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Effects of computarized [sic] cognitive training on working memory in a school setting

Tessy Tatiana Pumaccahua

EFFECTS OF COMPUTARIZED COGNITIVE TRAINING ON WORKING MEMORY IN A SCHOOL SETTING

A Thesis

Presented to the

Faculty of

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In Partial Fulfillment

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in

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by

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Approved by:

[redacted]

Dr. Eugene Wong, Chair, Psychology

6/7/2013

Date

[redacted]

Dr. Kelly Campbell

[redacted]

Dr. Robert Ricco

ABSTRACT

Strong academic performance and executive functioning are related to positive life outcomes. Conversely, decreased cognitive functioning may be associated with negative trends in developmental outcomes. One particularly important component of executive functioning is working memory, which is a strong predictor of life skills and academic abilities. The purpose of this study is to investigate the effectiveness of computerized cognitive training to improve working memory in a school setting. A total of 81 students with a mean age of 12.8 years were recruited from a private school in southern California that specializes in providing education to children with learning disabilities. Participants were assessed for levels of WM and completed a total of 20 hours of computerized cognitive training across 10 weeks. Analyses indicated that students with delayed working memory made gains in both measures of working memory, while their typical peers did not. Additionally, it was found that delayed students were able to approximate the visual working memory abilities of their typical peers at the end of the training. These findings show that computerized cognitive training is an effective intervention for children with working memory deficits, particularly in the area of visual working memory. Implications of these findings are discussed.

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CHAPTER ONE

INTRODUCTION

Academic success is a pivotal component of a child's development. Key components to this success include having a degree of flexibility and creativity to handle large amounts of new information, and effectively solve novel problems that arise with each new situation. Moreover, instrumental to academic success is self-control. Self-control allows a child to resist distractions and stay on task until completion (Diamond & Lee, 2011). Self-control is a part of the cognitive mechanism of *executive functions* (EF). Executive functions are the cognitive processes that allow an individual to concentrate on a task at hand, to control impulses, and are critical for the development of goal directed behavior (Welsh, 2002). In longitudinal studies, children from age three to eleven with lower self-control (i.e., those with less persistence, increased impulsivity, as well as poorer attention regulation) have been shown to have a variety of negative life-trajectories. Specifically, children with lower self-control had poorer health, earned less money, and committed more crimes as adults compared to children with better executive functioning, even after controlling for IQ, gender, and social economic status (Diamond & Lee, 2011).

Given the negative nature of these outcomes for children, research in education has sought to identify different ways to increase the cognitive mechanisms that underlie a child's ability to learn. The cognitive mechanisms that are the core components of EF include planning, problem solving, verbal reasoning, task switching, initiation, cognitive flexibility, inhibition, monitoring of actions, attention, and working memory (Barkley, 1997; Chan, Shum, Toulopoulou, & Chen, 2008; Monsell, 2003).

Working Memory and Academic Performance

Research in education has focused on the cognitive mechanism of *working memory* (WM) in order to increase learning among children. Working memory has been described as a system with a limited capacity that stores and processes information (Baddeley, 1986). Basic forms of both WM and inhibition are present early during development and continue to increase rapidly during a child's school-age years (Carlson, 2004). Additionally, WM and inhibition have been shown to be related to a variety of other real-word abilities such as theory of mind (Perner & Lang, 1999) and academic achievement (Biederman et al., 2004). Specifically, measures of performance on working memory tasks are demonstrated predictors of academic skills such as literacy (Swanson, 1994) and mathematics (DeStefano & LeFevre, 2004; Swanson & Jerman, 2006).

Working memory has also been shown to reliably predict performance on the following abilities related to academic success: reading and language comprehension (Daneman & Carpenter, 1980; King & Just, 1991); learning to spell and vocabulary building (Daneman & Green, 1986; Ormrod & Cochran, 1988); following directions (Engle, Carullo, & Collins, 1991); note-taking and writing (Benton, Kraft, Glover, & Plake, 1984; Kiewra & Benton, 1988); and reasoning and complex learning (Kylonen & Christal, 1990; Shute, 1991).

Along with the demonstrated positive relationships between WM and academic abilities, there are also relationships between low WM and decreased academic abilities. Children between the age of 7 and 14 years who perform poorly on measures of WM also perform poorly on national assessments of expected standards in science and mathematics (Gathercole, Brown, & Pickering, 2003; St Clair-Thompson & Gathercole, 2006).

Working memory problems are a central issue for children with mathematical disorders, given that WM plays such a large role in the ability to solve arithmetic problems (Passolunghi, 2006). Several studies estimate that approximately 3% to 8% of school-age children have mathematical disabilities (Desoete, Roeyers, & De Clercq, 2004; Gross-Tsur, Manor, & Shavlev, 1996). Specifically, children with mathematical disabilities have difficulties utilizing their working memory to monitor their counting process, which results in errors while solving problems (Hitch & Mcauley, 1991).

Another domain of concern for school-age children with WM weakness is learning to read. Working memory deficits have been identified among children displaying reading disabilities and dyslexia (Melby-Lervag, Lyster, & Hume, 2012; Swanson, 2006). In addition to academic disabilities, WM and inhibition have been related to neurodevelopmental disorders such as Attention-Deficit Hyperactivity Disorder (ADHD; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) as well as the Autism Spectrum Disorders (ASD; Kenworthy, et al., 2008). These children have severe impairments in social functioning and academic performance, which leads to difficulties that can often persist into adulthood (Biederman et al., 2000; Rasmussen & Gillberg, 2000).

Long Term Memory, Short Term Memory, and Working Memory

Given the wide spread influence of WM, including an impact on academic achievement, lifespan trajectories, and neuro-developmental disorders, WM is of central interest to researchers invested in making a difference in a child's life. In order to understand the WM literature, it is necessary to first be familiar with the history of research on memory including the different systems of memory.

The decision to divide memory into multiple systems occurred when psychologists noticed different cognitive abilities among patients with brain damage. Some patients had an inability to form new long lasting memories, but still performed well on a variety of previously learned tasks. However, other patients displayed normal rates of learning, but had very limited memory span. These findings led to the conclusion that memory must be based on separate systems, long term memory, short term memory, and working memory (Baddeley, 1992).

Long term memory is the amount of information that can be retained over long periods of time and recalled later. Despite the ability to recall information at a later time, this type of memory is subject to the forgetting process. Long term memory was initially proposed as a separate memory system that derived information from short-term memory stores (Atkinson & Shiffrin, 1968). Long term memory has been proposed to be separated further into different types of memory such as implicit, episodic, and declarative; however, the specifics of these memory types are beyond the scope of this paper.

Short-term memory (STM) refers to the amount of information that can be held over a brief period of time (Engle et al., 1999). Typically, it is assessed by verbal (e.g., letters or digits) or visuo-spatial recall (e.g., locations on a grid). Testing begins with a small list of items to be remembered and increases to larger ones with each successful recall. This process continues until the participant can no longer correctly recall the information. The amount of information that an individual can temporarily store and accurately recall is STM. Both WM and STM are similar in that they are limited by a storage capacity and subject to decay.

Despite the similarity between these two variables, the exact relationship between WM and STM has been proposed through distinct models; some researchers supported WM as a component of STM (Seamon & Kenrick, 1994) whereas others theorized that STM is a subset of WM (Cowan, 1995). Despite the lack of agreement about the relationship between these two memory systems, both are agreed to be distinct and highly related constructs, with WM being a more complex system (Engle et al., 1999; Klapp, Marshburn, & Lester, 1983).

