and a person’s ability to manipulate, attend to, and temporarily store information coming from the environment. This suggests that there is also some unitary mechanism integrating the components, the overarching central executive. There is still debate as to whether updating, shifting, and inhibiting are three separate processes, as some researchers purport that there are more similarities than dissimilarities (Mantyla et al., 2007). However, the three factor fractionation explanation of the central executive, consisting of shifting, inhibition, and updating, has recently dominated the working memory central executive research (Friedman et al., 2008).
These theories have created a dynamic framework from which to work with (Garon et al., 2008). Researchers have been able to explore the executive function’s differences, while still incorporating inhibition, shifting, and updating into the same overarching construct (Miyake et al., 2000; Mantyla et al., 2007). The three domains of inhibition, shifting, and updating represent specific supervisory skills that play a role in a person’s overall working memory ability. This integrative framework allows for the study of each component individually, as well as how each individual process contributes to the overarching system utilized in cognitively demanding working memory tasks (Miyake et al., 2000). This model has deepened the understanding of the working memory construct. By associating specific executive functions with working memory and understanding how they work both independently and synergistically, there is the potential to isolate specific processes in memory and learning.

Technology Support of Theory

There are processes which take place that are not necessarily directly observable in a child’s behavior, such as changes in brain chemicals and neural circuits, that, in turn, affect how the child outwardly behaves and responds to cognitively demanding tasks (Miller & Blasik, 2009). Only in recent years have theories, such as those of Baddeley (2000) and Miyake and colleagues (2000), been supported by empirical evidence of brain activation through the use of technological advances. What used to be viewed as abstract theoretical models pertaining to working memory and executive functions, are now beginning to gain support by advancing technologies such as fMRI and EEG studies.

In order to better understand and provide scientific, empirical support of these executive function processes, technology and theory are integrated to create a
comprehensive picture of what is taking place in the brain (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008; Gevins & Smith, 2000; Johnson, Hetzel, & Collins, 2001; Keage et al., 2008; Noble et al., 2005). Neuroimaging studies have been largely supportive of multi-component theoretical models of working memory, as well as in relation to where executive functioning and working memory processes take place in the brain (Osaka & Osaka, 2007). For example, studies show that executive attention takes place in the prefrontal cortex; brain activation has been observed on fMRIs as activation is increased in the prefrontal cortex when a person is engaging in a working memory task (Osaka & Osaka).

Further, fMRI studies suggest that the components of working memory are in fact, different components because they activate different corresponding regions in the brain (Dahlin et al., 2008; Osaka & Osaka, 2007). Several models of working memory (Baddeley, 2000; Cowan, 1999; Miyake et al., 2000; Oberauer, 2002) suggest that there are different processes taking place within the working memory system. The fMRI studies support those theories as activation can be observed to take place in various regions of the brain according to the task demands (Osaka & Osaka, 2007). One research study used fMRI brain imaging to track changes in brain activation regions during executive function tasks (Dahlin et al., 2008). Researchers tracked where specific tasks, such as updating and inhibition, took place in the brain according to activated brain regions. In this particular study, they were able to show that the brain processes of updating and inhibition are separate executive functions (Dahlin et al.). These results provide support for Miyake and colleagues’ (2000) fractionation of the central executive into three separate but related domains.
During visuo-spatial tasks in one study, EEG feedback was used to examine individual differences in ability to focus attention, sustain attention, and perform the task over time (Gevins & Smith, 2000). Cognitive ability profiles were obtained for participants, which provided information about cognitive strengths and weaknesses. Participants with higher cognitive abilities tended to optimize the manner in which they allocated task performance between brain regions. When completing a challenging mental task, high cognitive ability participants tended to use the side of their brain with which they were individually more skilled (Gevins & Smith). Participants with higher verbal abilities, even when solving non-verbal task, tended to incorporate the left side of their brain; whereas participants who had better non-verbal skills tended to incorporate the right side of their brain more readily, regardless of the modality of input (Gevins & Smith). These findings have implications for individual differences in working memory as well as how to assess the effects of interventions according to strengths and weaknesses of individuals.

With technological support of working memory theory, there can be greater and more specific research regarding the associated processes. Using working memory to assess intervention effects may shed light on which processes can be modified through interventions. Working memory is a critical executive capability, and is beginning to be treated as such. Even though working memory substantiates its own memory system, it does not stand alone. It integrates information from other memory systems, while providing a sufficient amount of support to other structures.
Working Memory Capacity and Associated Abilities

The ability to temporarily store and manipulate information in working memory is highly related to higher cognitive functions, such as focusing and sustaining attention in the face of distractions (Gevins & Smith, 2000). Working memory has correlates with learning and academic achievement (Schuchardt, Maehler, & Hasselhorn, 2008; Swanson, 1994), attention span and attention deficits (Barkley, 1997; Heitz & Engle, 2007; Kane, Poole, Tuhulski, & Engle, 2006), and intelligence and cognitive functioning (Ashcroft & Kirk, 2001; Bunting & Cowan, 2005; Conway, Kane, Bunting, Hambrick, Wilhelm et al., 2005). Because working memory can provide an indication of these abilities, working memory capacity has been the focus of much debate within the field. Researchers have conjectured whether the capacity limits are one item (Cowan, 2000), to four items (Oberauer, 2002), through seven items (Miller, 1956). Although capacity limit may be of significance, of more importance is what working capacity suggests about an individual in relation to associated abilities.

Working Memory and Academic Achievement

Not surprisingly, executive functions and working memory have been found to be related to areas of achievement within academic settings (Ashcroft & Kirk, 2001; de Jonge & de Jonge, 1996; Posner & Rothbart, 2005; Schuchardt et al., 2008; Swanson, 1994). One study revealed that working memory was related to reading comprehension and math ability in children and adults with and without learning disabilities (Swanson, 1996). Other research indicates that academic problems, such as dyslexia, are associated with phonological processing regions in the brain (Posner & Rothbart, 2005). It is
apparent that working memory is a mental process which is utilized in various academic
tasks and has implications for performance on such tasks.

Both math and reading are integral to school, all children are going to encounter
these common subjects. Studies have also found a link between working memory and
reading comprehension (de Jonge & de Jonge, 1996; Carretti, Cornoldi, DeBeni, &
Romano, 2005). Working memory is of particular importance to solving math problems
due to the need for integration of previously learned material, how to solve a problem,
and the presented question (Ashcroft & Kirk, 2001). Working memory is involved in the
cognitive process of solving math problems, and is a fundamental component of
understanding the associated tasks. Reading comprehension and working memory
capacity were the focus of studies that used children to investigate the interrelationship of
the skills (Carretti et al., 2005; de Jonge & de Jonge). One study found that working
memory and reasoning were both related to reading comprehension, but that these
constructs differed in their relation to reading speed (de Jonge & de Jonge).

Schuchardt and colleagues (2008) examined the relationship of dyslexia and
dyscalculia as they apply to working memory according to Baddeley’s (2000) model.
These researchers took this working memory approach to understanding learning
disabilities because many children with specific learning disabilities struggle to acquire
the basic skills of reading, math, and writing from the beginning of their education. Even
after special services and remediation of the school work, some students still have
enduring learning disabilities that remain unexplained. For example, researchers
(Schuchardt at al.) found that children with reading disabilities have significant
impairments in their phonological loop, as the children who had reading disabilities
averaged lower scores on all seven phonological measures used in this study. Additionally, children with math disabilities scored markedly lower on measures of the visuo-spatial sketchpad (Schuchardt at al.). This is an important finding because of its relevance for potential interventions to help these particular children. It also helps explain why conventional approaches to commonly seen learning disabilities are not always effective.

In another study involving reading comprehension and working memory, researchers found that poor reading comprehenders’ deficits were associated with specific difficulties in participants’ ability to update working memory, particularly in controlling information that is no longer relevant (Carretti et al, 2005). This provides evidence that updating in working memory is related to updating in reading comprehension, specifically in which information to recognize as newly relevant versus not necessary to maintain. Carretti and colleagues found that good comprehenders had better working memory updating abilities, but not necessarily overall working memory capacity. This has implications related to measuring working memory and suggests that broad working memory span tasks do not necessarily provide the most useful information.

**Working Memory and Attention**

Kane and colleagues (2006) investigated the attentional component of working memory and found that those with high working memory spans were less distractible. Even on simple attention control tasks that do not heavily tax memory, high span individuals outperformed low span participants, especially when inhibition of a habitual response was necessary. This is consistent with other literature, which suggests that there is some overlap between the different domains within the central executive (Miyake et
Researchers concluded that the executive component of attention was accounting for working memory span differences, whereby the attention component also controls other cognitive tasks (Kane et al., 2006).

Other research in the realm of attention and working memory capacity suggests that individuals with shorter working memory spans also have lower attention control and focus their attention at a slower rate than those with high attention control as measured by speed and accuracy of responding on tasks (Heitz & Engle, 2007). These researchers related the results to executive control in general, suggesting that inhibition is also playing a role, as this can predict the rate at which one will focus attention. The findings provide support that inhibition may play a key role in attention as well, which supports previous findings involving the contributions of inhibition and attention on working memory (Barkley, 1997).

In an ongoing longitudinal study (Friedman et al., 2007), early attention problems were investigated to the extent that they affect later executive function abilities. Results suggest that early attention problems can have serious implications for executive functioning and that attention problems are differentially related to the three executive functions later in life (Friedman et al., 2007). Attention problems that arise at different times will differentially effect the development of subsequent executive functions suggesting that the executive functions mature at different developmental stages and at different rates. It was found that consistent lower levels of attention problems at a young age could significantly predict better inhibition and updating abilities, as well as IQ performance, compared with those who exhibited attention problems (Friedman et al.). This is consistent with other findings (Barkley, 1997; Heitz & Engle, 2007; Kane et al.,
2006) and supports Barkley’s argument that ADHD results from response inhibition. However, this study could not determine whether executive function ability led to poorer attention, or poor attention led to executive functioning deficits, again a limitation of correlational research. The direction of the executive functioning-attention relationship is still up for debate and serves as an example of where more research is needed.

**Working Memory and Intelligence**

As discussed previously, working memory has a strong relationship with intelligence and thus serves as a fruitful expansion of typical methods of measuring cognitive abilities (Conway et al., 2005; Dunlosky & Kane, 2007). Researchers assessed strategy use in completing working memory tasks, and found that differences in effective strategy use existed in those with low and high cognitive abilities, which also correlated with performance on the span task (Dunlosky & Kane, 2007). This implies that those individuals with higher cognitive abilities tended to use more efficient strategies while completing the working memory task, and thus performed better. The ability to select efficient strategies to use was correlated with the individual’s ability to perform these tasks and has implications for how that person approaches other cognitively demanding tasks.

Due to correlational results, strategy use as being the cause versus strategy use having an effect could not be empirically concluded (Dunlosky & Kane, 2007). Strategy as a cause suggests that individuals may be more strategic across span tasks thus causing better working memory span; whereas strategy as an effect is exemplified by innate differences in working memory capacity accounting for strategy use or available resources. Participants with high working memory benefitted little from instruction to use
strategy, where as those with low span show marked improvement when told to use a strategy. Additionally, those with low working memory span could not use more sophisticated, demanding strategies although those with higher working memory spans readily used the advanced strategies. These findings support strategy as effecting working memory, where having additional working memory resources to allocate to the task allow for better, more sophisticated strategy use (Dunlosky & Kane).

Conway and colleagues suggest that working memory span tasks share a significant amount of variance with intelligence and purport that working memory ability is stable across the lifespan, similar to IQ (Conway et al., 2005; Friedman et al., 2008). This is an interesting, and somewhat problematic, view of working memory as it implies that working memory is not amenable to change or improvements through intervention. Working memory and IQ may be stable throughout the life span, but if a person is not employing efficient uses of working memory, research (Lehmann & Hasselhorn, 2007) suggests that the person can learn new ways to organize information. Other findings suggest that working memory span can be changed by giving the person suggestions for improvement, such as compensatory strategy use (Dehn, 2008; Dunlosky & Kane, 2007). These findings have implications for intervention approaches and give hope for the potential to improve working memory.

Associated Abilities Conclusion

Working memory has been relatively useful to almost all areas of psychology as it has been associated with cognitive, social, clinical, educational, neuropsychology and developmental psychology (Conway et al., 2005). Since working memory has foundations in areas of intellectual functioning and academic achievement, it is an
important construct to study and understand. However, most of the research in the area of working memory has been done with adults, which makes it difficult to extend findings to children for various reasons related to developmental issues. Executive functions and working memory abilities occur at different ages, at various developmental stages, at varying rates, and in unique ways in individuals. Understanding the developmental trends associated with higher order cognitive skills helps shed light on ways to appropriately measure these abilities and constructs in young children.

**Development of Working Memory**

Brain development and cognitive maturation early in life is critical to a person’s later executive functioning abilities, including the skills associated with working memory. The brain undergoes significant amounts of transformation as it develops. Early abilities develop into the higher order executive functions, such as working memory. At the core of brain functioning lies neurons and their differentiation into certain roles. This prepares the brain to manage all the functions life will demand of it. Memory and learning are direct results of the brain’s ability to receive, consolidate, interpret, store, and access information contained within it. These higher order processes start as very basic abilities in infancy, develop over time, and eventually interact to have the capacity to perform demanding and sophisticated cognitive tasks (Miller & Blasik, 2009). The basic foundation of these skills is typically present by school age (Garon, Bryson, & Smith, 2008; Wolfe & Bell, 2007). Later skills of information input, processing, and retention are impacted by the early executive function abilities because these basic skills are precursors of the highly organized and interactive executive functions.
Early forms of the executive functions begin to develop in infancy, starting with emotional regulation (Garon, Bryson, & Smith, 2008; Wolfe & Bell, 2007). Emotional regulation is believed to be a precursor to the more advanced cognitive skills such as problem solving, attentional control, mental manipulation, planning, and organizing information. Emotion regulation and cognitive control organize behavior by modifying how a child acts, thinks, and learns at a young age. In infancy and early childhood, brain activity associated with individual differences of frontal lobe functioning has been found to have correlates with working memory and inhibition control (Garon et al., 2008). Even at a very young age, there is likely some amount of controlled, effortful integration of cognition and regulation that constitute the foundation of the later, higher order cognitive skills as these skills are all associated with the frontal lobes (Wolfe & Bell).

