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The Effects of Working Memory Training and Encoding Strategy on Working Memory Capacity

Frank Tuthill

THE EFFECTS OF WORKING MEMORY TRAINING AND ENCODING

STRATEGY ON WORKING MEMORY CAPACITY

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A Thesis

Presented to the

Faculty of

California State University,

San Bernardino

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In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

in

Child Development

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by

Frank Joseph Tuthill

June 2018

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ABSTRACT

Undergraduate students from California State University, San Bernardino were recruited to examine the effects of working memory training and encoding strategy upon working memory capacity. Participants will be prescreened for low working memory capacity, and then will be tested on a battery of complex span measures. Participants will be divided into several strategy conditions: rehearsal, visual, and control. Then participants will be tested on their verbal working memory both before and after the 20 session n-back working memory training program. Participants are predicted to do the same or worse with the strategy instruction before working memory training while they will improve after training in comparison to control groups. The effects of strategy and training upon working memory capacity were nonsignificant. However, the direction of group differences is consistent with the maximization of individual differences with strategy instruction while cognitive training minimizes individual differences.

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CHAPTER ONE

INTRODUCTION

Background

Working memory (WM) has been defined as the ability to process information while simultaneously engaging in another cognitive task (Hall, Jarrold, Towse, & Zarandi, 2015; Minear et al., 2016). Since Baddeley and Hitch (1974) first proposed WM as an essential element of cognition, researchers have utilized WM to unify competing theories of cognition as well as to create models of cognition (e.g., Cowan, 2001; Engle & Kane, 2003; Lovett, Daily, & Reder, 2000; Meyer, Glass, Mueller, Seymour, & Kieras, 2001). In addition to its numerous contributions to cognitive theory, training programs based on WM have been successful in aiding individuals with Attention Deficit Hyperactivity Disorder(Bigorra, Garolera, Guijarro, & Hervás, 2016), working memory capacity (WMC, Studer-Luethi, Bauer, & Perrig, 2016) math difficulties (Bergman-Nutley & Klingberg, 2014), reading comprehension (Loosli, Buschkuehl, Perrig, & Jaeggi, 2012), and problem solving(Swanson, Moran, Lussier, & Fung, 2014). Overall, WM research has been an important research topic in psychology that has both theoretical and practical value.

Despite the wealth of research on WM, there have been several debates within the WM literature. While some researchers (e.g. Engle, Tuholski,

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Laughlin, & Conway, 1999; Fukuda, Vogel, Mayr, & Awh, 2010; Unsworth,

Fukuda, Awh, & Vogel, 2014) have found a strong predictive relationship

between WM and fluid intelligence, other researchers (e.g. Harrison et al., 2013;

Heitz et al., 2006; Tidwell, Dougherty, Chrabaszcz, Thomas, & Mendoza, 2014)

have not. Similarly, researchers examining the effectiveness of WM training

studies (e.g. Melby-Lervåg & Hulme, 2013; Melby-Lervag, Redick, & Hulme,

2016) have yielded mixed results. Gonthier and Thomassin (2015) found a

possible resolution to these inconsistencies suggesting that strategy use may

mediate the relationship between WM and fluid intelligence. Additionally, Melby-

Lervåg and Hulme(2013) proposed the lack of far transfer from WM training

programs and multiple measures of cognitive performance might also depend on

strategy use. Finally, Dunning, Holmes, and Gathercole (2013) suggested WM

training may be more effective with low WMC individuals. Therefore, the present

study examined the relationship between WM training and strategy use in a low

WMC population.

<div align="center">Working Memory: General Definitions</div>

Working memory has been described as an integration of short term

memory and the cognitive processes that manage information (Cowan, 2008;

Daneman & Carpenter, 1980). It has been important for researchers to define

the working memory construct in the context of other similar constructs such as

long term and short term memory. Short term memory has been differentiated

from working memory because short term memory is more vulnerable to decay

and is more limited in capacity relative to working memory (Cowan, 2008). For

example, Schweickert and Boruff (1986) found that information that is not

repeated every two seconds will gradually decay in short term memory. The

working memory construct utilizes short-term memory as a storage component

while including the cognitive processes that access and manipulates that

storage. Additionally, information in working memory persists longer than short

term memory but it is limited by the scope of attention, such that information in

working memory will fade once attention has shifted away (Cowan, 2008). In

contrast, long term memory is not limited by the scope of attention, and the

capacity of long term memory is equivalent to 10^{8419} average computers or 10^{8432}

bits of information, which is astronomically greater than WMC (Wang, Liu, &

Wang, 2003). Overall, working memory is a construct related to short-term and

long term memory, but has sufficient distinguishing characteristics to be declared

a separate construct.

The modern concept of working memory has been primarily defined

through the use complex span measurements of working memory. Daneman

and Carpenter (1980) developed one of the first complex span measures, the

reading span. In the reading span task, participants had to read sentences out

loud while remembering the last word in each sentence. After reading all the

sentences in a set, participants would have to repeat the last word in each

sentence in order. Daneman and Carpenter required participants to judge the

veracity of each sentence to prevent participants from ignoring the sentence

while encoding the last word into memory. This complex span demonstrated how working memory capacity has been measured by the storage-plus-processing paradigm through a reading comprehension task along with a word storage task (Cowan, 2001; Redick & Lindsey, 2013). Since the original creation of the reading span task, it has been modified so the target word is neither part of the sentence nor it is semantically related to the sentence (Conway et al., 2005). This modification reduced the influence of the sentences facilitating the encoding of the words into memory. Regardless of this modification, the original reading span was strong predictor of reading comprehension (Daneman& Carpenter, 1980).

The reading span task led to the development of other complex span tasks that provided an operational definition of WM. Specifically, Turner and Engle (1989) created the operation span task to examine whether the sentence reading component of the reading span was essential to the accurate prediction of performance on reading comprehension tasks. Turner and Engle substituted the sentences with simple mathematical equations such as $(8/2)-3=1$. Participants had to judge whether the mathematical equation was correct or incorrect while also remembering a word presented with the equation. Thus, Turner and Engle created a task similar to the reading span task in which participants had to judge whether a statement was true or false while learning the to-be-remembered word. Turner and Engle (1989) found that the operation span predicted performance on reading comprehension, and thus suggested working

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memory capacity (WMC) is a strong predictor of reading comprehension without a reading component. Therefore, the working memory construct, as defined through complex span tasks, can predict performance when the processing component of the task is unrelated to the storage component.

Since the development of the reading and operation span, numerous other complex span tasks have been developed. These tasks include the counting span (Case, Kurland, & Goldberg, 1982), the rotation span (Shah & Miyake, 1996), and the symmetry span (Kane et al., 2004). Similar to the operation span, each of these complex spans has a processing component in addition to the storage component. The counting span includes the task of counting a number of colored shapes in between the presentation of letters to be remembered (Case et al., 1982). The rotation span requires the judgment of whether the presented letter is aligned correctly or has been rotated while storing the orientation of previously presented images of arrows. The symmetry span requires participants to judge whether an image presented in an 8 x 8 grid is symmetrical while storing the serial order of locations presented in a 4 x 4 grid presented before the 8 x 8 grid (Kane et al., 2004).   Each of these complex span tasks has combined a simple span task that can be visual, spatial, or verbal with a processing task of a similar type. Thus, the complex spans tasks are the combination of the simple span task that has been used to measure short-term memory combined with a processing task.