The Working Memory Model

Working memory can be conceptualized as a temporary memory store, a rehearsal mechanism, as well as a process of controlled attention. One classic model of working memory that shares this conceptualization was proposed by Baddeley and Hitch (1974). This model describes two subsystems, the visuospatial sketchpad and the phonological loop, which assists with the rehearsal process. The model also describes a master system, the central executive, which oversees the functioning of the subsystems by controlling the allocation of attention. Baddeley (1992) proposed that the purpose of the phonological loop was to assist with speech perception and processing, whereas the function of the visuospatial sketchpad was to support visual perception. Finally, the central executive was proposed to be related to the development of planning and controlling attention (Cowan, 1998). This model has also been conceptualized as a temporary store (visuospatial sketchpad/phonological loop with rehearsal mechanisms) along with controlled attention (central executive).

Working memory is a higher cognitive process that involves STM, but also involves other processes such as attention, and is used to plan and carry out behavior (Miller, Galanter, & Pribram, 1960). Working memory often involves retrieving information while simultaneously performing distracting or interfering activities. For example, WM is used when solving an arithmetic problem without paper. Numbers are stored briefly as a representation, then combined in order to move onto the next step. Each number is progressively kept in WM until combined in order to achieve the goal of solving the problem and obtaining the answer.

Considering the available research on the relationship between memory and academic success, the strongest predictor of academic performance is working memory

(Swanson, 1994). The relationship between LTM and academic abilities is not explored as often as STM and WM, although it is agreed that LTM contributes to intellectual strength (Duckworth & Seligman, 2005). Short term memory has been linked to some measures of literacy (Swanson, Zheng, & Jerman, 2009) and math ability (Bull, Espy, & Wiebe, 2008), but compared to measures of WM, the STM measures were weaker. Overall, working memory has been consistently shown to be a better predictor of academic skills than STM (Daneman & Merickle, 1996; Engle, Tuholski, Laughlin, & Conway, 1999). Thus, much of the empirical attention is focused on working memory.

Working Memory and Neuroscience

In many studies, WM is defined as a domain general storage system for retaining small amounts of information over short periods of time and then making a response (Melby-Lervag & Hulme, 2012). Distractions related to attention and short term memory are known to affect WM (Colflesh & Conway, 2007). Working memory functions have also been demonstrated to be related to increased brain activity in the prefrontal cortex (Olesen, Westerberg, & Klingberg, 2004). Dopamine, a neurotransmitter commonly linked to the reward system, has been indicated to play a role in WM functioning by becoming more abundant after different activities related to WM (McNab et al., 2009). Neuroimaging studies have shown differences in brain activity associated with WM during the transition from childhood to adolescence (Klingberg, Frossberg, & Westerberg, 2002). These results suggest a refinement of WM during development as the prefrontal regions become more specialized for functions related to WM. Individuals with higher WM are less prone to be distracted by hearing their name called or looking at a flash in their peripheral vision (Conway & Engle, 1996). Additionally, individuals with strong working memory are less likely to mind-wander during tasks (Kane et al., 2007).

Measuring Working Memory

Historically, WM has been measured through recall capacity on span tasks or performance on the Stroop test. The Stroop test requires individuals to state a color-related word correctly despite that word being printed in a different color. For example, saying the word "green" out loud despite the word green being printed in a red color. Individuals with low WM are slower to provide correct responses and are more prone to making errors on the Stroop test (Kane & Engle, 2003). Children with low WM capacity are similarly prone to having difficulties with complex instructions, learning disabilities, and neuropsychiatric conditions such as traumatic brain injury, stroke, and schizophrenia (Klingberg, 2010). Impaired WM is also a primary characteristic of ADHD (Engle et al., 1991). The ability to improve these outcomes is of great interest to researchers in order to reduce the deficits associated with impaired WM.

Can Working Memory be Trained?

It is currently unknown to what extent WM can be improved. Some researchers have examined whether practicing can create changes in the neuroplasticity that underlies the areas of the brain that correspond to WM. In order to evaluate the changes in neuroplasticity, a study investigated neuroplasticity for WM in macaque monkeys (Rainer & Miller, 2000). The monkeys practiced delayed-response tasks with increasing difficulty over several weeks. The researchers concluded that the areas of the brain that were related to WM functioning were more resistant to stimulus decay. Research on humans has demonstrated several examples of successfully training attention (Sohlberg, McLaughlin, Pavese, Heidrich, & Posner, 2000). Although WM capacity is connected to attentional capacity, it appears that training WM is a more complex process (Engle, Tuholski, Laughlin, & Conway, 1999).

The process of increasing WM capacity in children involves teaching memory techniques or exposure to repeated trials of WM tasks. Teaching memory techniques usually involves teaching children mental rehearsal strategies such as chunking, mnemonics, visual imagery, and method of loci (Brown, Campione, Bray, & Wilcox, 1973; Butterfield, Wambold, & Belmont, 1973; De La Iglesia, Buceta, & Campons, 2005; Hulme, 1992; Klingberg, 2010). However, this is not usually beneficial for young children, given that they do not use mentally based strategies until approximately seven years of age (Gathercole, 1998).

On the other hand, exposure to repeated WM trials along with reinforcement contingencies and feedback, have also been shown to positively impact children's task performance, working memory, literacy, and mathematical abilities (Klingberg, 2010; Prins et al., 2011; Rabiner et al., 2010). In addition to the previously mentioned benefits, working memory training has also been shown to lead to an increase in intelligence as indicated by better performance on Raven's Progressive Matrices (Raven, Raven, & Court, 2003).

Training Working Memory

One way to increase the effectiveness of WM training has been to use an adaptive computer-based program to provide the training stimuli and feedback (Rabiner, Murray Skinner, & Malone, 2009; Shavlev, Tsal, & Mevorach, 2007). Specifically, the adaptive nature of the computer program allows it to make adjustments in difficulty based on the performance of the user. For example, if the user completed an exercise correctly, the next exercise presented would be more difficult. Conversely, if the exercise is completed incorrectly the next exercise would be less difficult. When the difficulty of repeated exposure to WM trials is not adaptive, faster reaction times may be produced, which is reflective of an increase in attention, but not an increase in WM capacity (Kristofferson, 1972; Phillips & Nettelbeck, 1984). It has been common for researchers to use non-adaptive versions of WM training programs as control groups.

Computerized Cognitive Training

Computerized Cognitive Training (CCT) typically involves providing a child with a task related to working memory via a computer program. Similar to the previously mentioned computerized programs, CCT typically begins with a low-difficulty task and the computer adjusts the difficulty as the child exhibits increases or decreases in his/her WM ability. The computer program is able to automatically adapt the difficulty level as the child's skills increase in order to create a state of flow and to provide an appropriate level of challenge (Prins et al., 2011; Csikszentmihalyi, 1975). Therefore, the training is always targeted to the child's WM capacity and the challenge is never too hard nor too easy to reduce motivation. The control groups for experiments that utilize CCT often use a computer program copy that does not adapt to the child's performance.

An assessment of the effectiveness of past cognitive training (CT) interventions by Abikoff (1991) showed that improvements in behavioral or cognitive skills were mostly moderate and short term. However, many of the studies reviewed by Abikoff were not computerized, since at that time computer technology was not as widely accessible by the general public. One early study by Kotwal, Burns, and Montgomery (1996) investigated the early potential of CCT on a 13 year old male who was diagnosed with ADHD. Although the parents did not report a change in behaviors, there was a difference in his cognitive performance after 35 sessions of a CCT program. This improvement was maintained when Kotwal and colleagues (1999) completed an assessment seven months after the last session. This finding lead past researchers to posit that CCT had the potential to improve WM skills in children, particularly those with attentional deficits.