Research findings suggest that working memory develops gradually over the first 3 years of life, and then has a spurt around the preschool age when the executive functions begin to integrate information automatically (Cowan et al., 2003; Garon et al., 2008). Both auditory and visual stimuli tasks have been used with young children and similar increases can be observed whereby children can be successful on increasingly complex tasks (Garon et al., 2008). Additional research suggests there is another increase around age 7, at which point children’s ability more closely resembles that of adults. By about age 14, the differences between children and adults working memory abilities are minimal (Gathercole & Pickering, 2000).

In a study by Gathercole and Pickering (2000), results indicated there was an overall difference between six-year-olds and seven-year-olds ability to perform common working memory tasks. Younger children may not possess the ability to rehearse
information, as this is considered a skill that is developed as a child matures and reaches approximately age seven (Gathercole & Pickering, 2000; Lehmann & Hasselhorn, 2007). These researchers based findings on developmental abilities and trends in children. This suggests that young children are beginning to fine tune their executive function and working memory skills when they begin school, but that there is room for improvement as the individual develops and matures.

As working memory develops, so do the strategies which children utilize (Bjorklund, Dukes, & Brown, 2009; Cowan, Saults & Morey, 2006). “By definition, strategies are effortful mental processes, consuming some portion of a person’s limited mental resources for their execution” (Bjorklund, et al., p. 159). As children mature, so do the means by which they process, organize, and access information. When compared to seventh graders, third graders had similar levels of mental effort exhibited during a dual task. However, the third graders were unable to improve their free recall on a task involving a trained strategy component. This suggests that although they were aware of the strategy and exhibited delay in responding when trying to use it, they were not able to utilize the strategy efficiently during the free recall task (Bjorklund et al.).

Other research has found similar, naturally-occurring skill acquisition. Cognitive development relies on physical, structural brain properties, specifically, the maturation of the fronto-parietal working memory systems (Keage et al., 2008). This study found three discrete developmental stages. Brain activation location improved around age 9, at age 12, and an additional increase around age 16. Researchers also found that 65% of variance within group membership was accounted for by age (Keage et al.). This
provides additional support of developmental changes in brain functioning that may account for behavior and performance on tasks.

Using Baddeley’s model of working memory as a guiding force for research, Hamilton, Coates and Heffernan (2003) investigated the visuo-spatial slave system development of 6-13 year olds by incorporating an interference component that affected the phonological loop. The researchers found that verbal tasks interfered with visual tasks and vice versa, suggesting central executive involvement in young children. Also, children increasingly tended to integrate activity of the visuo-spatial and phonological working memory components to help remember information from the environment. As they mature, so does their ability to integrate information from these two systems. This suggests that the individual slave systems do not only improve over time, but also the two systems interact more effectively with the central executive which allows for increased working memory ability (Hamilton et al.). Interventions that include the integration of both visual and auditory input may be beneficial in later recall.

Psychological research suggests that the development of executive functions and working memory abilities seem to happen in spurts. This is similar to what has been recently observed with neurophysiological research (Keage et al., 2008), whereby there is a gradual increase in ability, and then a significant jump over a period of 1-2 years. This suggests there are particularly active periods of development (Brocki & Bohlin, 2004; Garon et al., 2008). Different executive tasks had significant developmental improvements at different ages. This suggests different developmental trends for different executive functions, and is consistent with other research results (Garon et al., 2008; Keage et al., 2008; Garon et al., 2008).
Much of the working memory research that exists addresses working memory in adults or college age individuals, neglecting to measure working memory in school age or preschool age children. It is important to study working memory as it applies to children because of the implications it has for education and development (Cowan et al., 2003). Findings in developmental research suggest that there is a significant amount of variability between individuals at each stage of maturation, which has implications for the wide range of developmental trajectories (Keage et al., 2008). In recent years, research in the area of young children’s working memory has been increasingly prominent with the development of age appropriate measures.

**Working Memory Assessment**

Human memory and learning is an extremely complex and difficult entity to measure because neural circuits are dynamic and changing with regard to memory and learning (Bruel-Jungerman et al., 2007). There is some uncertainty about how to measure working memory in developmentally appropriate ways in regard to children. Small children present with challenges that adults do not. For example, studying inhibition in children younger than five years old can be affected by their ability to understand the procedure demand of the task (Tillman et al., 2008). Tasks that involve motor movement, but are aimed to provide an estimate of response time, may be affected by the child’s motor coordination. Additionally, there is often significant overlap between executive processes, such as a child’s attention deficits interfering with a measure of updating, creating an impure assessment (Friedman et al., 2008). Keeping these challenges in mind, working memory tasks have been adapted to use with children with the intent to avoid some of the common errors associated with unwanted variance (Garon et al., 2008).
Much of the research that addresses executive functioning and working memory tend to lack ecological validity (e.g. Friedman et al., 2000, Oberauer, 2002). These studies that focus on assessment in a controlled setting may not translate to other environments, specifically the school environment. Further, the assessments may be measuring different processes. General working memory and executive function assessment tools do not all measure the same process or component, but rather, different pieces of the larger construct. For example, some tasks may focus on the attention demands rather than the storage ones, as well as the reverse, focusing on storage demands and thus neglecting the attention type demands (Conway et al., 2005). Oberauer (2002) found that similar tasks can have different demand levels on “storage”, tapping the phonological store or visual cache, versus “processing”, tapping the articulatory control and inner scribe. Tapping both of these is ideal; having measures which assess both the storage and attention components creates a better representation of the working memory system.

Research also suggests that in order to understand many of the working memory difficulties in sufficient and useful ways, batteries of assessment tasks should be used to gain this information (Friedman et al., 2008; Gathercole & Pickering, 2000; Miyake et al., 2000; Schuchardt et al., 2007). Although these batteries provide valuable information, they are often time consuming. Examining the components of working memory (phonological loop, visuo-spatial sketchpad, episodic buffer) and central executive (inhibition, shifting, updating) with a theoretical perspective helps focus attention on the specific processes within the working memory system. With a theoretical base, assessments have the potential to be fruitful in the information provided. Although this is
not necessarily the norm at this time, more researchers have been taking this battery approach to assessing working memory. The batteries that do exist are lengthy, with some taking over three hours for adults to complete (e.g. Friedman et al., 2008).

**Assessing the Phonological Loop**

Using Baddeley’s multi-componential model as a framework, many studies have assessed the individual components with various measures (Alloway, Gathercole, Willis, & Adams, 2004; Miyake et al., 2000) The phonological loop has been researched and studied in depth, using measures such as listening span tasks. Tasks that are presented in auditory form activate the phonological loop, potentially both the articulatory control and phonological store, and the central executive must then become involved to manage the information. Tasks that assess the phonological loop typically consist of presenting an individual with some auditory information to be temporarily stored and reported. Examples of these tasks can involve numbers, words, non-words, and/or sentences (Alloway et al., 2004).

Researchers have adapted tasks from adult measures of working memory assessment for children, thus allowing research to extend to younger ages (Garon et al., 2008). After about three years of age, children are able to complete most working memory tasks as they have the basic abilities of developing executive functions necessary to carry out the tasks. Tasks such as digit span can be used, which is a measure of the phonological loop. These span tasks can be found on the assessment tools such as the WISC-IV (Wechsler, 2001), TOMAL-2 (Reynolds & Voress, 2008), and WJ-III (Woodcock, McGrew, & Mather, 2001). When additional mental tasks are added, such as
categorizing words while listening to them and tapping when certain words are heard (Carretti, Borella, & DeBenni, 2007), the task begins to incorporate the central executive.

Assessing the Visuo-spatial Sketchpad

Measuring the visuo-spatial sketchpad involves visual information and the storage, manipulation, and recall of what was presented. The visuo-spatial sketchpad recognizes both visual information and spatial information; the central executive integrates these two pieces of input (Hamilton et al., 2003). One visuo-spatial task is Corsi blocks. The blocks are attached to specific locations and are tapped by the examiner in a predetermined order. The child has to repeat the sequence in the same order as the examiner by tapping the blocks, or tapping the blocks according to some other directive (Stanford Binet-Fifth Edition; Roid, 2003; Garon et al., 2008). Other measures of the visuo-spatial sketchpad can include mazes (Hamilton et al., 2003) or matrices (Gathercole & Pickering, 2000; Korkman, Kirk, & Kemp, 2007; NEPSY-2; Unsworth & Engle, 2008). Participants are required to recall the location, movement, and/or changes after viewing the stimulus (Gathercole & Pickering; Unsworth & Engle). These tasks involve the integration of visual and spatial information to be stored and recalled, which is integrated with the help of the central executive.

Another task which assesses the visuo-spatial sketchpad can be found on the TOMAL-2 (Reynolds & Voress, 2008). In the Memory for Location task, participants are presented with a matrix of dots on a grid. The participant must then remember the location of the dots and reproduce the pattern on a blank grid once the stimulus has been removed. This particular assessment is administered by allowing the participant to look at a matrix of dots for a predetermined length of time, with part of the matrix filled and part
of it unfilled. Once the time has elapsed, the image is removed and the participant is a blank matrix where he/she is to place bingo chips in the correct location. This subtest is scored based both on location accuracy.

**Assessing the Episodic Buffer**

Measuring the episodic buffer has been done using tasks of operation and reading span (Dunlosky & Kane, 2007; Engle et al., 1999; Kane et al., 2004), but these tasks are not necessarily appropriate for young children. Operation span is done by presenting participants with a math equation that had an answer written and a word. The participant is supposed say whether the answer provided is correct or incorrect, activating the episodic buffer. They also had to remember the word that was at the end of the equation. Reading span tasks are similar to operation span tasks. Participants are presented with sentences to read and followed by a single word to be remembered. After several sets of this, two to five, the participant must recall all of the words in order for each of these tasks (Engle et al., 1999). This may be difficult for young children who are just learning how to read or add. Engle and colleagues also used a counting span task. In this task, participants had to count the number of dark blue circles, when presented with dark blue circles, light blue circles, and dark blue squares. They were to count out loud the number of dark blue circles and then continue to the next set where they immediately started counting out loud again. After a pre-determined number had been presented, participants had to recall the number of blue circles in each set in order. This is likely more useful with children.

Controlled Oral Word Association tasks, such as the Word Generation subtest on the NEPSY-2, are measures of the episodic buffer (Korkman, Kirk, & Kemp, 2007). In
these tasks, the participant is given a pre-determined length of time to name as many items as he/she can which adhere to a category. The individual is given the category immediately before the timing starts. This task is related to the episodic buffer because the attentional component of attention to category must be acknowledged while accessing previous knowledge. This is an appropriate measure with children as assessment batteries have norms that extend to young children.

**Assessing the Central Executive**

The central executive is typically measured through the either the phonological loop, visuo-spatial sketchpad, or through both. The tasks already mentioned tap the central executive, as it is involved in the interpretation of the information and controls attention to the task. The central executive is responsible for allocating attention, focus, and control of mental processes. Moving into the fractionation of the central executive by Miyake and colleagues’ (2000), inhibition, shifting, and updating have been studied as they individually contribute to the central executive’s ability to manage information.

**Assessing inhibition.** Inhibition is commonly studied via the Tower of Hanoi, or Tower of London, task as well as the anti-saccade and stop-signal tasks (Friedman et al., 2008; St. Clair-Thompson & Gathercole, 2006). Each of these requires some level of inhibition of an automatic response. The tower tasks also involve planning and organizing thoughts before acting, so they are not necessarily a pure measure of inhibition. The anti-saccade task requires a person to not look as a dot/stimulus when it flashes on a computer screen. The stop-signal task involves two sets of trials. In the first set, the participant learns how to categorize things, such as living vs. nonliving. In the second set, the participant is to do the same thing, but inhibit the categorizing when given
a particular signal (Friedman et al., 2008; St. Clair-Thompson & Gathercole, 2006). This can be done with small children and is an appropriate measure of inhibition.

The Conner’s Continuous Performance Task (CPT-II) is used to measure inhibition, as well as sustained attention, and is often used as part of a comprehensive assessment in the diagnosis of ADHD (Connors, 2002). The CPT requires an individual to respond as quickly as possible to visual stimuli on a computer screen by clicking a designated button. The individual is to do this for every stimulus except one, the letter X. The individual’s ability to stop themselves from clicking when an X appears on the computer screen is a representation of their ability to inhibit themselves in general.

The most common psychological task associated with inhibition is the Stroop task (Miyake et al., 2000; Fagot, Dirk, Ghisletta, & Ribaupierre, 2009). This is a task that involves reading a list of color words printed in various colors where one has to suppress the tendency to read the color word, and instead has to say the color the word is written in (Stroop, 1935). Because reading is an over-learned skill, disregarding what one is reading involves purposeful cognitive inhibition of responding. This internal control of overriding the automatic response is associated with executive functioning and is also linked to the frontal lobes (Miyake et al.). However, using this as a measure of inhibition in young children may not be valid because they may not have those over-learned reading skills that adults do. The Stroop task has been adapted in ways the incorporate the same concept. For example, children can be presented with pictures of a sun and moon, but need to say “night” when they see a sun and “day” when they see a moon (Garon et al., 2008). However, Fagot and colleagues conducted a study in which children ages 10-12 were used where it was supported that the Stroop is appropriate to use with children as a
measure of inhibition, and does, in fact, assess inhibition in a way that is consistent and valid.

**Assessing shifting.** Measuring shifting can be done through tasks that involve switching mental sets in order to complete some task such as the Wisconsin Card Sorting Test (Hartman, Bolton, & Fehnel, 2001). The Wisconsin Card Sorting Test is a widely used neuropsychological test assessment that requires participants to sort cards into four piles using feedback from the examiner. The examiner responds ‘correct’ or ‘incorrect’ according to the current sorting rule. When the sorting rule changes, the participant must mentally switch the way they sort the cards. Their ability to change their approach and incorporating the new sorting rule into their behavior is indicative of their mental flexibility (Hartman et al., 2001). Although this is challenging, this task can be used with children and is an appropriate measure of the shifting executive function within the central executive component of working memory.

Other shifting measures are number-letter, color-shape, category switch, and Trail Making Test-B (Friedman et al., 2008; Miyake et al., 2000). Each of these involves a switching of function to be applied to presented stimuli, such as switching between following a sequence of letters and a sequence of numbers on the Trail Making Test-B. Another example of set shifting is switching topics for categorizing presented words according to some other piece of information. Number-letter shifting involves a number-letter or letter-number pair where the participants need to indicate whether the number was even or odd when it appeared at the top of the screen, and whether the letter was a consonant was a consonant or vowel when it appeared at the bottom of the screen (Friedman et al.).
Color-shape shifting involves a cue letter indicating whether to say the color or shape of the colored shape on the screen. Category switch is classifying words as living or nonliving if the word is accompanied by a plus sign, or to classify the same word as bigger than or smaller than a soccer ball when the word is accompanied by a circle (Friedman et al., 2008). In this instance, the person has to switch between two different “sets”, dead or alive and bigger or smaller, of organizing information, but does not know in advance how they will be asked to classify each word. The number-letter, color-shape, and category switching are appropriate and useful for assessing children.