Another important difference between working memory and short term memory is the predictive utility of each construct. For example, Turner and Engle (1989) found that the operation span had a strong correlation with verbal SAT scores while the simple span task did not. Additionally, WMC is predictive of math performance (Raghubar, Barnes, & Hecht, 2010; Swanson, 2014), fluid intelligence (Ackerman, Beier, & Boyle, 2005; Fukuda et al., 2010; Gonthier & Thomassin, 2015), reading comprehension (Daneman & Carpenter, 1980; Just & Carpenter, 1992) and mind wandering (McVay & Kane, 2012; Unsworth & Robison, 2016). Although there is considerable overlap between short-term memory and WMC in predicting variance on multiple measures of cognitive ability, WMC predicts more of this variance than short term memory (Aben, Stapert, & Blokland, 2012). In addition, WMC predicts more variance in fluid intelligence than any other predictor (Cowan, 2008). Specifically, half of the variance in fluid intelligence has been attributed to differences in WMC (Nash Unsworth et al., 2014). Consequently, research on WMC, as defined through complex span tasks, has become increasingly more important than short term memory research.

Working Memory: Components and Theory

Baddeley and Hitch (1974) developed the quintessential multiple component models of WMC. In this three component model of working memory, the storage of information is divided between the phonological loop and the visuo-spatial sketch pad while the central executive directs the manipulation of

information in each of these stores (Baddeley, 2000). In this way, Baddeley and Hitch (1974) created the first theory to separate the storage of memory from cognitive control functions. The phonological loop is the storage system for verbal information (Baddeley, 2012). The most important finding regarding the phonological loop is the subvocal rehearsal of words that has enabled the maintenance of information in the phonological loop. The capacity of the phonological loop would vary as a function of word length as longer words required greater rehearsal time (Baddeley, Thomson, & Buchanan, 1975). Additionally, Baddeley et al. (1975) demonstrated that this maintenance process can be disrupted by having participants continuously utter an unrelated word, thereby interrupting subvocal rehearsal with vocal rehearsal. Overall, the Baddeley and Hitch (1974) model help researchers to conceptualize verbal WM, and a WM maintenance process specific to verbal memory.

The visuo-spatial component of working memory has been classified as the short term storage of visual information (Baddeley, 2012). Baddeley, Grant, Wight, and Thomson (1973) demonstrated that visual tasks interfere with the recall of visual information but do not disrupt verbally encoded information. As a result, they argued that the visuo-spatial sketchpad was a separate component of memory from the phonological loop. Klauer and Zhao (2004) expanded upon Baddeley et al. (1973) by examining whether visual and spatial tasks were separate components in this multiple component model. Klauer and Zhao (2004) demonstrated that participants' visual short term memory was more disrupted by

visual tasks than spatial tasks, and participants' spatial short term memory was more disrupted by spatial tasks then visual tasks. This result was found while accounting for different cognitive load in visual and spatial tasks, interference due to task similarity, phonological loop rehearsal strategies, and any disruption to the central executive from attention demanding tasks (Klauer & Zhao, 2004). Overall, there has been strong evidence for a visuo-spatial system separate from other components in the Baddeley and Hitch (1974) model of working memory, and has integrated visual short term memory as a component of overall working memory capacity.

The central executive component of the Baddeley and Hitch (1974) model of working memory is responsible for managing any cognitive manipulations of information in the visual-spatial sketchpad and phonological loop. Although Baddeley and Hitch's model of the central executive did not specify the particular functions of the central executive, the functions of the central executive were hypothesized to be the same regardless of the type of short term memory storage involved in the task (Baddeley, 2012). Therefore, any distraction that impeded the central executive should diminish performance on working memory(WM) tasks irrespective of the short term storage component of the task (Baddeley, 2012). As a consequence of the domain general applicability of executive functions, many researchers have focused upon the executive functions of WM to develop comprehensive models of cognition(Cowan, 2001;

Engle & Kane, 2003; Ericsson & Kintsch, 1995; Lovett et al., 2000; Meyer et al., 2001; Miyake et al., 2000).

Since Baddeley and Hitch's (1974) general description of the central executive, researchers have identified multiple executive functions including task switching (Draheim, Hicks, & Engle, 2016), updating (Ecker, Oberauer, & Lewandowsky, 2014), maintenance (Kessler & Oberauer, 2014), and inhibition (Hall et al., 2015). These executive functions have been unified into cognitive and attentional control models of working memory (Chow & Conway, 2015; Cowan, 2001; Engle & Kane, 2003). Thus, each of these executive functions can be described as being related to attention. In task switching, individuals have directed their attention from one mental representation and/or external stimuli to another (Draheim et al., 2016). Similarly, attention is needed to maintain the items in the memory store to prevent decay of that information (Ecker et al., 2014). The executive function of updating information in WM has been found to interfere with the maintenance function as it requires attention to be directed to removing or modifying a stored representation in WM (Ecker et al., 2014). Thus, the updating function has been found to draw attention away from the maintenance function. Finally, inhibition has been one of the last executive functions to develop in children, and tasks requiring inhibition of previous instruction and/or stimuli have been the most difficult for children (Davidson, Amso, Anderson, & Diamond, 2006). This function requires directing attention away from task irrelevant stimuli to task relevant stimuli. For example, task

switching may require participants to ignore a previous set of task rules to follow a new set of rules (von Bastian & Oberauer, 2013). Overall, the attentional control model of WMC led to empirical research on the relationship between executive functions and WMC

Executive functions are predictive of performance on complex span tasks. For example, McCabe, Roediger, McDaniel, Balota, and Hambrick, (2010) found a correlation of .97 between a WMC factor composed of four complex span measures and an executive function factor composed of four executive function measures. Therefore, almost all the variance in WMC could be accounted for by executive functioning, and greater performance on executive functioning measures increased performance on measures of WMC. Similarly, Miyake et al. (2000) found a strong relationship between the executive function of updating and the operation span. In contrast, Miyake et al. (2000) found no significant relationship between the operation span and the shifting executive function, suggesting that the operation span is mainly affected by the updating function. This inconsistency for the relationship between individual executive functions and a composite executive function factor upon WMC can be reconciled through the attentional model of WMC. All executive functions require the control of attention, and thus the variance explained by individual executive functions in WMC will overlap (Engle & Kane, 2003; Kane et al., 2004). Consequently, the updating component in the Miyake et al. (2000) study may have had all the shared variance of the attentional control construct, and thus the shifting

component could not explain any unique variance. Overall, the relationship between executive functions and WMC has suggested that attentional control is the common component responsible for performance on a multitude of cognitive measures.

The attentional control model of WMC has been supported by the convergent validity of WM tasks. The domain general perspective suggests that WM tasks have more shared variance than unique variance in explaining performance on wide variety of cognitive tasks including reading comprehension tasks, mathematical problem solving tasks, and fluid intelligence tasks (Engle et al., 1999; Oswald, McAbee, Redick, & Hambrick, 2015). Kane et al. (2004) found complex spans measures of WMC shared 70-85% of the explained variance in fluid intelligence measures regardless of whether those spans had visual, spatial, or verbal storage components.   Additionally, the short term memory tasks only shared 40% of their variance, suggesting that these simple span measures were domain specific (Kane et al., 2004). Furthermore, neuroimaging has revealed the frontal cortex of the brain, an area associated with controlled attention and planning, increases in activation according to WM load during the encoding, storage, and retrieval process (Chein, Moore, & Conway, 2011; Li, Christ, & Cowan, 2014). In contrast, areas of brain specific to visual and verbal information processing were highly activated only during the encoding process (Li et al., 2014). Therefore, the executive functions of updating and maintenance were activated during all parts of the complex span tasks, which would explain

why these functions and the WM tasks associated with them would explain most of the variance in individual performance.