The most current types of programs used for CCT include CogMed's *RoboMemo Working Memory Training*, BrainTrain's *Captain's Log* (Sandford & Browne, 1988), or a program created by the researchers themselves. These programs are typically designed to appeal to children and adolescents and involve different exercises including visuo-spatial working memory and verbal working memory. The method by which each program presents these exercises to users is unique to each software. For example in *RoboMemo*, the child is introduced to the character SuperMecha and instructed to help this robot defend the city from an invasion from the evil robots. In order to assist

SuperMecha, the user must complete various WM training tasks. Upon completion, the user may print out a certificate that indicates he/she has saved the city and completed the program (Prins et al., 2011).

Another commonly used CCT program, *Captain's Log,* is a cognitive training program with fifty adaptive exercises organized into three training sets: attention skills training, problem solving skills training, and working memory training (Sandford, 2007; Sandford & Browne, 1988). The working memory training set challenges the child to improve their ability to learn and remember through a series of exercises totaling up to 625 hours. The working memory training set contains three modules: real life working memory, working memory skills, and auditory working memory. Regardless of the specific program used to provide opportunities for children to practice WM training, each program is typically administered for five weeks, providing the child an hour worth of training each day.

The results from CCT have demonstrated increases in attention, WM, scholastic skills, and decreases in diagnostic symptoms in children with ADHD (Klingberg et al., 2005; Rabiner et al., 2010; Shavlev, Tsal, & Mevorach, 2007; Slate, Meyers, Burns, & Montgomery, 1998).

Additionally, Klingberg and colleagues (2002) showed an improvement in inhibitory control and reasoning abilities in 7 to 12 year old children with ADHD through an intense WM training schedule (25-40 minutes per day during 5 weeks).

Given that WM is related to a variety of higher cognitive abilities, it would be expected that WM training would result in transfer effects to non-trained similar and distantly related tasks, as well as ameliorate deficits related to poor WM capacity. However, it has been noted that both WM training and using cognitive techniques result in a lack of generalization from trained tasks to non-trained tasks. One case study described a subject who was able to retain more than 80 digits by associating the numbers to a series already stored in LTM, however this ability did not transfer to a larger capacity for verbal material (Ericsson, Chase, & Faloon, 1980). Diamond and Lee (2011) reported that training using CogMed can result in increased performance on EF tasks, however they also noted that this trend did not generalize to other unpracticed EF tasks. Klingberg (2010) makes the case that WM training has a larger effect on those with low WM capacity, and demonstrated observed improvements in remembering instructions and solving mathematical problems among children with low WM.

Although Klingberg supports the efficacy of WM training as an intervention for children with low WM capacity, other researchers are not as convinced (Levarg & Hulme, 2012; Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2010). Altogether the research represents a combination of mixed effectiveness, with some research demonstrating evidence for limited training effects, and some research showing evidence for distantly related transfer effects. One of the issues raised by the conflicting research involves settings for WM training that result in practical benefits.

Computerized Cognitive Training in a School Setting

To investigate the effective integration of CCT into different settings, a growing trend has been to move WM training and CCT towards applied settings such as schools. Working memory training has been explored by introducing it at schools for children with attention problems or those with ADHD. One study that best exemplifies this transition is by Mezzacappa and Buckner (2010). The researchers conducted a small pilot study in a school setting to investigate the potential for CogMed's RoboMemo to increase the WM functioning among young children from an economically disadvantaged neighborhood in Boston, MA. In earlier studies, low SES was often used as an exclusion criterion since it was reasoned that children's low SES would prohibit them from finishing the WM training either at home or at school (Klingberg et al., 2005).

The study by Mezzacappa and Buckner (2010) utilized a small group of participants and investigated WM functioning before and after the CCT training. These students were involved in the WM training five days a week for 45 minutes each session, over a five-week span. The researchers were able to implement the CCT within the school curriculum as a pullout program from regular classes, which has generally not been the case with other studies. Other researchers have introduced the CCT materials at the school, and had students complete the program at home (Klingberg et al., 2005); or had the programs at the school, but offered outside of the curriculum (Steiner, Sheldrick, Gotthelf & Perrin, 2011). After the five-week training period, students showed an improvement on all measures analyzed by Mezzacappa and Buckner (2010). Teacher's ratings of the student's behaviors increased by a large magnitude and student's performance on the Finger-Windows task (a visual spatial WM task) also showed improvement.

Another pilot study, which utilized a pull out program at a specialized school for students with learning disabilities, was conducted in southern California (Wong, Wiest, Pumaccahua, Nelson, & Neire, 2012). This study investigated changes in WM functioning before and after the use of a CCT intervention. These students were involved in the WM training for a total of 20 hours across 10 weeks. The results of this study demonstrated significant benefits in working memory for the participants.

It is important to continue investigating the effectiveness of CCT within the school setting for children with learning disabilities (LD). Students with LD tend to have greater problems related to working memory. In a large-scale study that examined the cognitive profiles of children with working memory deficits, it was found that these children typically have a variety of academic and behavioral problems including literacy, math skills, classroom behaviors and short attention spans (Alloway, Gathercole, Kirkwood, & Elliott, 2009). Without an appropriate intervention these children are at high risk of academic underachievement for the remainder of their scholastic career (Alloway, 2009; Gathercole & Alloway, 2008).

Given that CCT and WM training are still relatively new areas of research, it would be beneficial to conduct larger follow-up studies in order to establish the effectiveness of CCT within an applied setting. Children are required to use their WM capabilities in order to meet the demands of the curriculum; therefore it makes sense to offer them a chance to train their WM within their schools. Computerized cognitive training is an effective intervention that assists students with low WM capacity, attentional deficits, and those that struggle with ADHD. However, it is necessary to evaluate how effectively it can be integrated within the school setting on a larger scale.

Purpose and Hypotheses

The purpose of this study is to explore the effectiveness of CCT to increase the cognitive abilities of children with learning disabilities in a school setting over a period of 10 weeks. We expect different levels of gains depending on the initial levels of WM capacity of the school children, such that children with delayed WM will display greater gains for visual and verbal WM from CCT. We also expect gains for visual and verbal WM from those children with typical levels of WM, although these gains will not be as strong as the delayed WM group. Although it is expected that both the delayed and typical groups will have qualitatively different WM capacities after exposure to the intervention, the gap between each group is expected to decrease to the degree that the differences will no longer be significant.

Hypothesis 1:

Children with delayed WM capacity will improve in post-test verbal WM by a large magnitude compared to pre-test scores.

Hypothesis 2:

Children with delayed WM capacity will improve in post-test visual WM by a large magnitude compared to pre-test scores.

Hypothesis 3:

Children with typical WM capacity will improve in post-test verbal WM by a small magnitude compared to pre-test scores.

Hypothesis 4:

Children with typical WM capacity will improve in post-test visual WM by a small magnitude compared to pre-test scores.

Hypothesis 5:

Post-test improvement in verbal WM for both delayed and typical WM capacity will not be statistically different.

Hypothesis 6:

Post-test improvement in visual WM for both delayed and typical WM capacity will not be statistically different.

Hypothesis 7:

Given the expected differences in training effects for both delayed and typical WM groups, it is hypothesized that there will be an interaction for pre and post-test verbal WM scores and group classification of WM.

Hypothesis 8:

It is hypothesized that there will be an interaction for pre and post-test visual WM scores and group classification of WM.