**Assessing updating.** The third fractionated component of the central executive of working memory is updating. Updating has been measured with tasks such as the running-memory span task. In this particular task participants are presented with a list or words of unknown length and are required to recall only the last n items; the n changes, typically between two and five items (Conway et al., 2005 as used by Pollack, Johnson, & Knaff, 1959). This was originally presented as a letter memory task by Morris and Jones (1985) where participants were presented lists of letters which varied in length, where they had to replace the three or five most recently presented letters. Participants only remembered the most recent n letters and continually adjust their rehearsal list, once the list they were to remember is greater than n they must drop other, previously rehearsed letters.

Another assessment of updating that has been used in research is the spatial two-back task (Friedman et al., 2008). This involves a presentation of a series of spatial oriented objects where the participant has to indicate if the special location of the object is the same location as two trials back. This was an adaptation of the n-back task, a task
that has been considered the “gold standard measure of working memory capacity” (Conway et al., 1999). In this task subjects are given matrices of numbers and are asked to retain numbers to recognize whether the current number is the same as a number presented "n" numbers prior (Conway et al., 1999; Verhaeghen et al., 2004).

Assessment Conclusion

Accurately measuring psychological constructs is related to the validity of the test measures. “Validity is an overall evaluative judgment of the degree to which empirical evidence and theoretical rationales support the adequacy and appropriateness of interpretations and actions on the basis of test scores or other modes of assessment” (Messick, 1995, p. 741). Reducing the error associated with tasks improves the validity and utility of the measures and results. Understanding what the scores mean, what they mean in context of working memory theory, and what the scores mean in relation to what is being measured is all part of the assessment’s ability to accurately assess the construct it claims to. The validity of measures is beginning to be established in regard to measuring working memory and executive functions in children. This suggests that researchers can make meaningful inferences about the cognitive processes and can therefore begin to understand them in the context of other abilities.

Many of the working memory assessments have been correlated with learning, academic achievement, and reading comprehension (de Jong & de Jong, 1996; Schuchardt et al., 2008; Swanson, 1994), attention deficits such as those found in children with ADHD (Barkley, 1997; Heitz & Engle, 2007; Kane, Poole, Tuhulski, & Engle, 2006), and intelligence (Conway, Kane, Bunting, Hambrick, Wilhelm et al., 2005). This is in addition to working memory’s relation to various other tasks involved
everyday activities that are essential to benefitting from a learning environment (Ashcroft & Kirk, 2001; Gevins & Smith, 2000). With increasing research devoted to measuring working memory and executive functions in children, there lies the possibility for using this information as a potential approach to assessing intervention application.

**Working Memory Interventions**

There has been much research on the capacity and measurement of working memory and associated abilities, but there is still a paucity of research targeting how working memory performance can be improved (Carretti et al., 2007). Studies suggest that working memory capacity is limited, the limit is not exact, and this should not imply that working memory cannot be enhanced or improved with effective interventions and strategies, such as mnemonics training (Bjorklund et al., 2009; Dehn, 2008). Intervening at the level of working memory processes can potentially have implications in relation to some or all of the areas associated with working memory, including academic performance and achievement.

Interventions can take place at three different levels of skill: acquisition, fluency and generalization. Acquisition refers to learning a new skill or set of skills. Prior to the intervention, the child does not have the skill and thus acquires it via the intervention. The second level a skill falls into is that of fluency. Now that a child has a skill, he/she ought to be able to perform that skill with speed and accuracy. At this point, a time factor is critical. A child may possess a skill, and with unlimited time, there is no apparent change. Timing the skill is imperative at this level. Finally, there is the end goal of generalization. This is what the ultimate goal of most interventions is, that a child can eventually use the skill and fluency as it applies to novel situations. Although
generalization is associated with the most lasting results, it is often ignored (Ardoin et al., 2008).

Performance on working memory tasks can take place in relation to capacity, efficiency, and the interaction of the related processes (Dehn, 2008). Capacity is thought to be innate and limited. Research suggests that executive functions and working memory abilities are genetic and stable over a lifetime, similar to intelligence (Conway et al., 2005; Friedman et al., 2006; Friedman et al., 2008). However, there has been other research which suggests that these cognitive skills are, in fact, malleable and can be improved through intervention (e.g. Klingberg et. al, 2005; Verhaeghen et al., 2004). The claims that working memory is amenable typically refer to increasing the efficiency and interactive processes associated with working memory whereas those who believe that working memory is stable refer strictly to capacity (Dehn, 2008).

Posner and Rothbart (2005) state that neural networks “are shaped by genes, but can also be influenced by specific experiences such as educational interventions” (p. 102). However, much of the research which does exist is mainly in adults (Buschkuehl, Jaeggi, Hutchison, Perrig-Chiello, & Dapp et al., 2009; Verhaeghen et. al., 2004), people with traumatic brain injuries (Cicerone, Levin, Malec, Struss, & Whyte, 2006; Duval, Coyette, & Seron), and/or those with other deficits such as ADHD or mental retardation (Conners, Rosenquist, Arnett, Moore, & Hume, 2008; Klingberg et al., 2005). Interventions have been focused on building compensatory strategies for population which exhibits working memory deficits (Dehn, 2008), but have not investigated the implications working memory interventions can have on individuals who do not exhibit significant difficulties.
Interventions with Adults

Verhaeghen and colleagues (2004) were able to train five adults on a working memory task. In this study the n-back task was used as an assessment of working memory ability. The n-back task involves the participant being presented with a set of numbers, presented one at a time, where the participant is supposed to indicate whether the current number is identical to the n\textsuperscript{th} number back, requiring focus of attention and updating. Researchers used a 1-back through 5-back to test the limits of the ability to recall a certain number back and to examine improvements or changes over time. They found that there was a decrease in response time as well as an increase in accuracy after practicing this task over ten one-hour sessions. Thus, the ten hours of training indicated working memory improvement (Verhaeghen et al.).

These results have several implications (Verhaeghen et al., 2004). First, it suggests that working memory can be expanded through practice. However, this may be due to simply practicing the tasks so that it becomes cognitively less demanding. When tasks become learned, attentional demands decrease, and thus more executive function and cognitive resources become available for other tasks (Engle et al., 1999). Also, the participants only practiced and were assessed by the same specific task, which does not suggest any transfer effects to other areas. It is not known whether this working memory training had an effect on other working memory related skills. Although this particular study is promising to the extent that working memory can be improved, it does not provide any evidence that training has an effect on any real life skills.
Interventions for Patients with Traumatic Brain Injuries

Researchers have focused on groups of people with deficits, such as those with traumatic brain injuries. Cicerone and colleagues (2006) suggest that when working with patients with traumatic brain injuries, there are often deficits associated with executive functions that have the potential to benefit from intervention. In one study (Duval et al., 2008) that used a cognitive rehabilitation approach with a traumatic brain injured patient, application of learned skills to real life situations was a focus. Researchers worked with a single adult who had suffered from executive function deficits, as well as working memory deficits, from an acquired brain injury affecting the frontal lobe. In this intervention, there were two stages: one for the training of specific skills and one that used those skills in practiced real-life situations. This study demonstrated improved working memory and executive function abilities, and that these carried over into real life situations. In addition, three months later, the improvements remained undiminished (Duval et al.).

This finding is hopeful for those with working memory deficits related to acquired brain injuries, but may not have the same effect on those without a brain injury or may not be applicable to children. In addition, this particular intervention took place over several weeks and involved the direct one-on-one involvement of a therapist who supported the participant at each level of the intervention program (Duval et al., 2008). This may make the intervention difficult to replicate with children or large groups of people and may have a high cost of time compared with the improvements; however, this is not known at this time.
There are particular strategies used in the intervention program for traumatic brain injury which provide insight to other potential interventions (Duval et al., 2008). The dual encoding strategy taught the participant to activate both the phonological loop and visuo-spatial sketchpad simultaneously to increases chances for storage and recall. This is a skill that can be taught to a group of children, and have implications for learning in the classroom. Dual encoding is also discussed in a chapter by Dehn (2008) as an appropriate intervention and provides a basic outline of how to apply this strategy with children.

Two other simple strategies that were implemented in the Duval et al. (2008) study are the serial work strategy and the speed reduction strategy. The serial work strategy suggests that the participant should encode all presented information before manipulating it. The speed reduction strategy stressed the quality of performance rather than the speed, with the pace of response increasing once the skill is learned (Duval et al.). These strategies have not been used with multiple participants or with children, but they provide intervention strategies which may be useful with young populations.

**Interventions for Attention**

Engle and colleagues (1999) suggested that when tasks become familiar, attention resources are lessened which creates availability of additional cognitive resources. Researchers have concluded that the executive component of attention can account for working memory span differences, whereby the executive component also controls other cognitive tasks (Kane et al., 2006). Other research results suggest that early attention problems can have serious implications for executive functioning later in life (Friedman et al., 2007). So, Klingberg and colleagues (2005) investigated attention training in
children with a clinical diagnosis of attention deficit hyperactivity disorder and found that attention training can improve performance on working memory tasks.

Researchers used a computer based interactive intervention that was designed for the study (Klingberg et al., 2005). This computer program adjusted its difficulty level based on the individual child’s performance, thus individualizing the intervention experience of each child. The pre and post measure was a visuo-spatial task. The computer based training increased the performance of those children who underwent the training compared to controls who received a less-effective computer game program. Additionally, the parents of those children who received the training program reported significantly less attention and hyperactive symptoms. These results have implications for the transfer effects of working memory intervention. However, the entire group of participants was children with attention deficit hyperactivity disorder at very high levels, providing substantial room for improvement. In addition, these children had parents who allowed them to use the computer program in the home. So, for example, the same improvements in working memory may not be found in children who do not already exhibit significant attention problems. This is an area that could have the potential to help children with working memory deficits related to other executive functions, but at this time it is not known.

**Intervention for Children with Down syndrome**

In a study of children with Down syndrome who had working memory deficits, an intervention program was used to improve their performance on working memory tasks (Conners et al., 2008). The intervention in this study was a home-based parent implemented one, which took place over one or two three-month periods. Results
concluded that these children were able to improve their working memory in limited ways, such as verbal working memory and language comprehension. Although the improvements were small, there was some improvement in specific working memory areas especially on tasks that were similar to the training activities. So transfer effects were minimal, but existent. This study was done with children who had deficits beyond the scope of working memory. Results should be viewed as providing further evidence of working memory malleability rather than suggesting that interventions may not be beneficial outside the scope of the study.

**Interventions Incorporating Strategy Use**

Other researchers have investigated strategy use (Carretti et al., 2007; Dunlosky & Kane, 2007; Lehmann & Hasselhorn, 2007) and its effect on working memory ability. Efficient strategy use has been correlated with better working memory skills. This may be because more skilled memorizers naturally create mnemonic devices that help to encode information into long term memory in a way that facilitates efficient retrieval through associated cues (Carretti et al.). A child’s ability to learn the skill, become efficient at using it, and then apply it to novel situations may be dependent upon their age, ability level, or some combination of these and other factors. Whether or not working memory strategy skills can be taught to, and thus used by, those who are less proficient at recalling information has been the focus of current research.

Carretti and colleagues (2007) found that older adults were able to learn strategies to improve their working memory ability level and perform better on related tasks. Their training consisted of five sessions that took place over two weeks. Using a control group who did the same exercises but did not receive instruction on strategy use, researchers
found that teaching the strategies to participants and allowing them to practice the strategy significantly increased their performance on the post assessment. This is exciting because it provides evidence for the potential to improve working memory ability. This technique was not used with children in the study, but may be able to be done with children in the future.

Lehmann and Hasselhorn (2007) studied children’s strategy use as it happens as a developmental process where young children use basic or no real strategy and they naturally learn to use strategies, such as rehearsal. The ability to rehearse information at a sub-vocal level is a skill that develops naturally around age seven (Gathercole & Pickering, 2000). Teaching a child to utilize rehearsal may be possible at a younger age, and can help children thus begin to use more advanced strategies such as developing mental images of words (Dunlosky & Kane, 2007). This finding has been supported by other studies (e.g., Cowan et al., 2006), suggesting that children develop strategies naturally as well as can benefit from strategy building.

Dunlosky and Kane (2007) investigated strategy use in undergraduates. Participants reported on which, if any, strategy they used to complete an operation span task. The operation span involves a math equation and a word to be remembered. The task requires participants to assess a math equation for accuracy and remember the word for several trials, and they need to recall the words in order at the end of the set. Those participants with better working memory abilities reported using advanced strategies spontaneously, whereas those who did not do as well on the operation span task did not employ such strategies. When prompted to use a particular strategy, participants were able to improve their performance (Dunlosky & Kane). This has implications for teaching
strategy use and then reminding people to use the strategies when necessary. Children may not automatically know how to meaningfully connect information or use imagery, but they may be able to learn to use these strategies with teaching and prompting.

**Mnemonics.** One strategy which has gained empirical support is mnemonic strategy building interventions. These mnemonic strategies teach individuals to find ways to “enhance the meaningfulness of the material to be remembered, thereby facilitating learning” (Dehn, 2008, p. 280). This strategy helps improve both the encoding of information as well as the retrieval of it by providing meaning, integration, and structure to information that may seem to lack meaning to the learner. There are several mnemonic strategies, many of which are especially appropriate for young children. The most researched of these mnemonic strategies is the Keyword Method (Dehn). This strategy helps child to incorporate both visual imagery into the verbal information and is especially appropriate when children have little background knowledge from which to connect the new information. This dual encoding is similar to what has been used in other studies (Duval et al., 2008).

In the initial stage of teaching this strategy, the child is provided with concrete examples of how to connect the material to a more meaningful object. It has been found that the more individualized and personal the mnemonic is to the individual, the stronger it is in facilitating the learning of new information. Eventually the child learns to create the representation independently and begins to use it in novel situations. After the knowledge is learned, the mnemonic is phased out and the schema of that knowledge base is formed, allowing for easier integration of new information into the individual’s existing knowledge base. This type of intervention can be taught with the intent to help
the child learn to use their own methods for creating ways to integrate their own learning and applying it to new, challenging situations.