Working Memory Training

The most potentially valuable aspect of WM research has been its application for improving cognitive performance. If WM is predictive of general fluid intelligence and is also the essential limiting factor on many tasks, then any improvement in working memory capacity (WMC) should also correspond with an improvement in cognition. Consequently, many researchers (e.g. Minear et al., 2016; Schwarb, Nail, & Schumacher, 2016; Swanson, 2014) have trained participants on WM tasks, such as complex span tasks and n-back tasks, to determine whether this training would improve WMC and fluid intelligence. Additionally, the primary goal of this training was the transfer of these improvements from the laboratory setting to improved academic achievement, which has been a long standing goal of psychology and education (Barnett & Ceci, 2002). Barnett and Ceci described the goal of transfer as applying knowledge and skills across knowledge domains, periods of time, physical settings, social settings, functional goals, and testing modalities. Near transfer is defined as applying skills in two similar contexts while far transfer is defined as applying skills in two dissimilar contexts (Barnett & Ceci, 2002). For example, near transfer effect would be improvement on the rotation span also increases improvement on the symmetry span. In contrast, a far transfer effect would be improvement on the rotation span also increases improvement on a geometry

test. In the context of WM training, this means that researchers want participants to demonstrate far transfer effects in a wide variety of contexts not limited to improvements on complex span measures of WM.

The strongest evidence of the effectiveness of WM training has been found in neuroscience research on the n-back task. In this task, participants must determine whether the current item matches a specific element of a previously presented item n times back (Chen, Mitra, & Schlaghecken, 2008). For example, a 4-back task requires participants to determine whether the current word rhymes with a word presented four words earlier. One reason the n-back task has been popular in neuroscience research is that it has been associated with multiple executive processes, the most convenient task to use with neuroimaging (Chein et al., 2011; Kane, Conway, Miura, & Colflesh, 2007), and transfer has been more likely to occur when same regions of the brain are activated in both the training task and transfer task (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008). Because the n-back has required the use of executive functions such as updating, maintenance, and task switching (Chen et al., 2008; Verhaeghen, Cerella, & Basak, 2004), then improvements related to training on this task have been more likely to transfer to other tasks that utilize these executive functions. Consequently, much of the research supporting the transfer of WM training has been conducted using the n-back task for training.

One increasingly popular method of WM training is through adaptive computerized methods (e.g. "Cogmed Working Memory Training," CWMT, 2017;

Deveau, Jaeggi, Zordan, Phung, & Seitz, 2015). The CMWT program, developed

by the Karolinska Institue in Stockholm, Sweden, has employed adaptive span

and complex span tasks that increase in difficulty according to the progress of

the participant ("Cogmed Working Memory Training," 2017; Klingberg et al.,

2005). The CWMT program provides training on computerized complex span

tasks similar to those used by Foster et al. (2015) and Oswald et al. (2015) on E-

prime software. For example, the input module in CWMT and the computerized

symmetry span used by Foster et al. (2015) both have tested participants' matrix

span, which is remembering the locations of a stimulus in the order presented in

a grid. However, Foster et al. (2015) used a question regarding the vertical

symmetry of a shaped imposed on the grid as a distracter task while the CWMT

input module rotated the grid pattern 90 degrees after presenting the sequence

(Sonic Learning, 2017). Therefore, both these tasks employed the same short

term memory span task while varying the distracter task and the visual-auditory

aesthetics. The adaptation of the complex span task into a video game format

has the advantage of enhanced motivation to complete the task as well as

immediate feedback to performance (Deveau et al., 2015). Overall, these WM

training games integrate complex span tasks into a video game format.

Other computerized WM training programs have focused upon the n-back

task instead of complex span tasks. For example, Recall The Game, developed

at the University of California, Riverside, has required participants to keep a

space ship flying by collecting fuel cells (Deveau et al., 2015). Furthermore,

participants were required to collect the correct fuel cell while avoiding other fuel cells that did not match the target fuel cell either according to sight or sound. Deveau et al. (2015) described Recall the Game as incorporating multiple forms of sensory stimulation, progressively more difficult n-back tasks, reinforcement principles, and progressively more distracting elements to stimulate improvement in both WMC and executive functioning. Overall, Recall The Game has provided an example of how the n-back task could be incorporated into a digital game format to train working memory.

A natural question that has arisen from comparing these two different types of WM training games is whether the n-back and complex spans are both related to the WM construct. Schmiedek, Hildebrandt, Lövdén, Wilhelm, and Lindenberger (2009) found a strong correlation of .96 between n-back tasks and complex spans, suggesting that these two tasks measured the same WM construct. In contrast, Redick and Lindsey (2013) found a much smaller correlation of .20 between n-back tasks and complex spans from a meta-analysis of the literature, suggesting that these two tasks measure different aspects of the WM construct. Redick and Lindsey (2013) reconciled their findings with Schmiedek et al. (2009) by examining how each type of complex span task loaded on the WM latent variables. Specifically, complex span tasks and n-back tasks had stronger correlations when they both contained visuo-spatial components in comparison to when they both had verbal components to the task. Overall, Redick and Linsey (2013) concluded the complex span tasks and n-back

tasks were too dissimilar to use both as measurements of the same WM

construct. In response to Redick and Linsey (2013), Schmiedek, Lövdén, and

Lindenberger (2014) revisited the analysis of the convergent validity of the n-

back and complex span tasks. Specifically, Schmiedek et al. (2014) analyzed

the relationship between reasoning, age, and four WM measurement paradigms:

complex span, memory updating, sorting span, and n-back. They found that n-

back tasks and complex span tasks were strongly correlated to the general WM

construct; however, younger adults had a stronger correlation with complex span

and memory updating while older adults show no significant difference on loading

with each factor. Most importantly, the greatest amount of variance explained in

reasoning ability occurred when all four WM measurement paradigms were

loaded on the general WM factor (Schmiedek et al., 2014). Overall, the n-back

and complex span tasks are both valid measures of the WM construct.

WM training has been effective for treating individuals with ADHD.

Specifically, Klingberg et al. (2005) found that WM training with Cogmed

improved resulted in near transfer effects as the students with ADHD significantly

improved in their WMC, and significantly reduce their inattentive symptoms. In

regards to far transfer effects, Bigorra et al.(2016) and Bergman-Nutley and

Klingberg (2014) found persistent training effects 6 months after the WM training

intervention. Specifically, Bigorra et al. (2016) demonstrated that WM training

lead to improvement of multiple measures of executive functioning, and also

reduced the severity of ADHD symptoms as represented by composite scores

from both teachers and parents. Additionally, Bigorra et al. (2016) explained the far transfer effects were obtained due to intense training of 25 sessions of approximately 45 minutes of length on the Cogmed program as well as families provided additional rewards after each training session to participants. Similarly, Bergman-Nutley and Klingberg (2014) found that individuals with ADHD were better able to both recall and adhere to directions given after WM training. Overall, WM training has been helpful in address executive functioning deficits in individuals with ADHD.

There has been mixed evidence regarding the far transfer of WM training to increased academic performance, and general long term improvements in cognition. In their meta-analysis of 22 WM training studies, Melby-Lervåg and Hulme (2013) concluded that WM training produced near transfer increases to complex span tasks and other measures of WMC, but did not result in far transfer improvements in speaking, reading, or arithmetic.   Additionally, Melby-Lervåg and Hulme (2013) found that improvements in verbal working memory disappeared after approximately nine months while the improvements in visual working memory persist to at least five months but the maximum duration of these improvements have been unclear. Similarly, Redick, Shipstead, Wiemers, Melby-Lervåg, and Hulme (2015) found in their review of the WM literature that WM training enhanced performance on WMC measures while it did not have an effect on far transfer measures such as academic achievement goals. Furthermore, Redick et al. (2015) stated studies that did report far transfer effects

for WM training had a less rigorous methodology such as lacking a control group, small sample size, or follow up assessment. However, Studer-Luethi, Bauer, and Perrig (2016) challenged this perspective and asserted that there were important moderator variables that could explain the inconsistent far transfer of WM training across studies. Specifically, Studer-Luethi et al. (2016) found effortful control and low neuroticism were necessary for far transfer to occur after WM training. Overall, the near transfer of WM training has been well established while far transfer effects of WM training have been inconsistent and not fully understood.