CHAPTER TWO

METHOD

Participants

Participants consisted of 49 males and 32 females (N = 81), ranging from 11 to 18 years of age (*M* = 12.83). Recruitment of participants was conducted during 2010 - 2013 and took place at a private school in Southern California, which specializes in providing education for students with learning disabilities and related disorders. Specifically, 51 of the 81 participants received one or more formal diagnosis(es); see Table 1 for the specific diagnoses. Participants in this study were parent-referred or referred by a teacher. All participants were treated in accordance to the Ethical Principles of Psychologists and Code of Conduct (American Psychological Association, 2002).

Table 1. Diagnoses of Participants

Type of Disorder	Instances
Autism	3
Emotional Disturbances	5
Other Health Impairment	9
ADHD (including ADD) .	13
Specific Learning Disabilities	43

Note. A total of 19 children had multiple diagnoses. The number of students with each type of disorder (as identified in this table) does not sum to 51 because of the multiple diagnoses.

Measures

The following is a description of the measures that were utilized for the original data collection that produced the archived data set used in this project.

Wide Range Assessment of Memory and Learning

The Wide Range Assessment of Memory and Learning, Second Edition™ (WRAML2) was developed by Sheslow and Adams (2003) to provide an assessment of memory for individuals, ages 5 to 90. The WRAML2 consists of a battery of tests for general memory as well as optional subtests for working memory and recognition. Specifically, the general memory battery consists of tests to assess verbal memory, visual memory, and attention. These tests can be combined into an index of general memory. The WRAML2 has been demonstrated to have a high reliability for the general memory index (Sheslow & Adams, 2003).

The Working Memory assessment consists of two tasks, one for symbolic (or visual) working memory and the other for verbal working memory, which have been normed for children ages 9 and older. The scores of both subtests can be combined into a working memory index, which has been demonstrated to have high internal reliability (Strauss, Sherman, & Spreen, 2006). Only the verbal and symbolic working memory subtests (from the WRAML-2) were used during the pre and post-test phases of this project.

Verbal Working Memory Assessment

The assessment of verbal working memory was based on a task where participants were provided with a verbal sequence of animals and non-animals and then instructed to recall the sequence. An additional requirement for the participants, as they recalled the sequence, was to first report the animals and then the non-animals. For example, if given the list "cat, tree, fish" the participant would be expected to respond "cat, fish, tree." The participants were awarded one point for recalling the animals correctly, another point for recalling the non-animals correctly, and a bonus point for recalling both groups correctly without the intrusion of an incorrect response. If the participants responded incorrectly across two consecutive items, then the test was discontinued and the participant would only earn the points up to the point of termination.

There were three levels within the verbal working memory assessment, which were administered based on the age of the participant. For participants ages 9 to 13, Level A was followed by Level B. For participants ages 14 to 18, Level B was administered initially, followed by Level C. Although all three levels shared the same expectation, that participants recall the animals first and the non-animals afterwards, there was an important distinction between the three levels. In Level A, the participants were able to recall the animals in any order, followed by the non-animals in any order. In Level B, the participants were expected to recall the animals in order from smallest to largest, followed by the non-animals in any order. Finally in Level C, the participants were expected to recall the animals in order from smallest to largest, followed by the non-animals in order from smallest to largest. In order to be awarded a point, the participants had to correctly recall the animals and then the non-animals based on the specifications according to each level. There were a total 6 items in Level A, a total of 8 items for Level B, and a total of 6 items for Level C. The total number of points across the two respective levels were used to create an aggregate Verbal Working Memory raw score. The raw score was then transformed into a standardized value.

Symbolic Working Memory Assessment

The assessment of symbolic working memory was based on a task where participants were provided with a verbal sequence of numbers and/or letters and then instructed to point on a sheet to indicate the numbers and letters they heard. Two levels of this test were administered for participants ages 9 and older. Upon completion or discontinuation of the first level, the second level was conducted. In the first level, participants were only verbally provided sequences of numbers ranging from one to eight, and instructed to point on a sheet to indicate the numbers they heard in order from least to greatest. For example, if the participant was provided with the sequence "3 2 5" they would be expected to point on the sheet sequentially to indicate "2 3 5." The sheet was an 8.5 x 11" laminated card with the numbers one through eight arranged in two rows with small yellow circles around each number. A total of 14 items were provided on the Level A assessment beginning with two distinct digits and ending with six distinct digits.

The second level of the symbolic working memory task, Level B, also had the numbers one through eight. In addition to the numbers, it also included 10 letters (A through J). The second level had 14 items beginning with a sequence of three letters and numbers and culminating with a sequence of seven letters and numbers. Level B also had a new corresponding card for participants to indicate the sequences they heard, with two rows of numbers (1-8) followed by two rows of letters (A-J). The participants were instructed to point on the corresponding card to indicate the numbers first (in order from least to greatest) followed by the letters (in alphabetical order). For example, if the sequence "2 G 3 E" was provided, the participant would be expected to point in the following order "2 3 E G." Each correct sequence recalled was awarded one point, errors across three consecutive items resulted in the test being discontinued. Points were summed across both levels in order to provide a total symbolic working memory raw score. The raw score was transformed into a standard score.

Captain's Log

A computerized cognitive training program, *Captain's Log,* was used as the intervention for this study. Participants interacted with this training program primarily through the use of a computer mouse and keyboard. Captain's Log is designed to develop a wide range of cognitive skills through various brain training exercises and is organized into three training sets: attention skills training, problem solving skills training, and working memory training (Sandford, 2007; Sandford & Browne, 1988).

The working memory training set provides the opportunity for children to improve their ability to learn and remember through a series of challenges from three separate modules: real life working memory, working memory skills, and auditory working memory. Only two of the working memory training modules from the working memory set were used for the latest cohort, specifically the working memory skills and the auditory working memory modules. Previous cohorts were trained on an earlier version of Captain's Log.

The working memory training modules are composed of various games characterized by a common goal. For example, *Remember the Alamo* is a game in the working memory skills module. In this game, the user is visually presented with a series of letters and numbers for a brief period of time. On the next screen, the user is instructed to select from a variety of numbers and letters in order to reproduce the earlier presented series in reverse order. The numbers and letters are arranged on the right hand side of the screen in a vertical arrangement. As the child selects each number or letter using the computer mouse, a train travels across the screen until arrives at its "destination" and verbal praise is provided for making a correct choice.

In another game, *Racing Robots,* which targets auditory working memory, the user is provided with a screen displaying a race between a user controlled robot racer and a computer controlled robot racer. The goal of this game is to answer simple math questions correctly in order to move faster than the other racers and reach the finish line first. The user is auditorily presented with the math problems and then visually provided with three possible choices. A selection with the correct answer provides the user with verbal feedback and an increase in speed for their racing robot.

Participants in earlier cohorts completed games only from the Working Memory Skills module; however, the activities targeted the same skills. Captain's Log was programmed to run each module for 15 minutes, with the first session beginning at the simplest level and adjustments in difficulty were made based on the child's performance. Specifically, the adaptive nature of Captain's Log would adjust the difficulty of the modules to become easier if the participant made an error, or harder if the participant selected a correct response.