This particular approach to remembering information taps both the phonological loop and the visuo-spatial sketchpad. It gives children a concrete way of integrating the two systems; a skill they may not have developed yet (Bjorklund et al., 2009; Cowan et al., 2006). It has been suggested that when these two modalities work together, the overall outcome performance is enhanced. It also provides individuals with multiple modes from which to recall information, creating more opportunities for later recall accuracy and episodic buffer efficiency (Hamilton et al., 2003).

In a meta-analysis of mnemonic interventions, Verhaeghen and colleagues (1992) found that there were large effect sizes across the many studies. This indicates that mnemonics have the potential to improve skills. However, it is not known if these changes are applied in meaningful ways. It is also not known what types of changes are taking place. Dehn (2008) suggests that mnemonics are a compensatory strategy for individuals with deficits in working memory. However, this is speculation. Mnemonics improve skills associated with working memory, but there is no research regarding how mnemonics work or what processes are affected by such an intervention. It is not known whether mnemonics are solely compensatory or if mnemonics affect any of the processes within the working memory system.

**Transfer Effects of Intervention**

Dahlin and colleagues (2008) suggested that although there may be transfer effects to real world experiences, transfer does not take place within neural networks in the brain that were not directly linked to intervention techniques. Researchers used fMRI
to examine which areas of the brain were activated during two executive function tasks: updating and inhibition. They trained participants on updating tasks specifically, and obtained results that showed an increase in updating ability but did not affect inhibition. This has implications for how to approach interventions, suggesting that in order for someone to benefit from training, the training must incorporate multiple executive functions in order to see holistic improvement (Dehn, 2008).

Perhaps the most promising research involves the studies which suggest there are transfer effects that do take place after intervention in children (Thorell et al., 2009). Studies that address transfer effects to real life situations have used adult participants (Cicerone et al., 2006; Duval et al., 2008) or children with some other disability (Klingberg et al., 2005) and thus studies involving groups of typically developing children are limited. Thorell and colleagues studied the training and transfer effects within a group of preschool children. The children in the study were split into two groups. One group received the computer based visuo-spatial training system used by Klingberg et al. (2005) while the other group played computer games which were not designed to improve any skills. Both groups spent 15 minutes per day over the course of five weeks doing the training program or playing the computer game.

Pre and post measures were used to assess changes in ability level due to the visuo-spatial training in the study (Thorell et al., 2009). The children who received the training showed improvements on both visuo-spatial tasks as well as skills related to the verbal domain of working memory. The finding implies that training transfer effects were observed for trained tasks as well as non-trained tasks. This also suggests that when specific executive functions are improved, other areas of functioning can be positively
affected. This may be due to the reduced cognitive demands, allowing for more resources to become available.

**Intervention Conclusion**

Working memory and executive function intervention research does exist and has only recently begun to focus on young children. Most of the research within the domain of executive function intervention has involved training participants in a specific task and neglected to look at the application of the training to real life situations. However, even with this lack of ecological utility, studies have shown that participants can improve their working memory skills (Klingberg et al., 2005; Thorell et al., 2009; Verhaeghen et al., 2004). This is an exciting finding because it is evidence that skills at the foundation of many other abilities can be improved. However, most studies have not addressed the practical implications of such training and intervention.

The implications of interventions for working memory have the potential to benefit students in numerous ways. “However, this is still a relatively new area of research and it is for future studies to further investigate which cognitive functions can be trained and to what extent the effects of cognitive training can be generalized to other cognitive functions and behavior problems” (Thorell et al., 2009, p. 112). There is current support of many interventions as supplementing working memory, but there is a paucity of research dedicated to understanding what processes of the working memory system may be affected by interventions (Verhaeghen et al., 1992). For example, mnemonics have been investigated and found to be beneficial in improving academic skills, but there is no research that investigates what is happening to cause this change. Are mnemonics
truly compensatory or is this intervention able to free up cognitive resources and allow for improved performance of working memory components?
Chapter III

Method

The study used a working memory battery to investigate the effect of a keyword mnemonics intervention. Using Baddeley’s (2000; Baddeley & Hitch, 1974) model of working memory and Miyake et al.’s (2000) fractionation of the central executive, the working memory battery addressed each component of working memory as a separate construct. These components of working memory are the phonological loop, visuo-spatial sketchpad, episodic buffer where the central executive has been fractionated into inhibition, shifting, and updating (Baddeley; Miyake et al.). Hypotheses include improvements that could be seen in the working memory components.

This chapter outlines the specific manner in which this study investigated working memory and the intervention hypotheses previously discussed. First, the participants of this study will be discussed and described. Then, the measures used to operationalize each construct and assess each component of working memory executive functions will be addressed. Next, the procedure for administration of the measures used in this study is addressed, along with the data collection process. The keyword mnemonics intervention is outlined as it took place on each day of the intervention. Finally, the data analyses will be discussed as they will be used to examine the data.

Participants

Participants were recruited from eight fourth grade classrooms spanning two schools in a Pennsylvania school district. There were 55 students who participated, 25 males and 30 females. Most of the participants were either 9 (n=17) or 10 years old (n=37), with one 11 year-old at the start of the study. Each participant was assigned a
number for de-identification in the database, which was used as a means to keep track of each individual’s pre- and posttest information. School records indicated that all participants hearing acuity, visual acuity, and developmental status were assessed as these variables can have an effect on academic performance. Screening for hearing and visual impairments is part of school regulations and students who do not pass are addressed on an individual basis by the school. Exclusionary criteria for this study included a previous diagnosis of mental retardation, developmental disorder, an autism spectrum disorder, or uncorrected sight or hearing problems as these conditions would likely have a significant impact on the measurement working memory ability independent of other factors.

Participants were assessed using a working memory battery both pre- and post-keyword mnemonic intervention on an individual basis with one of the researchers. The individual assessment took approximately 25 minutes to administer. The mnemonic intervention took place across six 30-minute sessions spanning three weeks, with two sessions per week during the school day. This was a voluntary program for students to improve executive function skills associated with learning in school that was called the Memory Intervention and Neuropsychological Development (MIND) Program. Both parent permission and student assent were required to participate.

**Power Analysis**

Multivariate analysis of covariance (MANCOVA) is a statistical method that combines regression analysis and analysis of variance to provide information which lends itself to more accurate conclusions than a multivariate analysis of variance or analysis of covariance (Stevens, 2002). This is because covariates provide statistical control through
the reduction of within group variance (error) and elimination of systematic bias based on the covariate.

Before setting out to find participants, a power analysis was conducted to determine adequate sample size. The purpose of conducting an a priori power analysis is to establish the minimum number of participants needed to achieve pre-determined adequate power. Researchers who have done working memory interventions have had large effect sizes, larger than .90, and very small sample sizes (Carretti, et al, 2007; Verhaeghen et al., 2004). Verhaeghen and colleagues (1992) conducted a meta-analysis of mnemonic intervention studies where the groups included in the analysis had effect sizes around .70. Cohen (1992) categorizes the effect size of .40 for analysis of variance as a large effect for this type of analysis. With these studies in mind, the effect size used in the power analysis was set at .70, a large effect size. The power analysis was conducted using the computer program G-Power with an alpha level set at p=.0125 after the Bonferroni adjustment was made from the p=.05 level for three dependent variables in order to account for Type I error. This power analysis revealed a total sample size of 39, approximately two groups of 20, is required to have sufficient power in detecting the large effect size regarding the intervention.

Measures

This section describes the measures used to assess the phonological loop, visuo-spatial sketchpad, episodic buffer, and the three domains of the central executive: inhibition, updating, and shifting. Together, these measures represent a battery for the assessment of working memory components (phonological loop, visuo-spatial sketchpad, and episodic buffer) and the three domains of the central executive (inhibition, shifting,
and updating). A few of the measures are subtests from widely used psychological assessment batteries. Due to the relatively new introduction of the fractionation of the central executive, there is limited research targeting the three components of the central executive in children. Several measures used in this study have been adapted for children from previous studies and/or assessment tools which examine the same construct. Research supports the assessment tasks and makes recommendations for how to address the components of working memory in children (Friedman et al., 2008; Garon et al., 2008). For each construct assessed, there will be one measure utilized in this study; all measures are discussed in terms of description, reliability, and validity of the instrument.

**Phonological Loop**

The phonological loop of Baddeley’s (2000) working memory model can be assessed in a variety of ways. These tasks are commonly found on psychological testing tools used in everyday assessments. The assessment used to measure the phonological loop is the Digits Forward subtest found on the TOMAL-2 (Reynolds & Voress, 2008). This particular version of the digit span task is used because of its sensitivity to change. The Digits Forward subtest on the TOMAL-2 is scored based on individual digits correct to a ceiling, as opposed to an all or nothing scoring system, which is commonly found on other measures similar to this one. The accuracy raw score for Digits Forward was calculated as the number of digits the participant repeated in the correct order and place, as detailed in the TOMAL-2 examiners manual. This particular task measures the phonological loop as it relates to the storage component, rather than an active component. Participants are required to repeat the numbers verbatim. Using a split half method, the reliability for children ages 9-11 ranges from r=.96 through r=.96. The validity was
assessed under a two factor model, with one factor representing a general memory component and one factor representing an attention/concentration component. Digits Forward has a factor loading of .58 on the first rotated principal factor, with a factor loading of -.16 on the general memory factor and a loading of .82 on the attention/concentration factor (Reynolds & Voress).

**Visuo-Spatial Sketchpad**

The visuo-spatial sketchpad assessment being utilized is Memory for Location found on the TOMAL-2 (Reynolds & Voress, 2008). This assessment requires the participant to remember the location of dots on a black and white matrix board. Once the time has elapsed, the image is removed and the participant is given round bingo chips and a blank matrix where he/she is to place the bingo chips in the correct locations. This subtest is scored based on accuracy of location until a ceiling is reached. The accuracy score for Memory for Location was based on how many designs were recalled with one-hundred percent accuracy, which received a score of one. If any piece of the design was inaccurate, it was scored a zero, based on scoring in the examiners manual. Using test-retest as a means for reporting internal consistency, the Memory for Location has internal reliability for children ages 9-11 with levels ranging from .86 through .96. The validity was assessed under a two factor model, with one factor representing a general memory component and one factor representing an attention/concentration component. Memory for Location has a factor loading of .44 on the general memory factor and a factor loading of .17 on the attention/concentration factor (Reynolds & Voress).
Episodic Buffer

The Episodic Buffer assessment must be sure to tap working memory in a fashion which utilizes the present attentional factor of the working memory system with previous knowledge, as this is the episodic buffer’s role in the working memory system. One way this can be assessed is through a controlled oral word association task (Korkman, Kirk, & Kemp, 2007). The role of the episodic buffer in connecting the information to previous knowledge is implicated by the knowledge base of the category and one’s own vocabulary. The measure being utilized for the episodic buffer is also a subtest on the NEPSY-2, the Word Generation subtest (Korkman et al., 2006). This particular subtest requires participants to quickly and accurately spontaneously recall objects belonging to pre-determined categories over the time course of 60 seconds. Administration of this assessment involves the participant being instructed to recall as many items as they can within the given category in a 60 second interval. Immediately before the timing starts, the participant is given the category to which the objects ought to belong. This requires the attentional component of maintaining the category while accessing previous knowledge of objects that may fall within that category.

Scoring is based on the number of different words that fit the category (i.e. repetitions, non-words, and words that do not fit the category are not counted). Word Generation was based on how many original words the participant was able to recall during the 60 second time interval, which is based on the NEPSY-2 examiners manual. Word generation reliability coefficients are not reported specifically for the age group that was assessed, although norming tables extend through the youngest population of 3 years old. Using split-half reliability measures, the internal consistency ranges from .60
to .77 for the age group of 13 through 16 years 11 months. The Word Generation has two components, whereby these two measures have a correlation coefficient of .46, suggesting they are highly correlated but not exactly the same. Word Generation has a correlation with Letter Fluency on the Delis-Kaplan Executive Function System of .71. The Letter Fluency task is similar to Word Generation, so the high correlation is evidence of the validity of the measure.

**Central Executive**

The central executive has been fractionated into three distinct but related executive functions: inhibition, updating, and shifting (Miyake et al., 2000). Since the study that Miyake and colleagues conducted in 2000, this particular conceptualization of the central executive has been supported, paving the way for the development of measures to assess each executive function separately (Hartman et al., 2001; Garon et al., 2007; Lehto et al., 2003; Mantyla, Carelli, & Forman, 2007). Some studies have gone as far as to adapt the measures for children as young as four years old (Garon et al., 2007; Lehto et al., 2003) allowing for the assessment of children at the lower extreme of schooling. All three of the executive function measures were conducted using programmed E-Prime-2 computer software (Schneider, Eschman, & Zuccolotto, 2007). This software allows for the measurement of both accuracy and reaction time associated with responses. Participants were seated approximately 18 inches from the computer screen and indicated answers by stating their answer out loud while the researcher advanced the items by clicking a mouse button.

**Inhibition.** Inhibition was measured using a variation of the classic Stroop task (Stroop, 1935) and was adapted from the task used by Friedman, et al (2008). The Stroop
task consists of color words presented in matching (i.e.: yellow printed in yellow ink) and non-matching (i.e.: yellow printed in blue ink). It involves the purposeful stopping of the prepotent response of reading the word rather than naming the color the word is printed in. Participants were presented three types of trials: color words printed in the matching color, color words printed in a non-matching color, and a string of asterisks printed in one of the colors used. Since the participants are going to be children, reading level of the color words was considered. According to Marzano, Kendall, and Paynter (2005), the color words used in the Stroop task fall between the kindergarten and third grade reading levels. Therefore, it should follow that students in grade four ought to be able to recognize and readily read color words. Although Friedman and colleagues used adults and the Stroop is typically used with adults, a study by Fagot, Dirk, Ghisletta, and Ribaupierre (2009) found that children exhibit significant amounts of inhibition difficulties on the Stroop task, making the Stroop appropriate as a measure of inhibition for children within our population.

This was administered on the computer program E-Prime 2. The program recorded the response time in milliseconds where the researcher clicked a mouse button to advance the item and then indicated correctness on a separate form. Participants were to name the color of the ink as quickly and accurately as possible on all trials. There were 18 practice trials and 45 test items, with an equal number of matching color color-words, non-matching color color-words, and colored asterisks.

The dependent variables are each participant’s accuracy (correct was scored one, incorrect was scored zero). The response time calculated is based on each individual’s mean response time on the targeted task (different color word, i.e. yellow in blue ink)
minus that individual’s mean response time on the non-targeted task (colored asterisks). Reliability levels indicated by Friedman et al. are reported using the Spearman-Brown split half formula at .91 for internal consistency. The Stroop task has a factor loading of .42 as it relates to the inhibition construct in their sample.