Despite the lack of evidence of far transfer benefits to WM training, neuroscientists have found evidence of physiological changes in the brain as a result of WM training. In their review of 275 neuroimaging studies, Cabeza and Nyberg (2000) found that there was increased activity in the prefrontal cortex, especially when an n-back task was used to evaluate WMC, regardless of whether the processing and storage task used auditory, visual, and/or spatial stimuli in the WM task. Therefore, it has not been surprising that WM training has enhanced the connectivity between the prefrontal cortex, which has been associated with controlled and selection attention, to other regions of the brain that specialized in processing and storing particular types of stimuli (Astle, Barnes, Baker, Colclough, & Woolrich, 2015). More importantly, Astle et al. (2015) found children's' WMC increased in proportion to the increase in connectivity between the prefrontal cortex and other areas of the brain. Thus,

WM training has been associated with enhanced connectivity in the brain that has also been associated with increased WMC.

There has been a debate regarding whether WM training increased general cognitive performance, especially as measured through fluid intelligence. Melby-Lervåg and Hulme (2016) have argued that the meta-analyses of Au et al., 2015 and Karbach and Verhaeghen (2014) do not demonstrate sufficient evidence of fluid intelligence increase due to WM training. Specially, Melby-Lervåg and Hulme (2016) argued that these meta-analyses did not include all the relevant WM training research, inflated the effect size of WM training upon fluid intelligence performance measures, and the magnitude of this effect sized depended on the nature of the control group. Similarly, Dougherty, Hamovitz, and Tidwell (2016) found that studies using a passive, no contact control were more likely to find a relationship between fluid intelligence and WM training than studies that used an active control. Overall, Melby-Lervåg and Hulme(2016) concluded the relationship between WM training and fluid intelligence was mostly moderated by the type of control group, suggesting that methodological flaws influenced the findings. Au, Buschkuehl, Duncan, and Jaeggi (2016) responded to possibilities that passive control groups could lead to placebo and Hawthorne effects has not been proved. Specifically, Au et al. (2016) argued the effect size was not due to differences in control group but differences in treatment such as training method and intensity. Overall, Au et al. (2016) concluded that other

variables moderated by the effect size of WM training on fluid intelligence, and future studies should examine these moderators.

Working Memory: Strategies

One the potential moderating variables between WM training and cognitive performance measures is the effect of encoding strategies. The importance of the relationship between strategy use and WM training has been exemplified by explanations for the lack of far transfer effects due to task specific strategies (Melby-Lervåg & Hulme, 2013), individual differences in WMC (McNamara & Scott, 2001; Whitebread, 1999), relationship between fluid intelligence and WMC (Gonthier & Thomassin, 2015) and the spontaneous development of strategies during WM training (Dunning & Holmes, 2014). Although most WM measures are designed to minimized the impact of encoding strategies such as chunking (Shipstead, Redick, Hicks, & Engle, 2012), Portrat et al. (2016) has shown the chunking strategy can improve WMC even using stimuli that does not promote grouping similar to-be-remembered stimuli during short presentations of that stimuli. Overall, encoding strategies are worth investigating as moderating factor on WM training effects.

The relationship between the encoding strategy of chunking and WMC may be understood through the long-term working memory theory. Proponents of this theory have suggested that information can be rapidly encoded as chunks of similarly related information while connecting this information to representations stored in long term memory (Ericsson & Delaney,

1999; Ericsson, Delaney, Weaver, & Mahadevan, 2004; Ericsson & Kintsch, 1995; Unsworth, 2016). Because the general limit of the focus of attention has been determine to be four items (Cowan, 2001, 2008), the chunking strategy can explain why some articles report the limit of WMC to be seven (e.g. (Miller, 1956), 16 (e.g. G. Li et al., 2013), 24 (e.g. Chase & Simon, 1973) and 80 items (e.g. Ericsson et al., 2004). Therefore, encoding strategies have been shown to greatly enhance the number of items an individual can retain.

In the research literature, there have been at least two broad approaches to the study of chunking. Portrat et al. (2016) described these approaches as the memory expert, task specific approach and the more task general, goal orientated approach. The task specific approached is exemplified by studies on individuals with enhanced WMC for specific information such as chess locations (e.g. Chase & Simon, 1973) and digit span (e.g. Ericsson et al., 2004). In these studies, memory experts have created long-term memory representations such as common chess positions and series of numbers that enable them to work around the limitations of WMC (Gobet, 1998). For example, a chunk for a grandmaster chess player may include 6-8 chess positions while occupying only one space in the four item limit for the scope of attention. In contrast, the task general studies of WMC focused on the average limit across a wide variety of stimuli and contexts (Cowan, 2001). For example, . Li et al. (2013) used the encoding strategy of chunking to explain how the chunking strategy can exceed the four item focus of attention limit across different WM tasks. Specifically, G. Li

et al. (2013) suggested WMC is limited to four chunks with each chunk

containing four items. Thus, G. Li et al. (2013) concluded the upward bound of

general WMC is approximately 16 items as a result of four chunks with four items

each.

Another aspect of strategy use is related to the allocation of attention to

the processing and storage of information. Specifically, researchers have

examined the strategic allocation hypothesis in which individuals with high WMC

are more likely to devote more attention to the storage component of a task while

devoting less attention to the processing component than individuals with low

WMC (Kane et al., 2004; McNamara & Scott, 2001; Turley-Ames & Whitfield,

2003). McNamara and Scott (2001) found participants that were taught

rehearsal, repeating the to-be-remembered information silently, or semantic

chaining strategies, which involved created a story out of the information,

recalled more words during a WM verbal task. However, they also found that the

accuracy of the processing component did not decrease suggesting that there

was not less attention paid to the processing component. Additionally,

individuals with low WMC were ability to increase with strategy use though high

WMC individuals did not much benefit. Similarly, Turley-Ames and Whitfield

(2003) found improvement in WMC with strategy instruction with the greatest

improvement in low WMC individuals who learned the rehearsal strategy. The

increased benefit of the rehearsal strategy remained while controlling for the

amount of time spent on the to-be-remembered words. Overall, the encoding

strategy is more importance the strategic allocation of sources for WMC measures.

In addition to the importance of encoding strategies with verbal information, researchers have also found encoding strategy effects with visual stimuli. There is evidence that participants in a demanding visual storage task will create a visual chunk to store information (Brady, Konkle, & Alvarez, 2009; Patt et al., 2014; Zhang, Ding, Stegall, & Mo, 2012). Specifically, Patt et al. (2014) found participants would create shapes out of discrete to-be-remembered spatial locations instead of an eye movement rehearsal strategy. This rehearsal strategy would entail participants shifting their gaze between the shown spatial locations as a method of maintaining that information, similar to phonological rehearsal of shown words. Patt et al. (2014) found through monitoring participants' eye movements that there is one target area participants gaze upon suggesting that they did not use a visual rehearsal technique with their eyes. Participants reported that they used imaginary shapes and lines to remember the spatial locations (Patt et al., 2014). Therefore, the chunking encoding strategies improve visual working memory in additional to verbal working memory.