Procedure

Original Data Collection

Approval from the Institutional Review Board at CSU San Bernardino, as well as permission from the private school, was obtained prior to the onset of the study. All participants' parents were given an informed consent to read, sign, and return prior to the start of assessment; students provided assent for their participation. Assessment of WM was achieved through the use of WRAML2 and was completed a week before the cognitive intervention. The

WRAML2 is a norm-referenced measure of memory that includes subtests that evaluate working memory; all subtests are administered using a standardized format. Performance on the subtests of the WRAML-2 are reported in terms of a scaled score, which have a mean of 10 and a standard deviation of 3. In clinical settings, a criterion of one standard deviation below the mean is widely used to establish clinical significance (Kraemer et al., 2003; Thambirajah, 2005). This same approach was used to establish a student's classification of WM (i.e., delayed or typical) in this sample. Therefore, participants who scored seven or greater on the WM measures were categorized into the typical WM group. Conversely, those students who scored six or below on the same measures were categorized into the delayed WM group. Following pretesting, participants began the computerized cognitive training via the use of the Captain's Log (CL) program. Participants played CL games/activities 30 minutes per day, four days a week, for a total of 20 hours across 10 weeks.

Participants came in for training in groups of ten, across three time sessions. During these sessions, participants were seated at various stations throughout a classroom specifically dedicated for CCT. Laptops, computer mice, and headphones were provided to create the work stations. The layout of the stations was set-up with enough room in between participants to discourage distractions. Supervision of the ten participants during each of the CL sessions was provided by one or two adults (i.e., upper level students at CSUSB and/or teachers at the private school). Each adult was in charge of one specific day of the week. All supervising adults received two hours of training which familiarized them with the features of the CL program, as well as how to set up and administer the modules.

Students who were absent or late during sessions were given respective make-up sessions, in order to assure that all participants completed the 20 hours of CL training. A week after CL training was completed, all participants were assessed on their WM through the WRAML2. Assessment and cognitive training both took place at the participants' school during the regular school-day hours; thus, the training was provided within a "pull-out" model during the school day.

Analysis of Archival Data/Design

The data investigated by the current project was obtained from a previously existing data source, making this study archival in nature. Specifically, this project utilized the data collected according to the previously described methodology. The design and analyses of the data are outlined in the following section.

The independent variables investigated in this study included the time of assessment (pre vs. post) and the categorization of WM ability (delayed vs. typical). Additionally, the dependent variables assessed in this study included verbal working memory performance as well as visual (i.e., symbolic) working memory performance.

A mixed design was used for this study based on a 2 within-subjects (i.e., pre-test vs. post-test) by 2 between-subjects (i.e., delayed vs. typical) pre-experimental design. All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 21.0 for Macintosh with a significance level criterion of $p < .05$. A paired samples t-test was used to assess differences across pre-test and post-test scores of working memory. Furthermore, an independent samples t-test was used to assess differences between delayed and typical students. A factorial analysis of variance (ANOVA) was used to determine the presence of any interaction effects on working memory performance as a result of testing period (i.e., pre-test vs. post-test) and WM ability (i.e., delayed vs. typical). Practical significance was assessed through the use of a Cohen's D as well as an eta squared statistic (Ferguson, 2009).

CHAPTER THREE

RESULTS

Means and standard deviations for delayed and typical WM scores are presented in Table 2. Overall the means and standard deviations for the complete dataset are as follows: verbal WM pretest (M = 9.38, SD = 2.50), verbal WM post-test (M = 9.81, SD = 2.63), visual WM pretest (M = 9.30, SD = 2.38), and visual WM post-test (M = 9.79, SD = 2.84). A common observed trend was that each group (i.e., delayed and typical) showed improvement, however each improvement was investigated with a statistical analysis to discern the extent of the difference and magnitude.

Table 2. Overall Means and Standard Deviations for Working Memory Measures

		Pre-Test		Post-Test	
		Mean	Std Dev	Mean	Std Dev
Delayed	Verbal WM	5.45	0.82	7.27	1.73
	Visual WM	5.43	1.13	8.14	1.67
Typical	Verbal WM	10.00	2.07	10.21	2.53
	Visual WM	9.67	2.13	9.94	2.89

H1: A comparison of pre-test verbal WM scores and post-test verbal WM scores among children with delayed WM was conducted. The paired samples t-test indicated a significant difference between pre-test verbal WM scores ($M = 5.45$, $SD = 0.82$) and post-test verbal WM scores ($M = 7.27$, $SD = 1.73$), $t(10) = -3.03$, $p = .013$. The analysis of magnitude revealed that the difference was large, $d = 1.42$. The results of the analysis support hypothesis one, demonstrating that children with delayed WM experience large gains as a result of exposure to CCT.

H2: An accompanying comparison of pre-test and post-test of visual (i.e., symbolic) WM scores among children with delayed WM was conducted. The paired samples t-test was significant, $t(6) = -2.80$, $p = .031$. The analysis of magnitude also revealed that the difference was large, $d = 1.93$. The results of this analysis demonstrate that children with delayed visual WM improve to a large degree as a result of exposure to CCT.

H3: In order to assess differences among children with typical verbal WM a comparison of pre-test and post-test scores was conducted. The paired samples t-test for pre-test verbal WM scores ($M = 10.00$, $SD = 2.07$) and post-test verbal WM scores ($M = 10.21$, $SD = 2.53$) yielded no significant difference $t(69) = -0.86$, $p = .394$, $d = 0.09$. Children with typical verbal WM did not make a significant improvement as a result of exposure to CCT, therefore hypothesis three was not supported.

H4: An assessment of the differences among children with typical visual WM was also conducted to examine the differences between pre-test and post-test scores. The paired samples t-test for pre-test visual WM scores ($M = 9.67$, $SD = 2.13$) and post-test visual WM scores ($M = 9.94$, $SD = 2.89$) was not significant, $t(73) = -1.10$, $p = .274$, $d = 0.10$. Children with typical visual WM did not exhibit a significant improvement as a result of exposure to CCT, therefore hypothesis four was not supported.

H5: In order to assess the expected similarity of post-test verbal WM scores between children with delayed WM and children with typical WM, an independent samples t-test was conducted. Results of the analysis indicated a significant difference between the post-test scores of verbal WM of children with delayed WM ($M = 7.27$, $SD = 1.73$) and children with typical WM ($M = 10.21$, $SD = 2.53$), $t(79) = -3.70$, $p = .001$. Contrary to what was expected, children with delayed verbal WM did not approach the verbal WM abilities of their typical peers in terms of post-test scores, therefore hypothesis five was not supported.

H6: Similar to hypothesis five, the difference in post-test symbolic WM scores between children with delayed WM and children with typical WM was evaluated via an independent samples t-test. The analysis demonstrated that there was no significant difference between post-test scores of symbolic WM of children with delayed WM (M = 8.14, SD = 1.67) and children with typical WM (M = 9.94, SD = 2.89), $t(79) = -1.62$, $p = .109$. As was expected, children with delayed visual WM were able to approximate the post-test levels of their typical peers as a result of exposure to CCT, therefore hypothesis six was supported.

H7: To assess the possibility of an interaction on verbal WM abilities, a mixed-design 2x2 analysis of variance (ANOVA) with time of assessment (pre-test, post-test) as the within-subjects factor and verbal WM classification (delayed, typical) as the between-subjects factor was conducted. The resulting analysis revealed a significant main effect for verbal WM classification $F(1, 158) = 9.58$, $p = .002$, $\eta_p^2 = .057$, but no significant main effect for time of assessment $F(1, 158) = 1.12$, $p = .290$, $\eta_p^2 = .007$ (see Table 3 for descriptive data). However, the predicted interaction of time of assessment and WM classification was not significant, $F(1, 158) = .087$, $p = .769$, $\eta_p^2 = .001$ (see Figure 1). As a result, hypothesis seven was not supported. It appears that both classifications of WM ability experienced similar rates of gains in verbal WM as a result of exposure to CCT.