**Shifting.** The measure of shifting utilized in this study was a Category Switch task, also used by Friedman et al. (2008). In this assessment, participants are required to switch between categorizing objects as either living vs. nonliving object or bigger vs. smaller than a soccer ball based on a symbol presented with the word. If the object was presented with an asterisk, participants are to classify the object as living or nonliving. Meanwhile, when the object is presented along with a plus sign, they will indicate whether the item was bigger than- or smaller than- a soccer ball.

This measure was administered using E-Prime 2 computer program (Schneider et al., 2007). Participants were required to provide a verbal answer. Researchers clicked a mouse button to advance the items and recorded the answer on a separate sheet. There were 12 practice items and 36 test items, with 16 non-switching responses and 20 switching responses. It was considered a switch when the category, bigger vs. smaller or living vs. nonliving, changed between consecutive items.

The dependent variables are each participant’s accuracy as well as response time. The accuracy for Category Switch was scored on a zero or one for each item as well. The response time calculated for Category Switch was based on each individual’s response time between two consecutive switching items (an item which required the participant to say whether the word was bigger than or smaller than a soccer ball, followed by an item which required the participant to say whether the word was living or nonliving) minus the
response time between two consecutive non-switching items (two items which required
the participant to say whether the word was bigger than or smaller than a soccer ball).
Friedman and colleagues obtained reliability level for Category Switch of .85 with a
factor loading of .74 as it relates to the construct of shifting in their sample.

**Updating.** The measure used to assess updating is a Letter Memory task (adapted
from Friedman et al., 2008; adapted from Morris and Jones, 1990). In this task, several
letters are presented at 2.5 seconds per letter as part of varying list lengths (five, seven, or
nine) letters. Participants were required to recall the last 3 letters of the series of letters,
causing them to drop the letter that was fourth back while adding in the new letter.

The letters were presented via the E-Prime 2 computer program (Schneider et al.,
updating each time a new letter was presented, participants were required to rehearse the
three most recent letters aloud. For example, if the letters presented are G, N, A, F, K, E,
Q, the participants would have said “G…G-N…G-N-A…N-A-F…A-F-K…F-K-E…K-
E-Q…” and then recalled K-E-Q at the end of the trial. The number of letters presented in
each trial (5, 7, or 9) was varied randomly across trials to ensure that participants
continued to update the information. There were three practice items, one of each length,
and six test items, two of each length. Participants were required to provide a verbal
answer, which was recorded by the researcher.

Dependent variables include accuracy score and total response time. The
accuracy score for Letter Memory was based on correct recall of the letter, as well as
correct place recall. That is, if the participant recalled the three most recent letters out of
order, they received three points (one point for each letter); if they recalled all three
letters in the correct place and correct order, they received six points (one point for each letter, and one point for each correct place). If they recalled a single letter in the correct place, and missed the two other letters, they received two points (one point for the correct letter, and one point for the correct place). A maximum of six points was awarded for each time the participant had to recall the three most recent letters. The response time for Letter Memory was based on the mean response time to recall the three letters before starting the next string of letters. Based on Chronbach’s alpha, Friedman and colleagues found an internal reliability level of .91. In addition, based on their three-factor model, Letter Memory had a factor loading of .66 as it relates to the executive function construct of updating. As with the other measures used in that study, participants were all adults and this particular measure has not been used with children. However, similar tasks have been used by other researchers (Keage et al., 2007). For example, Keage and colleagues used a letter updating task with children as young as six years old.

Research Design

An experimental research design was employed for this study. Gender and the number of students in each school building in the treatment and control groups were controlled for. The treatment group received the intervention while the no-treatment control group did receive any services before post testing. Both groups were evaluated prior to the keyword mnemonics intervention and at the outset of the intervention. On the pretesting assessment, there should be no measurable differences in working memory between the groups. The covariance portion of the analysis will remove any variance due to individual differences at the pretest phase of this research project. Differences on the
working memory tasks on the post testing assessment are expected whereby the intervention group will exhibit improved working memory component skills.

In this study, the independent variable in each analysis was group membership, either experimental or no treatment control. Only the treatment group received the intervention prior to post testing, but all participants will be assessed both prior to and after the intervention to examine the effects the keyword mnemonics intervention has on underlying working memory processes (phonological loop, visuo-spatial sketchpad, and episodic buffer) and domains of the central executive (inhibition, shifting, and updating). The covariates were pretest performance on measures of each individual component. The dependent variables were the posttest performance results on those same measures following the keyword mnemonic intervention. A list of working memory components and their subsequent assessment measure can be found in Table 1.
Table 1.

*Working Memory Battery: Components, Assessment Techniques, and Dependent Variables*

<table>
<thead>
<tr>
<th>Component</th>
<th>Assessment technique</th>
<th>Dependent Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonological Loop</td>
<td>Digits Forward</td>
<td>Digits Correct Raw Score</td>
</tr>
<tr>
<td>Visuo-Spatial Sketchpad</td>
<td>Memory for Location</td>
<td>Total Accuracy Score</td>
</tr>
<tr>
<td>Episodic Buffer Generated</td>
<td>Word Generation</td>
<td>Number of Words</td>
</tr>
<tr>
<td>Central Executive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhibition</td>
<td>Stroop</td>
<td>Time and Accuracy Raw Score</td>
</tr>
<tr>
<td>Shifting</td>
<td>Category Switch</td>
<td>Time and Accuracy Raw Score</td>
</tr>
<tr>
<td>Updating</td>
<td>Letter Memory</td>
<td>Time and Accuracy Raw Score</td>
</tr>
</tbody>
</table>

**Threats to Validity**

Possible threats to internal validity the inherent differences of learning and teaching style within their classrooms and teachers. Further, internal validity is limited by the extent to which the measures assess the working memory processes of young children. Since many of these assessment tools have not been used specifically with children, the validity may suffer. In addition, because this was meant to be a brief assessment, the measures have been shortened, possibly affecting the validity of the measures. In addition, for the response time measures, researchers were responsible for recording when the participant responded. Individual reaction times may confound the actual response times of the participants.
A limit to external validity may be related to selection treatment because the participants are in the same classes and some are getting the intervention while the others are not. A consequence of this is restricted generalizability from this study as the participants may not be representative of the general population of children in schools. Participant effects were also possible. Students who volunteer to be part of a school tutoring program may inherently be more motivated to learn and improve their cognitive and academic skills compared with students who do not wish to go above and beyond the regular demands of the school day.

**Independent and Dependent Variables**

The independent variable is group membership of either treatment or no-treatment control; the treatment group will receive the intervention while the no-treatment control group will not receive any additional supports outside their regular daily school activities within the intervention timeframe. The intervention consisted of a keyword mnemonic strategy training implemented by researchers as part of a voluntary school tutoring intervention called the Memory Intervention and Neuropsychological Development (MIND) Program. All participants attended at least five of the six sessions. A no-treatment control group was to compare the post-intervention scores on the working memory tasks.

The dependent variables were each of the components of working memory as follows: phonological loop, visuo-spatial sketchpad, episodic buffer, and the three components of the central executive: inhibition, switching, and updating. The phonological loop is operationally defined as managing auditory information and was measured by the Digits Forward task. The visuo-spatial sketchpad is operationally
defined as being responsible for the management of visually presented information and was measured by Memory for Locations. The episodic buffer is operationally defined as a component responsible for holding semantic and abstract pieces of information, and has the capability of incorporating information from various sources: auditory-, visual- and semantically-stored information. It was measured by the Word Generation. Inhibition is operationalized as the ability to override dominant, prepotent, or automatic responses in order to complete the task at hand and was assessed with the Stroop task. Switching is operationally defined as the ability to flexibly switch back and forth between tasks or mental sets, without integrating them together and was assessed by the Category Switch task. Finally, updating is operationally defined as the ability to actively monitor incoming information while appropriately replacing old, no longer relevant information with new, relevant information and was measured by the Letter Memory task.

Procedure

Parental permission was obtained prior to the start of the intervention program; students were also asked to sign assent forms in order to participate. Once consent and assent was acquired, all participants were assessed with the working memory battery. Students interested in the intervention program were assessed approximately four weeks prior to the start of the keyword mnemonics intervention. The battery took approximately 25-30 minutes to administer. Random group assignment, treatment or no treatment control, will take place at the start of the intervention process. The treatment group received the key mnemonic training intervention directly implemented by researchers.

In order to avoid order effects, the working memory battery was counterbalanced such that there were two different orders of tasks. Half of the control group and half of
the treatment group completed order A on the pretest while the other half of the no
treatment control group and the other have of the treatment group received order B on the
pretest (Appendix A). During the post test, each participant will take the version which
they did not take in the pretest. This will also help to maintain internal consistency of the
measures.

**Intervention**

During the three weeks of the keyword mnemonic intervention, researchers
offered a total of six 30-minute training sessions, two days per week, during the allotted
school time. The specific mnemonic intervention strategy used was the keyword method
(Dehn, 2008). This strategy involves generating a word with some concrete meaning to
be drawn or imagined as a picture, utilizing imagery as a means to remember new
information. In addition, the keyword method involves the association of a well-known
word with the new word, thus, creating an image and a keyword with which to recall the
new information. When asked to provide the new information, the keyword mnemonic
works in this way: the child recalls the keyword, recalls what the picture was, and
remembers what is happening in that picture that helps them recall the new information.
This process links both visual and auditory input to enhance the recall of novel
information and stresses the importance of the keyword mnemonic being personal to the
individual creating it.

There was a pre-written script written for each intervention session that laid out
how to discuss the mnemonic training as well as provided examples of math or science
terms as well as states and state capitals to practice during each session (Appendix B).
Each session followed the same format. First, the students reviewed what keyword
mnemonics are, then the researchers would present pre-created keyword mnemonics to help remember novel math or science terms (i.e.: circumference), followed by opportunities for the students to create their own mnemonic for new math or science terms. During the second half of the session, researchers would present pre-created keyword mnemonics for states and state capitals. Then students were given an opportunity to develop their own keyword mnemonic for states and state capitals. This process allowed for both modeling of the keyword mnemonic as well as opportunities to use the strategy independently. Integrity of the intervention was also conducted via a checklist (Appendix C) that was completed three times for each group that received the intervention.

Participants were provided with examples of words with pre-produced keywords and pictures to remember the new word. Researchers demonstrated their thinking process and interacted with the students. Students were then given the opportunity to create their own keywords and images. Researchers provided the students with words, states and state capitals, paper, crayons, and time to create these keyword mnemonics for themselves. The activities were meant to be engaging throughout each session. The students appeared to be engaged as exemplified by their personalized pictures and keywords for each new word given to them. They also were able to recall the new words by using the recently created keyword mnemonics at the end of each session.

While the treatment group is participating in the intervention sessions, the no treatment control group will attend their regularly scheduled activity as they typically would; they will not interact with researchers between the pre- and post- assessments. To account for dose-response effects, all participants included attended at least five of the six
offered training sessions in order for their information to be used in the data analysis. Number of training sessions will not be analyzed beyond the minimal attendance policy in this particular study.

**Data Analysis**

**Data Screening**

All analyses were completed using PASW SPSS version 18.0. Means and standard deviations for each variable were calculated by group membership. Missing data was replaced with group means on that measure. In one instance, a no-treatment control group participant was absent for the whole week of the post testing and so that student did not complete the post testing portion of the study and was therefore dropped from the study. In addition, there were technical problems regarding the response time for two individuals on the updating measure; the computer program did not save a file for it. These cases were replaced with the group (experimental or control) means on that task.

**Multivariate Analysis of Covariance**

For each of the research questions, a multivariate analysis of covariance (MANCOVA) was utilized to examine the effects of the intervention on the components of the working memory system. A total of three MANCOVA analyses were conducted, with a separate one for each hypothesis. MANCOVA is a statistical method that combines regression analysis and analysis of variance to provide information, which lends itself to more accurate conclusions (Stevens, 2002). The regression portion accounts for the correlation between two variables, the covariate’s relationship to the dependent variable, which may affect the outcome, such as the relationship between pretest score and post test score. Meanwhile, the analysis of variance examines the
difference between levels of the independent variable, the treatment versus no-treatment control group. Therefore, it is the statistical method of choice for this study as it measures the changes within and across multiple variables associated with an intervention.

Covariates provide statistical control through the reduction of within group variance (error) and the elimination of systematic bias based on the covariate. The covariates must have some relationship to the dependent variable in order to maximally reduce error. Using more covariates typically results in a more sensitive test, increasing the likelihood of rejecting the null hypothesis (Stevens, 2002). In this study, the covariates will be the pretest performance on each measure being analyzed, with posttest performances as the dependent variables and group membership as the independent variable.

Assumptions

In order to conduct a MANCOVA, five assumptions will need to be met: independence of observations, normality, equal variances, linearity, and the relationship of regression planes for each group must be homogeneous (Mertler & Vannatta, 2005). Independence of observations assumes that individual observations were not impacted by other individual observations. Normality refers to the distribution of each dependent variable whereby these distributions should roughly fall within a normal distribution with the majority of data points falling in the mid-range. Equal variance refers to an assumed homogeneity of variance within each variable for the different groups; the variance should be similar and there should not be substantial differences in the amount of variance of one group versus another group on the same variable. The fourth assumption of linearity refers to the relationship dependent variables have to one another. All pairs of
dependent variables, pairs of covariates, and dependent variable-covariate pairs in each cell should have linear relationships. The final assumption relates to the regression planes of each covariate whereby the regression planes should be parallel or homogeneous. Alpha levels will be pre-set at $p<.05$ in determining the significance of differences found.

For each of the analyses there will be three covariates (three pretest assessment scores), three dependent variables (three posttest assessment scores), and two levels of the independent variable (treatment and no treatment control). The data analysis will include a comparison between the treatment group and the no treatment control group. Based on the co-varying of pretest performance, it is hypothesized that there will be between group differences post-intervention on the working memory measures such that the treatment group will show improved scores while the no treatment control group remains statistically unchanged.

The first research question is: Will the application of a mnemonics intervention positively affect the components of working memory as compared to a no treatment control group? It is hypothesized that Children who receive the mnemonics intervention will exhibit an increase in phonological loop, visuo-spatial sketchpad, and episodic buffer performance as compared to a no treatment control group. To evaluate this hypothesis, a multivariate analysis of covariance (MANCOVA) was conducted to investigate the effects of the intervention on multiple dependent variables (phonological loop, visuo-spatial sketchpad, episodic buffer). The data analysis included a comparison between the treatment group as and the control group. Based on the co-varying of pretest performance, it is hypothesized that there will be between group differences following
the mnemonics intervention on the working memory measures such that the treatment group will show improved scores while the control group remains statistically unchanged.