Another important aspect of the relationship between strategy and WM training is the strategy affordance hypothesis in which WMC is mediated by strategy use (Borella et al., 2017; Dunning & Holmes, 2014). Dunning and Holmes (2014) found 50% more participants used some type of grouping strategy after WM training, and this increased strategy use was more likely with

adaptive WM training. Additionally, the increased in strategy use corresponded to increased WMC after training (Dunning, & Holmes, 2014). Similarly, Borella et al. (2017) found greater processing speed improvements in the group that received WM training and strategy training in comparison to the WM training only group. However, Borella et al. (2017) found these benefits for strategy use only for near transfer tasks in which the strategy was still applicable but did not transfer to a reasoning task that required a different strategy such as the Letter Set task. Furthermore, Gonthier and Tomassin (2015) found that strategy use fully mediated the relationship between WMC and fluid intelligence as measured through the Raven's Matrices reasoning task. Specifically, they found participants with higher WMC were more likely to use constructive matching, which involved creating a solution and then matching it to the choices, and participants with lower WMC were more likely to use response elimination, which involved eliminating incorrect choices. Participants who used constructive matching performed significantly better on the Raven's Matrices then participants who used response elimination (Gontheir & Tomassin, 2015). Therefore, strategy use not only influences WMC measures, but also mediates the relationship between WMC and reasoning tasks.

The Present Study

The overall aim of the present study was to examine the effect of encoding strategy and cognitive training on complex span task performance in college students with low WMC. This was accomplished by addressing two specific

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issues. First, the present study examined the effect of adaptive cognitive training on WMC through the use of a gamified version of the n-back task. The n-back is one of the most commonly used measures of working memory. This is largely because the task has strong construct validity (Kane et al., 2007), and correlates highly with measures of fluid intelligence. Additionally, simultaneously updating and maintaining information in the context of a dual-task best represents modern cognitive control models of working memory (Engle & Kane, 2003). The cognitive control aspect of working memory involves the control of attention through executive functions. Chen and Mitra (2008) found that performance on the n-back task involves brain regions associated with the executive functions of updating, manipulating, and storing information in working memory. Therefore, training on the n-back task is believed to generate domain general increases in WMC through stimulating these regions of the brain.

There is currently a debate as to how the n-back task relates to complex span tasks. It has been argued, for example, that the two tasks involve different cognitive processes (Kane et al., 2007). Complex span tasks require serial recall with interference, whereas the n-back task requires recognition while discriminating between previous items (Kane et al., 2007). Therefore, Kane et al. argued that the n–back and complex spans differ in both the type of retrieval required (i.e., recognition vs. recall) and the type of interference that is present. Furthermore, Kane et al. found little to no relationship between the n-back task and the operation span task (Turner& Engle, 1989). In contrast, Shelton,

Metzger, and Elliott (2007) found a moderately strong correlation between the n-back and operation span tasks. The primary difference between these two studies was Shelton et al. (2007) used a modified n-back task that required recall without retrieval cues while Kane et al. (2007) required recognition of the target item in the n-back task. Thus, by examining whether training on a gamified, adaptive n-back task improves performance on a set of complex span tasks, the present study will contribute to resolving this issue. It should be pointed out that improvements in WMC as a result of n-back training may correspond to improvements on complex span tasks even if individual performance on one task does not predict individual performance on the other (Redick & Lindsey, 2013).

To examine the effectiveness of the adaptive n-back training, low WMC participants were randomly assigned to either a WM training condition or a passive control condition. In the training condition, participants received four weeks of working memory training on a gamified version of an n-back task for a total 19 training sessions. In contrast, the passive control group received no contact from experimenters between the pre- and post-testing sessions. Multiple measures of WMC were used during the pre- and post-testing sessions, including the operation, rotation, and symmetry span tasks, as well as the WRAML-2 measure of verbal working memory task. If the n-back training improves WMC, performance on the WRAML2 will improved from T2 to T3 (see Figure 1).

The second purpose of the present study was to examine whether n‑back training improves the effectiveness of memory strategies in participants with low WMC. According to the strategic allocation hypothesis (Engle & Kane, 2003), individuals with high WMC are more likely to strategically manage limited resources than individuals with low WMC. For example, Turley-Ames and Whitfield (2003) found that individuals with low WMC improved their performance on complex span tasks when they were trained in the use of a rehearsal strategy. However, participants did not benefit from semantic-or imagery-based strategy training. Turley-Ames and Whitfield speculated that low WMC individuals performed better on span measures with the rehearsal strategy because it was less demanding on cognitive resources than the visual and semantic strategies. Similarly, Dunning and Holmes (2014) found that while individuals with low WMC benefit from less resource demanding strategies such as rehearsal, they perform poorly when using more resource demanding strategies.

To examine the effect of encoding strategy on the effectiveness of WM training, three strategy conditions were used (see Figure 2). In the *rehearsal strategy condition* participants were instructed on how to use a rehearsal-based encoding strategy. Participants in the *visual strategy condition* received instruction on the use of memory strategy based on the formation of mental images. A third *no strategy control condition* was also created. Participants in the rehearsal and imagery strategy conditions received instruction on how to use their assigned strategy before completing the WRAML verbal working memory

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task during the pretest session. All participants completed the WRAML task three times: once during prescreening (T1), once during pretesting (T2), and once during post-testing (T3). All other outcome measures will be administered two times throughout the study, once during pre-testing and once during post-testing.

Predictions based on how individuals differ in terms of managing the limited resources of working memory, can be derived from the strategic allocation hypothesis (Engle & Kane, 2003; see Figure 3). Low WMC participants in the rehearsal strategy condition are expected to perform better on the WRAML task at T2 than at T1. Because the rehearsal strategy requires a minimal amount of cognitive resources, participants with low WMC should benefit from applying this strategy to the WRAML task. In contrast, T1 performance should be comparable, or better, than performance at T2 for participants in the imagery condition. Because it is more resource demanding than the rehearsal strategy (Turley-Ames & Whitfield, 2003), and the participants possess low WMC, the imagery strategy should impede performance on the WRAML task before cognitive training. However, if the n-back training increases WMC, participants in both the rehearsal and the visual conditions should show a significant increase in WRAML performance between T2 and T3. That is, participants in the WM training condition should benefit from improved WMC, and, therefore, be able to more effectively utilize the memory strategies than participants from the passive control group who were taught a memory strategy. Finally, if the visual strategy is a more

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effective strategy than rehearsal, it is possible that participants in the visual

condition will perform better on the WRAML at T3 than participants in the

rehearsal condition.

CHAPTER TWO

METHOD

Participants

Participants (N= 46, Male=7, Female = 39, M_{age}=22.57) were recruited from California State University, San Bernardino (CSUSB) using the SONA Experiment Management System. This system lists available studies that Psychology majors may participate in for extra credit. Participants were screened by the Learning Research Institute research team at CSUSB, and these individuals participated in several research projects. Participants were prescreened with the Wide Range Assessment of Memory and Learning, Second Edition (WRAML2) would be categorized as low, mid, or high WMC. Specifically, participants who were one standard deviation below the mean (≤7) on the scaled WRAML2 verbal working memory subtest were selected. Of the 432 participants screened with the WRAML2, 148 (34%) were low, 262 (61%) were mid, 17 (4%) were high, and data was missing for 5 (1%) of participants. Participants who possessed low WMC were contacted and asked whether they would be interested in WM training. Participants were compensated with $150 ($10 per hour for training) while participants in the control condition were compensated with $40. All participants received extra credit in an undergraduate psychology course of their choice for their participation in the prescreening and selection

process. All participants were treated according to the ethics code of conduct

established by the American Psychological Association (2002).