Table 3. Main Effects for Verbal Working Memory

Variable	df	F	eta	p
Classification	1	9.57	0.057	0.01*
Time of Assessment	1	1.12	0.007	0.29
Interaction	1	0.08	0.001	0.77

Note: * p < .05

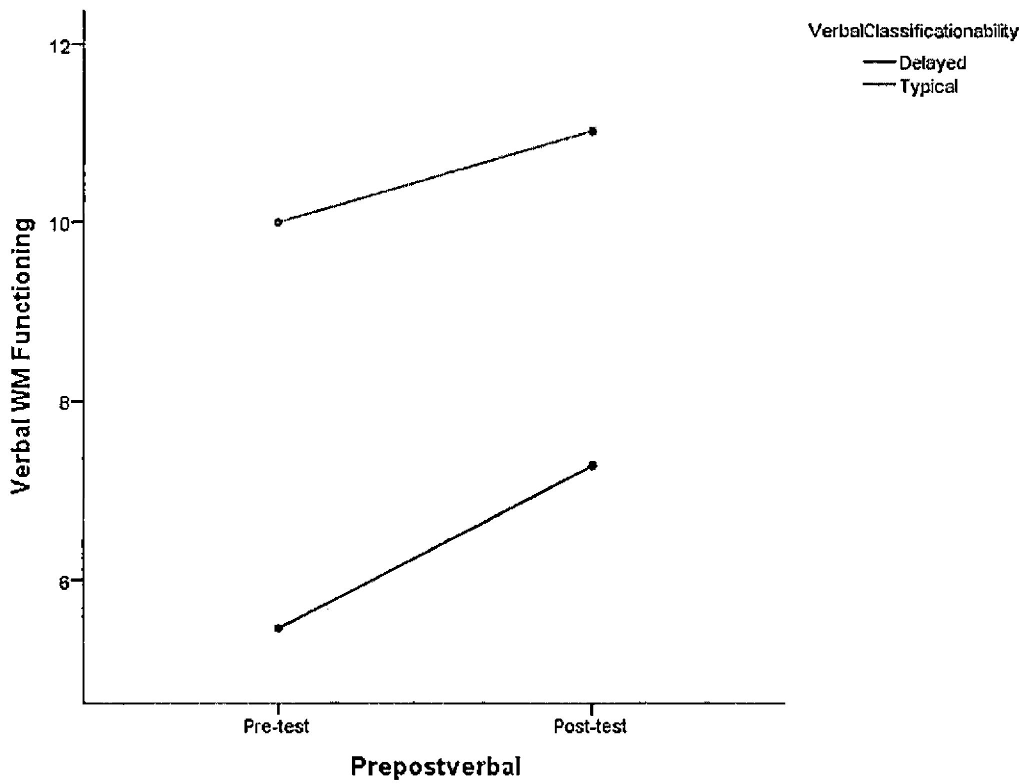

Figure 1. Analysis Investigating a Proposed Interaction for Verbal Working Memory.

H8: Finally, one last mixed-design 2x2 ANOVA of visual WM was conducted with time of assessment (pre-test, post-test) as the within-subjects factor and visual WM classification (delayed, typical) as the between-subjects factor. This analysis demonstrated a significant main effect for time of assessment $F(1, 158) = 4.65$, $p = .032$, $\eta_p^2 = .029$, and a significant main effect for visual WM classification $F(1, 158) = 19.13$, $p = .001$, $\eta_p^2 = .108$ (see Table 4 for descriptive data). These main effects were not qualified by an interaction between time of assessment and visual WM classification $F(1, 158) = 3.12$, $p = .079$, $\eta_p^2 = .019$ (see Figure 2). Although the predicted interaction was not significant, it did approach significance. As a result, although hypothesis eight was not supported there appears to be a trend in support of the prediction. Therefore, children with different levels of WM may experience varying rates of gains in visual WM as a result of exposure to CCT.

Table 4. Main Effects and Interaction for Visual Working Memory

Variable	df	F	eta	p
Classification	1	19.13	0.108	0.01*
Time of Assessment	1	4.65	0.029	0.03*
Interaction	1	3.12	0.019	0.07†

Note: *p < .05, †p approached significance

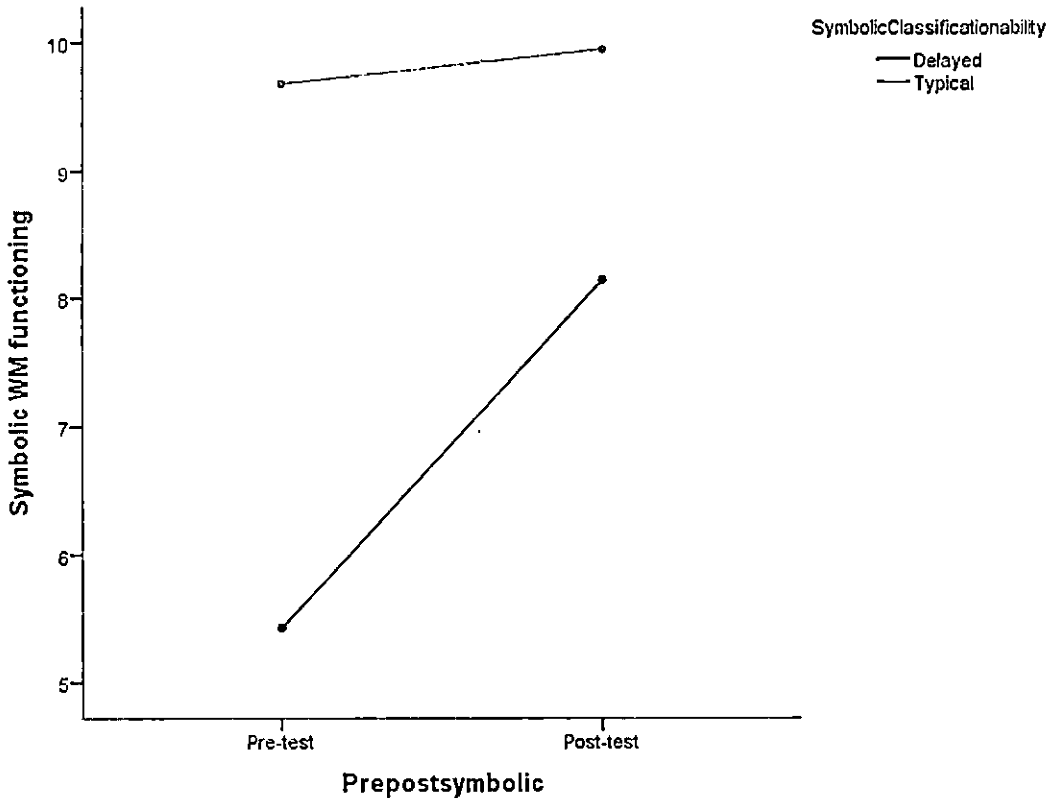

Figure 2. Analysis Investigating an Approximate Interaction for Visual Working Memory.

CHAPTER FOUR

DISCUSSION

Overall the results highlight a trend consistent with the hypotheses. Specifically, students with delayed WM were observed to make greater significant gains as a result of CCT in comparison to students with typical WM. Because of this pattern of findings the results will be combined when discussing their implications.

Hypotheses 1 and 2

The first and second hypotheses were related to expected gains for children with delayed WM as a result of exposure to CCT. Overall, both hypotheses were supported, and demonstrated large effect sizes. Thus, it would appear that CCT greatly improved this group of children's WM, despite their previous classification as delayed WM. In fact, the magnitude of change was so large that the post-test scores of this group would have enabled them to be re-classified as typical WM in terms of decision making for group classification.