The second research question is: Will the application of a mnemonics intervention result in an increase in inhibition, shifting, and updating performance compared to a no treatment control group? It is hypothesized that children who receive the mnemonics intervention will exhibit an increase in inhibition, shifting, and updating performance as compared to a no treatment control group as evidenced by reduced response time and increased accuracy. Two multivariate analysis of covariance (MANCOVA) were conducted to investigate the effects of the intervention on the dependent variables (inhibition, shifting, updating). One MANCOVA examined the response times and the other MANCOVA examined the accuracy. The data analysis includes a comparison between the treatment group and the no treatment control group. Based on the co-varying of pretest performance, it is hypothesized that there will be between group differences following the mnemonics intervention on the working memory measures such that the treatment group will show reduce response time and increased accuracy while the control group remains statistically unchanged.
Chapter IV

Results

This chapter presents the results of the analyses discussed in the previous chapter. Results include descriptive statistics, preliminary analyses and tests of assumptions, and the MANCOVA analyses for the hypotheses regarding the effects of a keyword mnemonics intervention on the individual components of the working memory system.

Descriptive Statistics

There were a total of 55 participants involved in the study, all of whom were included in the database for analysis. There were 28 participants who were assigned to the no-treatment control group and 27 participants assigned to the group who received the intervention. The mean age for the sample was 9.71 years, with 17 nine-year-olds, 37 ten-year-olds, and one 11-year-old. There were 25 male participants and 30 female participants, with approximately half of each sex comprised of students from each of the two schools. There was also equal representation of sex, school, and classroom in the experimental and control groups. There were four classrooms in each school, with 29 students from one school and 26 students from the other school (see Table 2).
Table 2.

*Participants in Each School, Classroom, and Group*

<table>
<thead>
<tr>
<th>School</th>
<th>Classroom</th>
<th>Males</th>
<th>Females</th>
<th>Experimental</th>
<th>Control</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
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<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
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<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>A</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>16</strong></td>
<td><strong>13</strong></td>
<td><strong>14</strong></td>
<td><strong>15</strong></td>
<td><strong>29</strong></td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
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<tr>
<td>B</td>
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<td>1</td>
<td>5</td>
<td>3</td>
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<tr>
<td></td>
<td><strong>Total</strong></td>
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<td><strong>17</strong></td>
<td><strong>13</strong></td>
<td><strong>13</strong></td>
<td><strong>26</strong></td>
</tr>
</tbody>
</table>

*Note.* N=55; 27 experimental; 28 control

Participants were first placed into groups according to their classroom and then sorted by sex. Then, half of the boys and half of the girls from each classroom were placed into the experimental group while the other half of the boys and half of the girls in each classroom were placed in the control group. This was done to control for confounding variables, such as intervention group size in any one classroom or sex representation within each group. Age was not considered at this point of the study. Means and standard deviations for each variable are reported in Table 3, Table 4, and Table 5.
Table 3.

Means and Standard Deviations of Non-Executive Components

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experimental M (SD)</th>
<th>Control M(SD)</th>
<th>Total M(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Word Generation</td>
<td>48.56 (10.14)</td>
<td>51.36 (12.13)</td>
<td>50.00 (11.22)</td>
</tr>
<tr>
<td>Pre Digits Forward</td>
<td>40.67 (14.97)</td>
<td>37.54 (11.82)</td>
<td>39.07 (13.43)</td>
</tr>
<tr>
<td>Pre Memory for Location</td>
<td>8.04 (4.93)</td>
<td>6.36 (4.64)</td>
<td>7.18 (4.82)</td>
</tr>
<tr>
<td>Post Word Generation</td>
<td>52.37 (11.34)</td>
<td>53.44 (10.98)</td>
<td>52.92 (11.06)</td>
</tr>
<tr>
<td>Post Digits Forward</td>
<td>44.67 (13.75)</td>
<td>43.37 (11.57)</td>
<td>44.01 (12.58)</td>
</tr>
<tr>
<td>Post Memory for Location</td>
<td>9.63 (4.83)</td>
<td>8.04 (4.62)</td>
<td>8.82 (4.75)</td>
</tr>
</tbody>
</table>

Note. N=55; 27 experimental; 28 control. M = Mean; SD = Standard Deviation; Pre = Pretest; Post = Posttest

Table 4.

Means and Standard Deviations of Executive Components Accuracy

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experimental M (SD)</th>
<th>Control M(SD)</th>
<th>Total M(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Stroop</td>
<td>43.81 (1.33)</td>
<td>43.57 (1.64)</td>
<td>43.69 (1.49)</td>
</tr>
<tr>
<td>Pre Category Switch</td>
<td>31.70 (2.99)</td>
<td>43.57 (3.33)</td>
<td>31.78 (3.14)</td>
</tr>
<tr>
<td>Post Stroop</td>
<td>43.85 (.907)</td>
<td>44.07 (1.27)</td>
<td>43.96 (1.11)</td>
</tr>
<tr>
<td>Post Category Switch</td>
<td>33.15 (2.07)</td>
<td>33.05 (1.94)</td>
<td>33.10 (1.99)</td>
</tr>
<tr>
<td>Post Letter Memory</td>
<td>28.74 (5.44)</td>
<td>29.00 (4.47)</td>
<td>28.87 (4.87)</td>
</tr>
</tbody>
</table>
Table 5.

Means and Standard Deviations of Executive Components Response Times

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experimental M (SD)</th>
<th>Control M (SD)</th>
<th>Total M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Stroop RT</td>
<td>171.90 (156.43)</td>
<td>214.48 (238.95)</td>
<td>193.58 (201.98)</td>
</tr>
<tr>
<td>Pre Category Switch RT</td>
<td>83.04 (318.10)</td>
<td>196.08 (328.05)</td>
<td>140.59 (325.24)</td>
</tr>
<tr>
<td>Pre Letter Memory RT</td>
<td>8124.45 (3989.99)</td>
<td>7480.51 (3694.33)</td>
<td>7796.63 (3820.31)</td>
</tr>
<tr>
<td>Post Stroop RT</td>
<td>129.44 (149.73)</td>
<td>153.64 (204.50)</td>
<td>141.76 (178.48)</td>
</tr>
<tr>
<td>Post Category Switch RT</td>
<td>91.26 (317.38)</td>
<td>142.43 (470.70)</td>
<td>117.31 (400.11)</td>
</tr>
<tr>
<td>Post Letter Memory RT</td>
<td>6364.81 (2880.81)</td>
<td>6218.27 (2702.41)</td>
<td>6290.20 (2766.37)</td>
</tr>
</tbody>
</table>

Note. N=55; 27 experimental; 28 control; RT = Response Time in milliseconds; M = Mean; SD = Standard Deviation; Pre = Pretest; Post = Posttest

Preliminary Analysis and Test of Assumptions

Preliminary data analysis included screening of missing data and tests of normality. In addition, the assumptions of linearity, equal variances, homoscedasticity, and homogeneity of the covariate’s regression planes were addressed prior to conducting the MANCOVA related to the research questions.

Missing data in the database was minimal and was addressed first. In one case, a no-treatment control group participant was absent for the whole week of the post testing phase so that student did not complete the post testing portion of the study. In addition, there were technical problems regarding the response time for two individuals on the
updating measure (Letter Memory); the computer program did not save the file for those two. All other participants had data for every variable measured at both pre- and post-intervention. Missing data were minimal (less than 5% of the overall data and less than 5% of the data within any group) and assumed to be missing at random. All missing data, including the case that had no posttest data, was replaced with group (intervention or control) means on that measure. This was a conservative decision since the overall mean is not affected when this approach is used (Mertler & Vannatta, 2005).

The preliminary analysis also included screening for normality. Most measures had no indication of problematic scenes or kurtosis. On the pretest administration of letter memory, the response time had high scenes (5.26) and kurtosis (32.36), with values that were much higher than recommended. An examination of histograms revealed an extreme outlier. However, it was discovered that a data entry error was accounting for the one outlier that was heavily effecting the distribution. The error was corrected, which brought the skewness and kurtosis down to more reasonable levels. A re-examination of histograms suggests that the continued non-normality of this measure is a reflection of the lack of distribution of times, as many participants had very similar response times. All other variables were within recommended ranges and have generally normal distributions.

Mahalanobis distances were used to examine the data for multivariate outliers, with a critical value set at 22.49 of the Chi-Squared Distribution for each of the analyses run. There was one extreme outlier found using this method; the posttest response time for the category switch measure was significantly different for one participant. Upon inspection of this participant’s response times for each individual item on the category
switch measure, it was noticed that there was one response time which was more than twice as long as all other response times within that measure. However, because it could not be determined whether this was a researcher error in advancing the measure on the computer, or whether the test was spoiled by an interruption, or whether the child was distracted on their own with no influence from the environment, this data point was deleted and replaced with the group mean.

Linearity was addressed through examination of the Pearson correlation of the within-cell bivariate scatterplots between the pairs of dependent variables, pairs of covariates, and DV-covariate pairs. This portion of the data screening and pre-analysis process reveals that this assumption is met since the scatterplots appear to be linear. The dependent variables for each research question are presented in the bivariate scatterplots (Figure 1, Figure 2, Figure 3).
Figure 1. Bivariate Scatterplot of Dependent Variables for Research Question #1.
Figure 2. Bivariate Scatterplot of Dependent Variables for Research Question #2.
Figure 3. Bivariate Scatterplot of Dependent Variables for Research Question #3
All response times were calculated in milliseconds. Before conducting the analysis, the response times were transposed. Because the mean differences between target response and non-target response were based on the participants’ response times on the measures, there were times where the participants actually responded quicker on the targeted task and slower on the non-targeted task. This created standard deviations that were larger than the means on the inhibition measure and the shifting measure. One thousand milliseconds were added to all response times on the inhibition and shifting tasks in order to compensate for negative response times and create means that were larger than the standard deviation.

A preliminary MANCOVA was run for each of the research questions to address assumptions regarding homoscedasticity and homogeneity of regression slopes. The assumption of homoscedasticity was examined through Box’s M test for each of the research questions. None of the p-values were significant, all having very low F-ratios. Thus, Wilks’ Lambda was used as the test statistic. Finally, homogeneity of regression slopes was examined for interaction among the independent variable (intervention or control group) and the covariates (pretest performance). All three preliminary MANCOVAs produced non-significant test-statistics, with p-values of the test statistic well over .05. If interactions had been significant, the following full MANVOCAs could not have been conducted due to non-parallel hyper-planes.

**Non-Executive Components of Working Memory**

**Research Question One**

What is the effect of a keyword mnemonics intervention on the non-executive components of working memory when compared to a no treatment control group?
To answer research question one, a multivariate analysis of covariance (MANCOVA) was conducted. It was hypothesized that children who receive the keyword mnemonics intervention will perform better on the phonological loop, the visuo-spatial sketchpad, and the episodic buffer tasks as compared to a no treatment control group. The independent variable was treatment group (experimental or control). The dependent variables were the posttest accuracy scores for Digits Forward (phonological loop), Memory for Location (visuo-spatial sketchpad), and Word Generation (episodic buffer). Meanwhile, the pretest scores on Digits Forward, Memory for Location, and Word generation were used as covariates. This removes the effects of each individual’s pretest performance from examination of the posttest performance.

Results of a MANCOVA using the pretest performance as the covariate reveal that the groups do not differ on posttest performance results for all three non-executive components. Factor interaction was not significant [Wilks $\lambda = .992$, $F (3, 48) = 0.124, p = .945$, multivariate $\eta^2 = .008$]. Additionally, the covariates do not significantly influence the combined dependent variable for the phonological loop [$F (1, 50) = .153, p = .697$, multivariate $\eta^2 = .003$], the visuo-spatial sketchpad [$F (1, 50) = .012, p = .914$, multivariate $\eta^2 = .000$], or the episodic buffer [$F (1, 50) = .153, p = .697$, multivariate $\eta^2 = .003$].

Upon further inspection of mean differences on each measure for the non-executive components, there is no overarching trend of one group performing better than the other (Table 6). On two of the measures the means are higher for the experimental group, word generation for the episodic buffer and memory for location for visual-spatial sketchpad, than the control group. However, on the digits forward measure of phonological loop, the control group had a higher mean improvement. A follow up
ANOVA was conducted, using the difference scores as score as the dependent variable and group membership as the independent variable. The separate ANOVA results reveal that none of these differences were statistically significantly different.

Table 6.

Non-executive components’ mean improvement

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experimental M (SD)</th>
<th>Control M (SD)</th>
<th>Total M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word Generation</td>
<td>3.81 (7.23)</td>
<td>2.00 (1.78)</td>
<td>2.89 (8.39)</td>
</tr>
<tr>
<td>Digits Forward</td>
<td>4.00 (11.36)</td>
<td>5.83 (11.22)</td>
<td>4.93 (11.22)</td>
</tr>
<tr>
<td>Memory for Location</td>
<td>1.59 (4.67)</td>
<td>1.68 (3.58)</td>
<td>1.64 (4.11)</td>
</tr>
</tbody>
</table>

*Note. N=55; 27 experimental; 28 control; M = Mean; SD = Standard Deviation*

Additionally, box plots of the difference scores for the accuracy of the Word Generation, Digits Forward, and Memory for Location tasks were examined and are shown in Figure 4, Figure 5, and Figure 6. The outliers were examined for participants with individual differences. There was no participant who consistently performed much better or much worse than the rest of the participants. Each time there was an outlier, it appears that it was a unique case of either good performance or poor performance on that given day for that individual.
Figure 4. Box Plot for the difference between the pretest and posttest accuracy of Word Generation.
Figure 5. Box Plot for the difference between the pretest and posttest accuracy of Digits Forward.
Figure 6. Box Plot for the difference between the pretest and posttest accuracy of Memory for Location.
Central Executive Domains of Working Memory Accuracy

Research Question Two

What is the effect of a keyword mnemonics intervention on the accuracy of central executive domains of inhibition, shifting, and updating performance when compared to a no treatment control group?

To answer research question two, a second multivariate analysis of covariance (MANCOVA) was conducted. It was hypothesized that children who receive the keyword mnemonics intervention will exhibit an increase in accuracy on the inhibition, the shifting, and the updating tasks as compared to a no treatment control group. The independent variable was treatment group (experimental or control). The dependent variables were the posttest accuracy scores for Stroop (inhibition), Category Switch (shifting), and Letter Memory (updating). Meanwhile, the pretest accuracy scores on Stroop, Category Switch, and Letter Memory were used as covariates. This removes the effects of each individual’s pretest performance from examination of the posttest performance.