<div align="center">Materials</div>

<u>Working Memory Measures</u>

 The WRAML2 measures the working memory of people from 5 to 90 years

of age (Sheslow & Adams, 2003). This measure contains six components that

measure verbal memory, visual memory, and attention. Verbal memory is

measured by the story memory and verbal learning subtests. Visual memory is

composed of the design memory and picture memory subtests. The finger

windows and number-letter subtests measure the attention component. The

composite of these six components is used for the General Memory Index score

to measure overall performance. The General Memory Index has a test-retest

reliability of .82 (Sheslow, & Adams, 2003). Additionally, the WRAML2 has

demonstrated external validity through is correlation with other measures of

memory including a correlation of .60 with the Wechsler Memory Scale-III, .68

with the California Verbal Learning Test-II, and .44 with the Wechsler Intelligence

Scale for Children. Overall, the WRAML2 has been shown to be a reliable and

valid measure of memory.

 In regards to construct validity, McGill and Dombrowski (2016) found that

most of the variance explained by the General Memory Index and verbal memory

component was shared. Additionally, the verbal memory component explained

little to no unique variance after the variance explained by the General Memory

Index and Attention/Concentration were removed, suggesting that these two constructs measure the same phenomenon (McGill & Dombrowski, 2016). Consequently, the verbal working memory test is a strong predictor of the General Memory Index. Additionally, the high correlation between WM and attention is predicted by cognitive control and attention theories of WM (Engle & Kane, 2003), which fits the theoretical framework of the current study. Furthermore, the scaled scores of the verbal working memory subtest allow for the classification of participants into the categories of low WM, average WM, and high WM. Specifically, the WRAML2 verbal working memory subscale has a scaled average of 10 with a standard deviation of three. These scaled scores are adjusted for the age of the participant, which enables comparisons across a wide range of ages. In the present study, participants who had a scaled scored of seven or below were classified as low WM and were included in the study.

The WRAML2 verbal working memory test is administered verbally by an experimenter and has two parts. In the first part, participants were instructed that a list of words would be read. This list contains both animal and non-animal items. Participants would repeat the animal items first in size order from smallest to largest. Then participants would list the non-animal items in any order. Participants would earn one point for listing the animal items in the correct order, one point for listing all of the non-animal items, and one more point if both previous points were earned. The second part of the verbal working memory subtest is similar to the first except that participants have to list both the animal

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and non-animal items in size order. Experimenters would record the order of the words spoken by the participants well as any intruding words that were not present on the word list.

The present study also included the use of three computerized complex span measures developed by Foster et al. (2014): operation, symmetry, and rotation span. These tasks required the E- Prime 2.0 software, and a Windows based operating system (http://englelab.gatech.edu/tasks.html). Each complex span task had a distracter task along the to-be-remembered items. Participants practiced both the distracter task, and the span task as part of the testing sequence. Foster et al. (2014) found that these shortened computerized complex span measures reliably measured WMC and were also able to predict the same amount of variance in fluid intelligence as longer measures of WMC. Therefore, these tasks fulfill the objectives of the present study for a reliable and valid measure of WMC.

During the operation span, participants judge whether the solution to a simple math problem (e.g. (2 x 2) -1 = 3) was true or false before recalling a sequence letters presented before the math problem.   On the response screen, participants had to click a box next to the correct letters in the order they appeared from a total of 16 different letters. Participants were scored according to numbers of correct letters remembered in the correct sequence. During the symmetry span, participants judged whether a grid pattern is vertically symmetrical before recall a sequence of squares presented in a 4 x 4 grid

pattern. On the response screen, participants were required to click the boxes in the order they appeared. Participants were scored according to the number of correction locations in the correct order. Finally, participants had to remember the order, size, and direction of arrows presented on screen while judging whether a rotated letter was orientated correctly or mirror reflected. On the response screen, participants selected from 16 different arrows in the correct. Participants were scored based upon the number of correct arrows order selected in the correct order.

<u>Working Memory Training</u>

Participants received 20 WM training session over a four week period. These training sessions lasted from 30-45 minutes. Previous studies have found significant improvements in WMC from 20 WM training sessions cumulating in over 15 hours of training (e.g.; Au et al., 2015; Deveau et al., 2015; Bergman-Nutley & Klingberg, 2014). Additionally, Dunning and Holmes (2014) found through a double-blind randomized controlled trial that 10 training sessions were sufficient for significant improvements in WMC. Therefore, the present study was likely to obtain significant results with a 20 session training program.

The WM training was conducted using computerized n-back tasks developed by the Brain Game Center for Mental Fitness and Wellbeing at the University of California, Riverside. One of these tasks was the tapback n-back task that was presented on Ipads. The tapback task required participants to recall the appropriate visual stimuli n items back by selecting the appropriate

response. This task would become progressively harder by increasing the n-back as participants improved on the task. The other task was also administered using Ipads. Recall The Game is a n-back training task in video game format. The objective of the game is to collect fuel pods that match the color, shape, and/ or sound of a fuel pod presented n-items backs. The present study limited the games settings to sounds only. The fuel pods were presented as a blue circle, yellow triangle, green star, and a red cylinder. Each fuel pod also was associated with a unique sound. Additionally, Recall The Game has a hold-out feature in which one of the characteristics would be absent from the target fuel pod. For example, the blue circle fuel pod may reappear as a green circle when a shape-matching rule is in place. The holdout feature forces participants to engage in task switching as the rules change. Overall, both WM training tasks were adaptive n-back tasks that trained participants WMC.

<div align="center">Procedure</div>

Participants were prescreened using the WRAML2 to determine whether they had low WMC. The WRAML2 verbal working memory test is administered verbally by an experimenter and has two parts. In the first part, participants were instructed that a list of words would be read. This list contains both animal and non-animal items. Participants would repeat the animal items first in size order from smallest to largest. Then participants would list the non-animal items in any order. Participants would earn one point for listing the animal items in the correct order, one point for listing all of the non-animal items, and one more point if both

previous points were earned. The second part of the task was similar to the first, but both the animal items and non-animal items had to be listed in size order from smallest to largest. Participants would earn one point for list the animal items in the correct order, one point for listing the non-animal items in the correct order, and an additional point if both of the previous points were earned.

After the prescreening, low WMC participants were contacted, and ask whether there were interested in further testing. If participants were available, then they were scheduled for two separate days of pre-testing for approximately 60-90 minutes. On Day 1 of pretesting, participants were tested with the following measures: Operation Span, Symmetry Span, and the Rotation span. The experimenter read the instructions for each span task and was present to answer any questions. Additionally, participants were randomly assigned to the rehearsal strategy or the imagery strategy for the second WRAML2 verbal working memory test. The strategy instructions were modified from the instructions devised by Turley-Ames and Whitfield (2003). In the rehearsal condition, participants were instructed to silently repeat the list of words as they were presented. In the imagery strategy condition, participants were instructed to picture each word and add it to a scene. An example of the wording of the instructions is presented below:

> Before starting a second version of the…task you…completed [during the prescreen], we ask that you try a particular strategy that may improve your performance on this [task]…When you are presented with a to-be-

remembered world, we would like you to create a visual image or picture

of the to-be-remembered word…As additional words are added to a set,

please add to your previously created image or picture the new words.

(Turley-Ames & Whitfield, 2003, p. 457)

For the WM training portion of the study, participants were assigned to a

numbered I-pad for the duration of WM training. Software access for the WM

training was obtained through contacting the director of the Brain Game Center

at University of California, Riverside. During session 1, participants were

instructed with the use of the I-pads, to use headphones throughout training, and

were familiarized with the WM training task. Participants were scheduled for five

days a week over a four-week period, and they were trained in a quiet room

provided by the Learning Research Institute at California State University, San

Bernardino. Participant attendance was recorded, and reminders were sent for

WM training.