This finding is similar to previous studies that have investigated gains made by special education children after exposure to CCT (Dahlin, 2011). Klingberg, Forssberg, and Westerberg's (2002) study would have yielded similar magnitudes of change in WM among children with ADHD had such values been reported. Although the effect sizes of these changes were not included within the original paper, a calculation was possible using their reported values. These calculations showed that the children with ADHD were able to make medium gains in visual WM and large gains in verbal WM.

A follow up study by Klingberg and colleagues (2005) revealed that children with ADHD were able to make significant gains for both visual and verbal WM after exposure to CCT. Once again, although measures of effect size were not included originally in their paper, a calculation based on the provided values within the article revealed medium gains for visual and small gains for verbal WM.

In general, the current study's findings are consistent with past research that has examined gains for children from groups characterized by having deficits in WM. The group of children involved in the current study was able to make large gains for both visual and verbal WM. Additionally, these gains were so large that they would no longer qualify to be classified as having delayed WM. This practical gain is very important considering the academic consequences associated with lower levels of WM, including difficulty with arithmetic (Passolunghi, 2006) and reading (Melby-Lervag, Lyster, & Hume, 2012; Swanson, 2006). A further investigation of the rate of change in WM in comparison to gains made by their typical peers was provided by hypotheses five through eight.

Hypotheses 3 and 4

The third and fourth hypotheses predicted significant gains of small magnitude for children with typical WM as a result of exposure to CCT. These hypotheses were not supported. Children with typical levels of visual and verbal WM were able to make gains that were small in magnitude as a result of CCT, however these improvements to their WM abilities were not statistically significant. To clarify, it appears that children with typical WM abilities, both visual and verbal, did not benefit from exposure to CCT.

The current results regarding typical WM children are not entirely consistent with previous work. Some authors have demonstrated WM benefits for children in control groups in addition to children with WM deficits, suggesting that even typically functioning children can experience improvements as a result of CCT (Klingberg et al., 2002; 2005). However, upon closer review, the control groups in these studies demonstrated only small effect sizes in both visual and verbal WM after completing a calculation based on available data. Moreover, it is important to note that the type of statistic (i.e., one-tailed t-test compared to the two tailed t-test used by this current study) may be a key difference as to why the typical children in our study did not also share the similar significant results to those in the previous studies by Klingberg and colleagues, despite the effect sizes being fairly similar. In particular, the nature of one-tailed t-tests makes it easier to obtain significant results compared to two-tailed t-tests.

Based on the findings regarding children (in this study) with typical levels of WM, it appears that exposure to CCT does not result in improvement for WM, and perhaps levels of WM for this group may already be near their peak performance leaving little room for improvement. Such a conceptualization would be consistent with researchers who argue that working memory has limited capacity (see Cowan, 2001). The results of a recent meta-analysis of CCT by Melby-Lervag and Hulme (2013) concluded that benefits of improving cognitive abilities among typically developing children and healthy adults are very doubtful. Taking into consideration both of these accounts, it may be the case that children without WM deficits have already naturally developed towards their WM capacity.

Hypotheses 5 and 6

The fifth hypothesis was related to expected similarities between children with delayed and typical verbal WM abilities at the conclusion of computer training. This hypothesis was not supported. Although the children with delayed WM were able to make increases in their post-test verbal WM abilities to the extent that they would no longer be classified as delayed WM, these gains were not great enough to be comparable with their typical peers. More specifically, the gains in verbal WM made by the delayed group were still significantly behind their typical peers.

The sixth hypothesis was related to expected similarities (between the delayed and typical WM groups) in terms of post-test scores for visual WM abilities. This hypothesis was supported. Not only were the delayed children able to increase their visual WM to the point that they would no longer be classified as delayed, they were able to approximate their typical peers' post-test level performance of WM. This combination of findings reveals that children with delayed WM make different levels of gains, specifically that children benefit more so in terms of visual WM than verbal WM.

An interesting study that shares these findings was conducted by Abikoff and colleagues (2008). A group of children, ages 7-12 and diagnosed with ADHD, attended a six week summer intervention program. During their participation in the program, the children were able to engage in 30 minutes of CCT daily for visual and verbal WM. The findings demonstrated that there were significant increases in visual-spatial WM, however no increases for verbal WM were observed. Possible reasons for this particular pattern of differences between visual and verbal WM functioning may have cognitive and developmental underpinnings.

Several researchers have suggested that there are increased cognitive demands related to visual WM rather than verbal WM (Bayliss et al., 2003; Dahlin, 2011;

Gathercole, Pickering, Ambridge, & Wearing, 2004). There is also a similar relationship with attention and visual WM compared to verbal WM (Fougnie & Marcis, 2006). The taxing combination of cognitive demands and attention requirements creates a situation where children with visual WM deficits may have a lower initial ability and consequently more room for improvement once these deficits are overcome, in comparison to their typically functioning peers.

Although the increased demands of cognitive processing may result in WM deficits, studies that investigated differences in the development of verbal and visual WM among children have also been conducted (Alloway, Gathercole, & Pickering, 2006; Koppenol-Gonzalez, Bouwmeester, & Vermunt, 2012). The findings support the notion that although verbal and visual WM continue to increase across development, the earlier of the two systems to develop is visual WM (Pickering, 2004). Perhaps the earlier dominant use of visual WM is what allows children who have initial deficits in this area to advance more quickly than with verbal WM. A developmental history demonstrating an earlier relationship with visual WM, combined with opportunities for enhancement from CCT, and overcoming cognitive burdens may explain the large gains observed for visual WM. In other words, despite having an initial cognitive set back, an individual is eventually able to function rather efficiently in their dominant WM system through focused practice.

Despite this promising developmental trend, the analyses related to hypotheses seven and eight were intended to reveal more information about the differences in rates of benefits that children obtain from CCT.

Hypotheses 7 and 8

Rates of benefits for verbal WM were not observed to vary significantly as a result of initial classification of WM ability, as a result hypothesis seven was not supported. Additionally, a similar assessment on the rates of benefits for visual WM was not observed to vary significantly either as a result of initial classification of WM ability and thus hypothesis eight was also not supported. However, it is important to note that the interaction tested by hypothesis eight was observed to approach the level of significance. This may provide tentative evidence that rates of gains in WM as a result of CCT are different between both verbal and visual WM depending on initial levels of WM.

The results related to hypotheses seven and eight are similar to the pattern of findings observed for hypotheses five and six, such that it appears that a positive trend is stronger for visual WM rather than verbal WM as a result of CCT. As previously discussed, differences in development of WM may play a role on the observed differences.

For example, Jarvis and Gathercole (2003) found a dissociation between verbal and visual WM among children, suggesting that even into late adolescence these subtypes of WM develop at differing rates. Additionally, Koppenol-Gonzalez and colleagues (2012) observed better performance in visual processing tasks rather than verbal processing in children, ages 4 to 15, supporting differences between theses two subtypes of WM. Specifically, among the older participants it was observed that children were able to supplement their performance on visual processing tasks by recoding visual information phonologically, which allowed them to outperform younger children who lack this ability. Similar to the younger children, it may be the case that children with delayed WM in the current study were not able to supplement different domains of WM tasks by utilizing additional WM skills to the same extent as their peers with typical WM.

However, another study found strong correlations between visual and verbal WM among older children suggesting a more general pattern of development (Alloway, Gathercole, & Pickering, 2006). Given that the research of the development of WM is mixed, it may likely be the case that children with typical WM have a greater overlap of visual and verbal WM, whereas children with WM deficits experience different rates of development.