Results of a MANCOVA using the pretest performance as the covariate reveal that the groups do not differ on posttest performance results for the accuracy of all three executive components. Factor interaction was not significant [Wilks $\lambda = .986$, $F (3, 48) = 0.221$, $p = .881$, $\eta^2=.014$]. Additionally, the covariates do not significantly influence the combined dependent variable for accuracy related to inhibition [$F (1, 50) = .580$, $p =.450$, multivariate $\eta^2=.011$], the shifting [$F (1, 50) = .041$, $p = .840$, multivariate $\eta^2=.001$], or updating [$F (1, 50) = .000$, $p = .998$, multivariate $\eta^2=.000$].
Upon further inspection of mean differences on each measure for executive components of inhibition, shifting, and updating, there is no trend of one group’s accuracy improving more than the other (Table 7). On two of the measures the means are higher for the experimental group, category switch for shifting and letter memory for updating. A follow up ANOVA was conducted, using the difference scores as score as the dependent variable and group membership as the independent variable. The separate ANOVA results reveal that none of these differences were statistically significantly different.

Table 7.

*Central executive components’ accuracy mean improvement*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experimental M (SD)</th>
<th>Control M (SD)</th>
<th>Total M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroop</td>
<td>.04 (1.49)</td>
<td>0.50 (1.86)</td>
<td>.27 (1.68)</td>
</tr>
<tr>
<td>Category Switch</td>
<td>1.44 (2.71)</td>
<td>1.20 (3.15)</td>
<td>1.32 (2.91)</td>
</tr>
<tr>
<td>Letter Memory</td>
<td>2.52 (5.26)</td>
<td>2.14 (6.15)</td>
<td>2.33 (5.68)</td>
</tr>
</tbody>
</table>

*Note. N=55; 27 experimental; 28 control; M = Mean; SD = Standard Deviation*

Again, box plots of the difference scores for the accuracy of the Stroop, Category Switch, and Letter Memory tasks were examined and are shown in Figure 7, Figure 8, and Figure 9. The outliers were examined for participants with individual differences. There was no participant who consistently performed much better or much worse than the rest of the participants. Each time there was an outlier, it appears that it was a unique case of either good performance or poor performance on that given day for that individual.
Figure 7. Box Plot for the difference between the pretest and posttest accuracy of Stroop.
Figure 8. Box Plot for the difference between the pretest and posttest accuracy of Category Switch.
Figure 9. Box Plot for the difference between the pretest and posttest accuracy of Letter Memory.
Central Executive Domains of Working Memory Response Time

Research Question Three:
What is the effect of a keyword mnemonics intervention on the response time of central executive domains of inhibition, shifting, and updating performance when compared to a no treatment control group?

To answer research question three, another separate multivariate analysis of covariance (MANCOVA) was conducted. It was hypothesized that children who receive the keyword mnemonics intervention will exhibit decreased response time on the inhibition, the shifting, and the updating tasks as compared to a no treatment control group. The independent variable was treatment group (experimental or control). The dependent variables were the posttest response time scores for Stroop (inhibition), Category Switch (shifting), and Letter Memory (updating). Meanwhile, the pretest response times on Stroop, Category Switch, and Letter Memory were used as covariates. This removes the effects of each individual’s pretest performance from examination of the posttest performance.

Results of a MANCOVA using the pretest performance as the covariate reveal that the groups do not differ on posttest performance results for the response times of all three executive components. Factor interaction was not significant [Wilks $\lambda = .992$, $F (3, 48) = 0.127$, $p = .944$, $\eta^2=.008$]. Additionally, the covariates do not significantly influence the combined dependent variable for response time related to inhibition [$F (1, 50) = .047$, $p = .829$, multivariate $\eta^2=.001$], the shifting [$F (1, 50) = .363$, $p = .549$, multivariate $\eta^2=.007$], or updating [$F (1, 50) = .051$, $p = .822$, multivariate $\eta^2=.001$].
Upon further inspection of mean differences on each measure for executive components of inhibition, shifting, and updating, there is no trend of one group’s response time decreasing more than the other (Table 8). On the updating measure, letter memory, the decrease in response time is greater for the experimental group. A follow up ANOVA was conducted, using the difference scores as score as the dependent variable and group membership as the independent variable. The separate ANOVA results reveal that none of the means’ differences were statistically significantly different.

Table 8.

*Central executive components’ response time mean improvement*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Experimental</th>
<th>Control</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Stroop RT</td>
<td>-42.46 (224.64)</td>
<td>-60.84 (239.88)</td>
<td>-51.82 (230.55)</td>
</tr>
<tr>
<td>Category Switch RT</td>
<td>8.23 (438.87)</td>
<td>-53.66 (569.00)</td>
<td>-23.28 (505.56)</td>
</tr>
<tr>
<td>Letter Memory RT</td>
<td>-1758.64 (4333.96)</td>
<td>-1262.26 (2872.66)</td>
<td>-1506.43 (3677.65)</td>
</tr>
</tbody>
</table>

*Note.* N=55; 27 experimental; 28 control; M = Mean; SD = Standard Deviation; RT = Response Time in milliseconds.

Finally, box plots of the difference scores for the response time of the Stroop, Category Switch, and Letter Memory tasks were examined and are shown in Figure 10, Figure 11, and Figure 12. The outliers were examined for participants with individual differences. There was no participant who consistently performed much better or much worse than the rest of the participants. Each time there was an outlier, it appears that it was a unique case of either good performance or poor performance on that given day for that individual.
Figure 10. Box Plot for the difference between the pretest and posttest Stroop response time.
Figure 11. Box Plot for the difference between the pretest and posttest Category Switch response time.
Figure 12. Box Plot for the difference between the pretest and posttest Letter Memory response time.
Chapter V

Discussion

This study examined the effect of a keyword mnemonics intervention on the individual components of the working memory system (episodic buffer, phonological loop, visual-spatial sketchpad, and central executive domains of inhibition, shifting, and updating) as originally described by Baddeley (2000) and further fractionated by Miyake and colleagues (2000). This was done via measurement of each component in isolation of the other components both pre- and post- intervention. The intervention was chosen as one that could be delivered to a group of students and one that could potentially be used in regular education classrooms. Keyword mnemonics use both visual and auditory methods for remembering novel information.

Summary of Results

Although mnemonics interventions have been used in the classroom setting in the past, they have been believed to be largely compensatory when working memory abilities are deficient (Dehn, 2008). There is research available which has investigated the effects of various interventions on overall measures of working memory and achievement following the intervention. However, research which directly measured individual components of working memory as they may be affected by an intervention is less common. For this study, it was hypothesized that the keyword mnemonics intervention would have effects on each component of working memory whereby experimental group participants would perform better on each measure as evidenced by increased accuracy and/or decreased response times. Those participants who received the intervention would
have increase accuracy on all six measures as well as faster response times for the central executive domains.

The first research question hypothesized that children who receive the keyword mnemonics intervention will perform better on non-executive component tasks than a no treatment control group. Results of the first analysis to examine the non-executive components of working memory (the episodic buffer, phonological loop, and visual-spatial sketchpad) indicate that there was no statistically significant difference between the experimental and control groups. After controlling for differences in pretest results by using the pretest scores as the covariate, the two groups did not differ in performance on the posttest. Even when looking at the rate of improvement of mean differences, there was no statistically significant differences found.

The second research question hypothesized that children who receive the keyword mnemonics intervention will exhibit an increase in accuracy on central executive performance tasks as compared to a no treatment control group. This analysis was run to examine whether there was a difference in accuracy performance between the experimental and control groups on measures of the central executive domains of inhibition, shifting, and updating. Results indicated no statistically significant difference between the two groups after controlling for pretest performance.

The third research question hypothesized that children who receive the keyword mnemonics intervention will exhibit a decrease in response time on central executive performance tasks as compared to a no treatment control group. The third and final analysis examined the speed at which participants’ response time changed following the intervention. Again, no differences were found in the main analysis or follow-up analysis.
Again, results indicated no statistically significant difference between the two groups after controlling for pretest performance.

However, there were non-significant differences between the intervention and control group that are of interest. Updating accuracy was one of the central executive domains that was different for the intervention and control groups. Although not statistically significantly different, it is interesting because updating tasks are arguably the task which is most closely associated with overall working memory since it has the temporary storage and manipulation of information. Updating is also the domain which is most closely associated with reading comprehension. It would be interesting to investigate the participants’ reading comprehension scores on academic tests and compare it to their updating abilities. The ability to recognize what information is important and which information is no longer relevant is precisely what the updating measure assessed.

**Conclusions**

The overall findings are not surprising given studies that suggest that in order to effect change at a neuropsychological level; interventions need to be specific to that area of functioning and intensive (e.g. Dahlin et al., 2008). For example, Verhaeghen and colleagues had participants practice a specific working memory task for ten hours, and tracked their improvement on that single task. Verhaeghen’s study used adults to practice a task that had no application to real life situations. The lack of ecological validity was a common finding among research studies that investigated working memory interventions. Additionally, there were few studies that focused on working memory in children (Gathercole et al., 2004).
In addition, there is research suggesting that keyword mnemonics, and other mnemonics, interventions are largely compensatory (e.g. Dehn, 2008). Although these claims were not based in direct research studies, they were likely based on what research regarding executive functioning malleability which claims that those processes are innate (Conway et al., 2005; Friedman et al., 2008) and need intensive intervention to affect change (Dahlin et al., 2008). Other research which has found that certain executive functions can be influenced and improved through intervention (e.g. Klingberg et al., 2005; Posner & Rothbart, 2005). These studies’ interventions were intensive and specific to the executive function skill that was measured, rather than having a global approach such as a keyword mnemonic intervention.

**Implications**

This study may provide some insight to how keyword mnemonics interventions affect the way children organize information. It is a process that appears to help in academically focused situations, but may not necessarily affect the underlying processes involved in accessing information or immediately organizing information. It is possible that practicing ways to organize new information utilizing verbal and auditory modes may help in future, novel situations where these skills are needed, regardless of how similar the practice and assessment tasks are. However, this study does not support change in the individual components of working memory or the working memory components that were directly measured.

The generalizability of skills is the long term goal of all interventions and is often overlooked in intervention research. Although the findings do not suggest change in working memory, it does not imply that the potential to affect the working memory...
system with an intervention is not possible. The skills that the participants were taught in this study are ones that may be used in school for years to come, with educational implications that are not able to be measured directly. Anecdotally, children commented that they practiced using the keyword mnemonics in their classes while they were meeting with researchers. Although not measured, it is possible that the participants were able to generalize the keyword mnemonics to other situations when they were learning new information, using verbal and visual cues to help them later recall the information.

Results of this study indicated no significant differences or improvements between groups in the fractionated areas of working memory, including the phonological loop, visuo-spatial sketchpad, episodic buffer, as well as the fractionated components of the central executive, inhibition, shifting, and updating. This may be due to several factors. The intervention was a general classroom intervention that was not designed with the intent of tapping any specific executive functioning skills. So, this finding is consistent with past research which has suggested that in order to affect change in executive functioning, interventions need to directly tap that construct (Dahlin et al., 2008).

This study sheds light on what may be taking place internally when an intervention is being used and will hopefully open the door for future research. When skills can become generalized across settings, thus utilizing new skills in unfamiliar situations, students can benefit optimally. Understanding how this happens and learning which interventions have the potential to reach beyond the scope of the study will broaden the opportunities to help children, both with and without learning struggles, in ways that are beyond what could be measured in a single study.
This study provides support to the area of research which suggests working memory abilities, not just working memory capacity, is less amenable to intervention and more likely able to be supported through compensatory strategies. It seems as though keyword mnemonic interventions may not impact the components of the working memory system. This has implications regarding the use of keyword mnemonic interventions in the classroom. There is substantial research which suggests that mnemonic strategies (Dehn, 2008; Verhaeghen et al., 1992) can be effective in helping children recall what they’ve been taught by helping provide multiple modes and possibilities for remembering information by making it meaningful to that individual.

Additionally, it should not be ruled out that this intervention did not affect overall working memory. It may have impacted the children’s ability to store and recall the information they are taught, or it may have increased overall working memory. Researchers broke working memory into its fractionated components, and measured those in isolation. The intervention was not aimed to improve isolated components, but rather how to organize information as a whole. Because the working memory system was not measured as an integrated system, a conclusion regarding the keyword mnemonic’s effect on the working memory system cannot be drawn.

**Limitations**

This study has a number of limitations, including small sample size with potentially low generalizability of results. The sample size was large enough to produce results and run the proposed analysis, but too small to make generalized statements of the effectiveness of the intervention and therefore limiting the external validity. The sample was also from a single grade in a school district in western Pennsylvania. Although this
grade was chosen specifically because of the developmental level of children in that age range, it does not provide a wide scope of ages or developmental stages. Perhaps children much younger, who have not yet begun to organize information in different ways, may have shown improvements. Conversely, older children may have seen the application of the keyword mnemonic strategies and applied it more readily to new situations. This is not known, but may be interesting to research in the future.

One limiting factor may include the way these constructs were measured. Response time was measured via researchers clicking the mouse button as soon as the participant responded. There were several researchers involved, making it possible that the response times were confounded by the researchers individual reaction times. Although this was done to maintain consistency and to ensure that the participants did not advance the screen before they had responded, it may have inadvertently added an un-measureable variable.

More work is necessary to develop these measures for child samples, because the executive component task measures had been used with an adult population in other studies (Friedman et al., 2008, Miyake et al., 2000), but not with children. In order to make the assessments more appropriate for 9- and 10-year-olds and reasonable to be done within the school, the number of items on each measure was decreased. This may have decreased the reliability and validity of the measure. More research needs to focus on the isolated measurement of these neuropsychological constructs in order to develop optimal measures for young children such as those used in this study.

Also, the updating task may have been too confusing and not appropriate for that age child, as many of the participants had to practice several times before appearing to
understand the task. There was a trend seen where the 10-year-olds performed better (both more accurate and quicker) than the 9-year-olds. This suggests that the task was highly cognitively demanding and not measuring only the ability to update, but rather the child’s ability to remember what to do in combination with his/her ability to update. This also supports developmental trends in working memory and is consistent with other research.

The pretesting, intervention, and post testing had to take place at times that were not originally intended due to school wide state testing. The pretesting for all participants took place almost 4 weeks before the start of the intervention phase. In those four weeks, there was a holiday break and almost three-weeks of academic state-wide testing. This may have been a confounding factor in that all participants had approximately two months between pre- and post- intervention testing. Students may have felt burnt out at the start of the intervention, as it started immediately after state testing was finished. Meanwhile, those students in the control group were able to go back to their regular class routine for the weeks before post testing. This is not known, but is a potential confounding and unmeasurable factor.