The post testing procedure was similar to the pretest procedure. Near the

end of the WM training, both control and training condition participants were

contacted to scheduled post testing on two separate days. Day 1 post testing

included the operation span, symmetry span, and rotation span. Day 2 post

testing included the WRAML2. Payment for participants was granted to the

Coyote One Card, which could be use with any store or cafeteria on the

California State University, San Bernardino campus. After the post test was

completed, participants were debriefed and thanked for their participation.

Design and Data Analysis

The present study employed mixed design to examine the effects of strategy and WM training on students with low WMC. The within-subjects factor is Time Period, which includes the prescreen, pretest, and posttest. The between-subject factors are WM Training (Training, No Training) and Strategy (No Strategy, Rehearsal, Visual). WMC was measured through the WRAML2 verbal working memory subtest, and the composite span score consisting of the average proportion correct from the Operation Span, Symmetry Span, and Rotation Span. WRAML2 scores were collected during the prescreen to identify low WMC participants, and to established baseline scores before any strategy and training. During the pretest, WRAML2 scores were measured in the context of Strategy (No Strategy, Rehearsal, Visual). For the posttest, WRAML2 scores were measured in the context of both Strategy (No Strategy, Rehearsal, Visual) and WM Training ((Training, No Training). Composite span scores were measured to compare the WRAML2 scores to more commonly used measures of WMC. Additional planned comparisons were conducted between the prescreen and pretest to examine the influence of Strategy and Time Period before any WM Training. Finally, planned comparisons were conducted between the pretest and posttest to examine differences between Strategy, Time Period, and WM Training.

CHAPTER THREE

RESULTS

In order to examine whether the present study was able to replicate research on the near transfer effects of working memory training, a 2 (Time Period: Pretest, Posttest) X 2 (WM Training: Training, No Training) ANOVA was conducted on both WRAML2 and composite SPAN score. For the WRAML2 data, there was not a significant interaction between Training and Time Period, $F(1, 44) =$ 3.12, MSE= 8.30, p = .084, η_p^2= .07 (see Figure 4). For the composite SPAN, there was not a significant interaction between Time Period and WM Training, $F(1, 43)$ = .02, MSE= .007, p = .887, η_p^2 < .001 (see Figure 5). Therefore, the present study was unable to find near transfer effects of working memory training to complex span measures.

A 2 (WM Training: Training, No Training) X 3 (Strategy: No Strategy, Rehearsal, Visual) X 3(Time Period: Prescreen, Pretest, Posttest) mixed factorial design was used to examine the effect of strategy and working memory training upon working memory capacity (WMC) in low WMC participants. WM Training and Strategy were examined between-subjects while Time Period was examined within-subjects. WMC was measured using the WRAML2 during three time-periods: prescreen, pretest, and posttest.

Figure 3 displays the changes over time in WRAML2 score according to strategy in the no training and training groups respectively. There was a significant main effect of time period, $F(2, 80) = 33.40$, $MSE= 11.98$, $p < .001$, $\eta_p^2 = .46$. Post hoc LSD tests showed participants scored higher on the pretest ($M = 24.5$, $SE = .91$) than on the prescreen ($M = 18.9$, $SE = .65$). However, there was no significant difference in WRAML2 scores between the pretest ($M = 24.5$, $SE = .91$) and posttest ($M = 24.5$, $SE = .91$). Therefore, participants' scores increased from prescreen to pretest, but there was no additional increase from the pretest to the posttest. There were no significant differences in WRAML2 scores for the interaction between WM training and Time Period, $F(2, 80) = 2.25$, $p =.112$, $\eta_p^2 = .05$. There were no significant differences in WRAML2 scores for the interaction between Strategy and Time Period, $F(2, 80) = 2.25$, $p = .321$, $\eta_p^2 = .06$. There were no significant differences in WRAML2 scores for the interaction between WM Training, Strategy, and Time Period, $F(2, 80) = .85$, $p =.498$, $\eta_p^2 = .04$. There were no significant differences in WRAML2 scores for the main effect of WM Training, $F(1, 40) = 1.84$, $p =.183$, $\eta_p^2 = .05$. There were no significant differences in WRAML2 scores for the main effect of Strategy, $F(2, 40) = 1.89$, $p = .165$, $\eta_p^2 = .09$. Finally, there were no significant differences in WRAML2 scores for the interaction between WM Training and Strategy, $F(2, 40) = .39$, $p =.682$, $\eta_p^2 = .02$.

There were no statistically significant effects for strategy, training, and their interaction upon WRAML2 scores in the 2 (WM Training: Training, No

Training) X 3 (Strategy: No Strategy, Rehearsal, Visual) X 3(Time Period:

Prescreen, Pretest, Posttest) analysis. The standard procedure of null

hypothesis significance testing would end the investigation at this point.

However, there has been research (e.g., Jones & Tukey, 2000; Wilkinson & Task

Force on Statistical Inference, American Psychological Association, Science

Directorate, 1999) suggesting that effect size and direction data may be valuable

even in the absence of statistical significance. Therefore, the present study

conducted the planned comparison between prescreen and pretest for strategy

effects. Additionally, the present conducted the planned comparison between

the pretest and posttest to examine strategy effects as a function working

memory training.

The first planned comparison investigated changes from prescreen to

pretest in WRAML2 scores in a 3 (Strategy: No Strategy, Rehearsal, Visual) X 2

(Time Period: Prescreen, Pretest) analysis. This analysis was conducted to test

the hypothesis that participants with low WMC benefited the most from the

rehearsal strategy in comparison to the visual and control conditions before any

WM training has occurred. There were significant within-subject differences in

WRAML2 scores between the prescreen ($M = 18.2$, $SD = 3.82$) and pretest ($M =$

24.3, $SD = 5.24$), $F(1, 43) = 60.61$, $MSE = 14.04$, $p < .001$, $\eta_p^2 = .59$.

Consequently, participants improved on the WRAML2 from prescreen to pretest.

Although participants who received the visual strategy instruction ($M = 26.4$, SD

$= 6.17$) scored higher on the WRAML2 than participants who received the

rehearsal strategy instruction (M= 23.4, SD = 4.10) and control strategy instruction (M = 23.4, SD = 5.08) during the pretest, these between subject differences were not statistically significant, $F(1, 43) = 1.22$, $MSE = 27.94$, p= .306, η_p^2 = .05 (see Figure 7).

The second planned comparison investigated differences during the pretest and posttest. There were not statistically significant differences between WRAML2 scores between the pretest (M = 24.3, SD = 5.24) and the posttest (M = 25.6, SD = 4.33), $F(1, 40) = 2.08$, p=.157, η_p^2= .05. Although participants who received the visual strategy instruction (M = 27.1, SE = 1.28) performed better overall on the WRAML2 than participants who received the rehearsal strategy instruction (M = 23.5, SE = 1.65) and the control strategy instruction (M = 24.3, SE = 1.02), these differences were not significantly different, $F(2, 40) = 2.03$, p = .144, η_p^2= .09. Similarly, there were no significant differences on the WRAML2 between participants who did not received WM training (M= 25.4, SE = 1.34) and those who did receive WM Training (M = 24.6, SE = .79), $F(1, 40) = .26$, p = .610 , η_p^2= .01. Additionally, the interaction between strategy and training did not have a significant effect on posttest WRAML2 scores, $F(2, 40) = .47$, p = .626, η_p^2 = .02 (see Figure 8).