It is of interest to point out that one other study by Ivarsson and Strohmayer (2010) observed trends that are opposite from the current project, such that verbal WM rather than visual WM were increased among children with ADHD. However, Ivarsson and Strohmayer point out that despite not seeing significant gains in visual WM as a result of WM training, a large effect size was observed and that their lack of statistical power may have been related to the small number of participants.

A final practical consideration in explaining the observed differences is related to the nature of how the CCT was administered. The CCT is conducted in a quiet area in order to foster an environment where the children can focus their attention without distracting their neighbors. By maintaining a relatively quiet training area, a child's attempts to use vocalizations to assist with the CCT may have been discouraged. Therefore, the maintenance of a quiet training environment may have limited students' gains in verbal working memory.

General Discussion

Overall, the patterns of findings from this project support CCT as a powerful intervention for children with deficits in WM, particularly in the area of visual WM. Given the relationship between working memory impairments and poor academic outcomes, it appears that CCT can be used as an effective intervention for children at high risk for educational underachievement. Furthermore, after considering the relationship between WM and executive functioning, it would appear the detrimental life outcomes associated with low executive functioning could be improved as a result of increasing WM among identified at-risk students. Although the relation between executive functioning and academic skills was not assessed within the context of this study, it is well known that WM has a strong relationship with cognitive abilities both inside the laboratory as well as in real-world settings. It would be expected that the gains experienced by the children with delayed WM would translate into improved academic performance.

Limitations

One of the possible limitations of this study may have been the unequal gender distribution across groups. As mentioned in the participants' section, two thirds of the participants were young males, and one third of the participants were young females. Therefore, an important consideration about the interpretation of the results needs to be made. Specifically, these results may be more applicable to males than females. However, it is important to note that some previous studies have mentioned a lack of gender differences on WM assessments (Alloway et al., 2006; Klingberg et al., 2005), whereas others shared similar distributions of gender (Dahlin, 2011; Holmes et al., 2010; Klingberg et al., 2002; Mezzacappa & Buckner, 2010; Prins et al., 2011; Shavlev et al., 2007). Even though occurrences of WM deficits would be expected to vary among males and females (e.g., males are twice as likely to be diagnosed with ADHD than females; Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007), gender would not be expected to function as a confounding variable regarding changes in WM as a result of exposure to CCT. Therefore, despite an unequal distribution of gender in this study, it is expected that the interpretation of the results should generalize across both male and female children.

Another possible limitation is that the number of children in the study with delayed WM was relatively small compared to typical WM. This could potentially affect the data analysis, however all distributions were found to not violate homogeneity. Therefore, similar patterns would still be expected given a larger number of delayed participants.

One final consideration involves a potential regression towards the mean effect, specifically for the delayed group since their mean scores shifted towards the overall mean during the post-test measurement. However, it is thought to be unlikely that such regression towards the mean has occurred, due to the utilization of a highly standardized and normed measured of WM (i.e., the WRAML2). Moreover, the pretest and posttest means for verbal and visual working memory among students in the delayed group were not at the extreme end of scaled scores (which have a range of 1-19); this reality reduces the likelihood of a regression to the mean effect.

Future Directions and Recommendations

The results of this study indicate that CCT is an effective strategy for students with deficits in WM, specifically in the area of visual WM. Given the relationship between WM, literacy, and mathematics, as well as the potential for CCT to improve these academic skills, it would appear that CCT could be a valuable intervention for children identified as having problems with WM within the Response-to-Intervention (RTI) model.

The RTI model is a widely used academic intervention in American educational settings, which enables educators to identify different strengths and weaknesses of children (Fuchs, Mock, Morgan, & Young, 2003). It involves an initial school-wide screening period followed by placement into different tiers of instruction that vary in terms of intensity. The intensity of the instruction is related to the deficits experienced by the students. Future studies may examine the effectiveness of CCT as an intervention within the RTI model to improve a student's academic performance by targeting core cognitive deficits.

Given the possibility for CCT to be incorporated within the RTI model, it would also be of interest for future researchers to investigate how CCT could lead to increases in various measures of academic performance. Previous research has identified that CCT leads to improved performance in mathematical reasoning abilities (Holmes, Dunning, & Gathercol, 2009) and reduction of off-task behaviors during academic tasks (Green et al., 2012). However, a more practical measure of academic benefits such as grades, teacher/parent ratings, and scores on national assessments would help demonstrate that CCT provides benefits beyond training WM.

By taking into account the potential for CCT to function as an intervention for children with WM and academic deficits, future researchers could also investigate the combined strength of CCT, study skill training, as well as other cognitive strategies, to improve academic performance. Although CCT may lead to increases in WM performance, it may be that the synthesis of CCT along with additional types of trainings, which are more closely related to academics, will produce stronger practical outcomes.

Another future focus of empirical work could be to examine whether differences in disabilities could result in different rates of improvement as a result of CCT. For example, an investigation of the effectiveness of CCT for students with ADHD, reading disorders, high functioning autism, or other disorders characterized by deficits in WM may be valuable for educators. Additionally, an exploration of the effects of CCT to reduce symptomology associated with disorders related to WM deficits could speak to the clinical benefits of this intervention.

In terms of measuring the longevity of working memory training, one additional assessment of WM after the post-test assessment would assist in determining long-term gains associated with CCT. Currently, there is a limited amount of research that has investigated the long-term effects of CCT training. The existing literature has demonstrated some positive effects (Jaeggi, Buschkuehl, Jonides, & Shah, 2011); however, the long-term benefits of CCT still need more investigation.

Additionally, research could investigate the effects of differences in CCT training periods. For example, published studies have utilized training periods ranging from 25 to 45 minutes daily across a period of five weeks (see Abikoff et al., 2008; Dahlin, 2011; Klingberg et al., 2002; Mezzacappa & Buckner, 2010). On the other hand some studies have utilized a similar daily training interval, but across a period of 6 to 10 weeks (see Alloway & Alloway, 2009; Holmes et al., 2010). In the current project, the students were trained 30 minutes a day across 10 weeks. These difference may have an impact on outcome measures. Currently, no existing research has shown that one type of training duration is more effective than the other. Future research could investigate the differences in WM improvements between the typical 5-week program compared to the longer 10 week program to determine if a specific length of training could be more effective.

Finally, a future recommendation would be to conduct an assessment of the motivation and attitudes of the participants. The rational behind this assessment would be to understand whether or not the children regarded their experience with WM training to be rewarding. This consideration is important given the existing relationship between motivation and learning, particularly if the children did not enjoy their experience. Previous research has demonstrated that CCT, which incorporates game-like features, increases motivation, attention, and WM performance of children with ADHD (Piers et al., 2005). Therefore, an additional practical measure of WM training could be whether or not the children considered the training to be enjoyable and if they would recommend it to their peers.

Conclusions

Although not all hypotheses were supported, the general trends observed among individuals with deficits in WM are particularly powerful. The benefits of CCT still warrant additional research, the current findings regarding CCT are largely in agreement with previous literature. As a whole, parents and educators may find this information particularly useful when considering how to remedy issues associated with working memory.

APPENDIX

INSTITUTIONAL REVIEW BOARD APPROVAL

Human Subjects Review Board
Department of Psychology
California State University,
San Bernardino

PI: Eugene Wong and Tessy Pumaccahua

From: Jason Reimer

Project Title: Effects of Computerized Cognitive Training on Working Memory in a School Setting.

Project ID: H-13SP-05

Date: 5/10/2013

Disposition: Expedited Review

Your IRB proposal is approved. This approval is valid until 5/10/2014.

Good luck with your research!

Jason Reimer, Co-Chair
Psychology IRB Sub-Committee

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