Another limitation of this study that should be considered in future research is related to the measures used to assess working memory. The individual components were isolated with the intention of each individual component having the opportunity to be changed or improved with the intervention. There was no measure of overall working memory where the participants had to integrate multiple components. This may prove to be a key element in measuring whether a keyword mnemonics intervention has an impact on working memory ability. Integrating multiple modes of information, managing,
organizing and manipulating that information, then using it to carry out a task is what the working memory system aims to do. Thus, measuring each component independent of each other may not be the most valid approach to assessing the impact of an intervention aimed at improving working memory. In isolation, the components may not be affected, but when interacting as in integrated system in a working memory task, the working memory system may show change.

**Future Research**

Future research may focus on the improved quality of the measures related to assessing the fractionated components of working memory. Although several of the measures used had norms for children, others did not. In order to measure the executive components in children, adult tasks had to be adapted. This is common across studies which used children (e.g. Garon et al., 2008) where adult measures were adapted for the child participants. This suggests that additional research needs to be completed which aims to measure the components of working memory in young children.

Future research using various interventions may also consider the measurement of working memory as a system in addition to the fractionated components. Because this study did not measure the system as an integrated whole, it was difficult to determine whether working memory as it functions in everyday activities was improved. Adding this component of an inclusive measure of working memory may also shed light on how the interventions affect those who use them. For example, one may not improve his/her inhibition skills specifically, but may benefit from practicing utilizing the working memory system as in integrated entity throughout the intervention, thus creating a more efficient system.
References


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Kessler, Y., & Meiran, N. (2006). All updateable objects in working memory are updated
whenever any of them are modified: Evidence from the memory updating paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, p. 570-585.


Osaka, N., & Osaka, M. (2007). Neural bases of focusing attention in working memory:


Psychology Software Tools, Inc.


Verhaeghen, P., Marcoen, A., & Goossens, L. (1992). Improving working memory in the


Appendix A
Pretest

Paper-Based First (version A)

Code: __________
Examiner: ________________________

Demographic Information:

Age: ______
Gender: ______
School: ___________________________

Accuracy Raw Scores:

Word Generation ______  Stroop ______
Digits Forward ______  Category Switch ______
Memory for Location ______  Letter Memory ______
Word Generation (NEPSY-II)

1. See how many different animals you can name, like *cat* or *dog*. Say them as quickly as you can. Are you ready? Go. (60 seconds)

2. Now see if you can name some things you can eat or drink. Say as many different ones as you can, like *pizza* or *milk*. Do it quickly. Ready? Go. (60 seconds)

3. Now say all the different words you can think of that start with the letter “S” like *sun* and *sand*. Do not use any names of people and places, like *Susan* and *Springfield*. Say the words as quickly as you can. Ready? Go. (60 seconds)

4. The next letter is “F”. Tell me as many different words starting with “F” as you can think of, like *fun* and *farm*. Do not use any names of people and places, like *Frank* and *Florida*. Say them as quickly as you can. Ready? Go. (60 seconds)

<table>
<thead>
<tr>
<th>Semantic</th>
<th>Initial Letter</th>
</tr>
</thead>
</table>

Total  __________
Digits Forward (TOMAL-II)

Say: I’m going to say some numbers. Listen carefully, because when I’m done, I want you to say them just like I did.

Scoring: 1 point for each digit recalled in the correct placement.

End: After items 1-4 have been administered, discontinue when the examinee earns 3 or fewer points on each of two consecutive

<table>
<thead>
<tr>
<th>Key</th>
<th>Their response</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 8 – 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. 3 – 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. 6 – 8 – 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. 2 – 1 – 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. 4 – 6 – 1 – 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. 3 – 2 – 4 – 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. 6 – 9 – 1 – 3 – 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. 10 – 6 – 8 – 5 – 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. 6 – 4 – 9 – 2 – 1 – 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. 4 – 3 – 5 – 1 – 6 – 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. 1 – 3 – 9 – 6 – 8 – 3 – 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. 6 – 5 – 10 – 1 – 8 – 3 – 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. 9 – 4 – 10 – 1 – 2 – 8 – 10 – 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. 9 – 1 – 3 – 10 – 5 – 2 – 8 – 4 – 6</td>
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<td></td>
</tr>
<tr>
<td>15. 2 – 1 – 5 – 3 – 8 – 4 – 9 – 2 – 6 – 10</td>
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</tr>
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</table>

Max: 81 points  Total:  

138
Stroop Task (score 1 for correct; score 0 for incorrect)

<table>
<thead>
<tr>
<th>On the Screen</th>
<th>Correct answer</th>
<th>Response (note SC if they self-correct)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td><em>Blue</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td><em>Orange</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orange</td>
<td><em>Green</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*****</td>
<td><em>Purple</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td><em>Purple</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>***</td>
<td><em>Yellow</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td><em>Red</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td><em>Yellow</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*****</td>
<td><em>Blue</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purple</td>
<td><em>Green</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td><em>Green</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td><em>Red</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>***</td>
<td><em>Green</em></td>
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<td></td>
</tr>
<tr>
<td>Red</td>
<td><em>Orange</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purple</td>
<td><em>Orange</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*****</td>
<td><em>Orange</em></td>
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<td></td>
</tr>
<tr>
<td>Green</td>
<td><em>Blue</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>****</td>
<td><em>Red</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. ***** Orange
2. Red Purple
3. *** Green
4. Orange Orange
5. Red Red
6. Blue Blue
7. Orange Red
8. ***** Yellow
9. Red Blue
10. Yellow Green
11. Orange Orange
12. ***** Red
13. Purple Purple
14. Orange Blue
15. Red Red
16. Green Green
17. **** Red
18. Blue Blue
19. Yellow Yellow
20. ***** Blue
21. **** Yellow
22. Blue Yellow
23. **** Orange

139
<table>
<thead>
<tr>
<th>On the Screen</th>
<th>Correct answer</th>
<th>Response</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex: + table</td>
<td>Bigger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: * bicycle</td>
<td>Not Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: + coat</td>
<td>Bigger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: * cloud</td>
<td>Not Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: * mug</td>
<td>Not Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: + pebble</td>
<td>Smaller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: + marble</td>
<td>Smaller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: * snowflake</td>
<td>Not Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: * bear</td>
<td>Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: * lion</td>
<td>Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: + tree</td>
<td>Bigger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ex: * alligator</td>
<td>Alive</td>
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</table>

Category Switch Task (score 1 for correct; score 0 for incorrect)

Total: ___
<table>
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<th>On the Screen</th>
<th>Correct answer</th>
<th>Response (note SC if they self-correct)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. * bicycle</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2. + table</td>
<td>Bigger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. * mug</td>
<td>Not Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. + cloud</td>
<td>Bigger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. + tree</td>
<td>Bigger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. * pebble</td>
<td>Not Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. + marble</td>
<td>Smaller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. * snowflake</td>
<td>Not Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. * bear</td>
<td>Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. * lion</td>
<td>Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. + coat</td>
<td>Bigger</td>
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</tr>
<tr>
<td>12. * alligator</td>
<td>Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. + mushroom</td>
<td>Smaller</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. + bird</td>
<td>Smaller</td>
<td></td>
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</tr>
<tr>
<td>15. + goldfish</td>
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<td></td>
</tr>
<tr>
<td>16. * lizard</td>
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<td>17. * pebble</td>
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<td>18. + table</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>19. * cloud</td>
<td>Not Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. + coat</td>
<td>Bigger</td>
<td></td>
<td></td>
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<tr>
<td>21. + mug</td>
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</tr>
<tr>
<td>22. * bicycle</td>
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</tr>
<tr>
<td>23. * marble</td>
<td>Not Alive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24. + mushroom</td>
<td>Smaller</td>
<td></td>
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<tr>
<td>25. + bear</td>
<td>Bigger</td>
<td></td>
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<td>26. + lion</td>
<td>Bigger</td>
<td></td>
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<tr>
<td>27. * tree</td>
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<td>28. + alligator</td>
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<td>29. * snowflake</td>
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<td>35. * coat</td>
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<td></td>
</tr>
<tr>
<td>36. * cloud</td>
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Total: ____
## Letter Memory Task

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<th>Correct answer</th>
<th>Response</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>K—I—P</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>O—F—H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>B—D—Y</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 5     | C—O—F          |          |       |
| 7     | S—F—W          |          |       |
| 9     | T—M—H          |          |       |
| 9     | K—H—B          |          |       |
| 5     | J—P—G          |          |       |
| 7     | M—R—A          |          |       |

Total: ___
Appendix B

PLAN FOR INTERVENTION:

Sessions will consist of instruction from researchers provided to 8-10 students. Each session will be approximately 30 minutes and will be divided into two segments. The first part of each session will be teaching the mnemonic strategies and reviewing each time. The second part of each session will allow the students to apply a mnemonic of their own to provided words and states/capitals. This will provide an opportunity to practice using the keyword method.

1) Segment 1 – Technique

“We are going to learn about some techniques that will help us learn and remember information better. The strategies are called mnemonics. You can create your own, or you can use one that was already created. Some of you may have used them, or heard of them. An example may be a way to remember something like the colors of the rainbow—remember Roy G. Biv—red, orange, yellow, blue, green, indigo, and violet. We are going to go over a few ways you can help yourself remember other types of information. We’ll practice using one technique, one mnemonic, and help you with examples. Then you’ll get a chance to make some of these up on your own.

The first type of mnemonic is called the Letter technique. Teaching letter strategies involves the use of acronyms. Does anybody know what an acronym is? ——Acronyms are words whose individual letters can represent elements in lists of information, such as the word HOMES to represent the Great Lakes (write on a board or have this written out for them on a handout), Huron, Ontario, Michigan, Erie, Superior. Acrostics are sentences whose first letters represent to-be-remembered information, such as “My very educated mother just served us nine pizzas,” to remember the nine planets in order (e.g., Mercury, Venus, Earth, Mars).

Another technique is called Imagery. This has been used for thousands of years, beginning way back with the Romans. The story goes that Roman politicians and speakers used this method to remember parts of a speech given in front of a large crowd. In order to remember the parts of the speech, they would visualize themselves walking through a house, and each room represented a part of their speech or story.

The last technique is the Keyword method. With this type, we create a picture to remember, along with a “keyword” that is kind of like a “code word” to help us remember. A teacher might teach a new vocabulary word by first identifying a keyword that sounds similar to the new word and is easily represented by a picture or drawing. Then the teacher would come up with a picture that connects the word to be learned with its definition. Here is an example:

A teacher is trying to teach her students the definition of the old English word *carline*. She would first identify a good keyword. In this instance, “car” is appropriate because it is easy to represent visually and it sounds like the first part of the vocabulary word. *Carline* means
“witch”, so the teacher would show the students a picture of a car with a witch sitting in it. When asked to recall the definition of carline, students would go through four-steps:

1. Think back to the keyword (car),
2. Think of the picture (a car),
3. Remember what else was happening in the picture (a witch was in the car), and
4. Come up with the definition (witch).

5. 2) Segment 2- Mnemonic Strategies-Applied

VOCABULARY WORDS
“So now we are going to apply the Keyword technique. We are going to use it to learn new vocabulary words, and to help us remember states and capitals. First of all, the vocabulary word:

The word is “bedlam.” And it means a state of chaos. Our keyword is “bed” and the image is a bunch of people running around on top of a bed.

The next word is “confer.” It means to meet and talk. The keyword is “fur” and the image is furry animals sitting around talking.

STATES AND CAPITALS
“Now we are going to use the technique for remembering states and capitals. We will have a keyword for the state, one for the capital, and one to link the two.

The first one is Salem, Oregon. The keyword for Salem is “sailboat,” the keyword for Oregon is “ore” and the image is a sailboat with an ore on it.

The next is Harrisburg, Pennsylvania. The keyword for Harrisburg is “hairy,” the keyword for Pennsylvania is “pen” so the image is a hair pen.

What would be some keywords for Trenton, New Jersey?”

New Jersey          Trenton          A jersey hanging on a tent
("jersey")           ("tent")
Appendix C
Intervention Integrity Evaluation for Keyword Mnemonics

Researcher: ___________________________  School: ________________
Observer: ____________________________  Date: ________________
Number of Students in Group: ______  Session Number: _______
Start Time: __________________________  Stop Time: ____________

<table>
<thead>
<tr>
<th>Intervention component</th>
<th>Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Researcher introduced the topic/reviewed mnemonics</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Researcher handed out keyword mnemonics information sheet</td>
<td>No</td>
</tr>
<tr>
<td>3. Researcher put the kids into small groups to work on constructing their mnemonics</td>
<td></td>
</tr>
<tr>
<td>4. Researcher gave a vocabulary example and explained it</td>
<td>Yes</td>
</tr>
<tr>
<td>5. Researcher gave out the picture for vocabulary example</td>
<td>No</td>
</tr>
<tr>
<td>6. Researcher presented the vocabulary for the students to come up with a mnemonic for</td>
<td></td>
</tr>
<tr>
<td>7. Researcher gave students 5 minutes to complete this task, researchers gave help if</td>
<td></td>
</tr>
<tr>
<td>needed, and went over the example</td>
<td></td>
</tr>
<tr>
<td>8. Researcher went over the students’ keyword mnemonics</td>
<td>Yes</td>
</tr>
<tr>
<td>9. Researchers presented the second vocabulary word and gave students 5 minutes to</td>
<td></td>
</tr>
<tr>
<td>complete the task</td>
<td></td>
</tr>
<tr>
<td>10. Researchers went over the students’ examples</td>
<td>Yes</td>
</tr>
<tr>
<td>11. Researcher presented the state and capital mnemonic and explained it</td>
<td>Yes</td>
</tr>
<tr>
<td>12. Researcher handed out the state and capital example</td>
<td>No</td>
</tr>
<tr>
<td>13. Researcher presented the state and capital for the students to come up with a</td>
<td></td>
</tr>
<tr>
<td>mnemonic for</td>
<td></td>
</tr>
<tr>
<td>14. Researcher gave students 5 minutes to complete this task, researchers gave help if</td>
<td></td>
</tr>
<tr>
<td>needed</td>
<td></td>
</tr>
<tr>
<td>15. Researchers went over the students’ examples</td>
<td>Yes</td>
</tr>
<tr>
<td>16. Researcher reviewed the mnemonics learned today</td>
<td>Yes</td>
</tr>
</tbody>
</table>