The next set of analyses examined whether there were possible confounding variables that influenced the WRAML2 scores. Because participants self-selected whether they would participate in WM training, there could be between group differences not controlled by the study that would be

revealed during the prescreen. Therefore, a2 (WM Training: Training, No

Training) X 3 (Strategy: No Strategy, Rehearsal, Visual) factorial ANOVA was

conducted on the prescreen WRAML2 scores. There were statistically significant

differences between participants available for WM training, and those who were

not available for WM training, $F(1, 40) = 6.71$, $p = .013$, $\eta_p^2 = .14$. Participants

who were not available for WM training ($M = 20.5$, $SE = 1.13$) scored higher on

the WRAML2 prescreen than participants who were available for WM training (M

$= 17.2$, $SE = .66$). There were not statistically significant differences between

prescreen WRAML2 scores based upon assignment to strategy conditions, $F(2,$

$40) = .625$, $p = .541$, $\eta_p^2 = .03$. Additionally, the interaction between training and

strategy was not significant for prescreen WRAML2 scores, $F(2, 40) = .247$, $p =$

$.781$, $\eta_p^2 = .01$. A 2 (Training, Passive Control) X 3 (Passive Control, Rehearsal

Strategy, Visual Strategy) factorial ANOVA was conducted on whether age was

statistically different between groups. Overall, there were no significant

differences in age between groups, $F(5, 40) = .85$, $p = .524$, $R^2 = .10$.

The final set of analyses examined whether there were possible

confounding variables that influenced the composite SPAN. First, a 2 (WM

Training: Training, No Training) X 3 (Strategy: No Strategy, Rehearsal, Visual)

factorial ANOVA was conducted on the pretest composite SPAN. There were no

main effects of WM Training and Strategy ($F<1$) on the pretest composite SPAN.

Second, a (WM Training: Training, No Training) X 3 (Strategy: No Strategy,

Rehearsal, Visual) X Time Period (Pretest, Posttest). There was a significant

main effect of Time Period between pretest and posttest composite SPAN scores, $F(1, 39) = 6.33$, $p = .016$, $\eta_p^2 = .14$. Participants scored higher on the posttest composite SPAN ($M = .66$, $SE = .03$) than on the pretest composite SPAN ($M = .61$, $SE = .03$). There was not a significant interaction effect of Time Period and WM Training on composite SPAN, $F(2, 39) = .34$, $p = .559$, $\eta_p^2 = .01$. There was not a significant interaction effect of Time Period and Strategy on composite SPAN, $F(2, 39) = 1.62$, $p = .221$, $\eta_p^2 = .08$ (see Figure 9). There was not a significant interaction effect of WM Training, Strategy, and Time Period on composite SPAN, $F(2, 39) = .37$, $p = .693$, $\eta_p^2 = .02$ (see Figure 10).

CHAPTER FOUR

DISCUSSION

The present study examined the effect of encoding strategy and cognitive training upon working memory capacity (WMC) in college students with low WMC. Therefore, the present study measured WMC at three time periods to examine baseline WMC, WMC with strategy instruction, and WMC with strategy instruction and cognitive training. Participants scored higher on the WRAML2 measure of verbal working memory during the pretest than on the prescreen. Specifically, participants classified with low WMC based upon standardized WRAML2 scores increased to either average or high WMC on the pretest. The present study predicted that participants would do better on the WRAML2 with the rehearsal strategy than the visual strategy and the control condition. However, participants who were given the rehearsal strategy performed equally as well as participants who did not receive any strategy instruction in the control condition. Although it was not a statistically significant difference, participants with the visual strategy instruction had the highest average scores on the WRAML2 on during both the pretest and posttest. Thus, the hypothesis that the visual strategy would impair performance due to higher demands on the WRAML2 during the pretest was not supported. Because the increases on the WRAML2 during the pretest with either strategy instruction condition were not

significantly different from the control group, there was no support for the hypothesis that strategy instruction improves performance beyond the benefits of retaking the WRAML2.

The present study predicted improvements in WRAML2 scores after n-back cognitive training. Specifically, participants would score higher on the WRAML2 during posttesting, and participants who had both strategy instructions and n-back training would score the highest on the WRAML2. Additionally, the present study predicted that the benefits of n-back training would enable participants given the visual strategy instructions to score higher on the WRAML2 than participants in either the control or rehearsal condition. Overall, there were not significant differences between the pretest WRAML2 scores and posttest WRAML2 scores. Participants who receive the visual strategy instructions consistently scored higher on the WRAML2 on both the pretest and posttest, but these differences were not significantly greater than either the rehearsal or control conditions. When examining nonsignificant trends from pretest to posttest in the no training group, the no strategy group made miniscule gains, which was expected for a control group for both strategy and training conditions (see Figure 6). In contrast, the rehearsal group improved while the visual group did worse on the posttest than the pretest (see Figure 6). When examining nonsignificant trends from the pretest to the posttest in the training group, all strategy conditions made small gains in WRAML2 score with the greatest gain for the visual strategy condition (see Figure 6). While average WRAML2 score for

participants in the visual strategy condition was not significantly higher than the rehearsal or control group, it was in the predicted direction for the posttest.

The present study also predicted improvements in WMC as measured through three computerized span tasks developed by Foster et al. (2015). Overall, there was a significant improvement in composite span scores from the pretest to the posttest. However, these gains were not significantly different according to training, strategy, or the interaction between training and strategy. Therefore, the hypothesis that cognitive training would improve WMC as measured through computerized span tasks was not supported. Both participants in the training group and no training group had small improvements in their composite span scores (see Figure 5). Unexpectedly, participants in the rehearsal strategy condition for the WRAML2 had the least change in composite span scores from pretest to posttest while both the participants in the no strategy control and visual strategy condition scored higher during the posttest (see Figure 9).

In contrast to previous research (e.g., Karbach & Verhaeghen, 2014; Astle et al., 2015; Au et al., 2015), n-back training did not transfer to improvements on the shortened complex span measures developed by Foster et al. (2015). However, the marginally nonsignificant relationship between WRAML2 scores and n-back training suggests there may be a transfer between these two tasks. This result is consistent with Redick and Linsey's (2013) conclusion that n-back tasks train different components of working memory than is measured during

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complex span tasks. Similarly, Schmiedek et al. (2014) found that while n-back

tasks and complex span tasks are strongly correlated with a latent working

memory construct, these two types of tasks can be weakly related to each other

due to paradigm, content, and measurement error differences between these

tasks. Additionally, the composite SPAN measure consisted of three complex

span measures, which is more likely to capture a general working memory factor

than any one task alone (Schmiedek et al., 2014). Thus, the present study

suggests n-back training may improve a processing component of WMC that has

a greater effect on WRAML2 performance than a general working memory factor

measured by the composite SPAN.

The improvements on the WRAML2 from the prescreen to the pretest may

be explained by levels of processing theory (Craik & Tulving, 1975) and long-

term working memory theory (Ericsson & Delaney, 1999; Ericsson & Kintsch,

1995). According to leveling of processing theory, recall of words can be

improved through analyzing items based upon their meaning and relationship to

other items (Craik & Tulving, 1975). This deeper analysis of words is

hypothesized to create stronger memory traces in long term memory in

comparison to shallow analysis, which could include focusing on the sound of the

words and the number of syllables in those words. During the WRAML2,

participants had to categorized to-be-remembered words as either animal or

nonanimal items while also listing these words in size order. Consequently,

participants created strong memory traces of those words by analyzing both the

size and category of each word. These memory traces can improve performance on working memory tasks by facilitating the grouping of words and easing the mental representations of words (Ericsson & Kintsch, 1995; Oberauer, Jones, & Lewandowsky, 2015). Oberauer et al. (2015) demonstrated that these memory traces can improve performance on complex span tasks after repeated exposure to the same word lists in a complex span task regardless of cognitive load or task difficulty. In the present study, participants may have performed better on the pretest WRAML2 due to learning how to better represent and recall the word lists.

Although strategy did not significantly effect performance on the WRAML2, the present study can contribute to understanding the strategy mediation theory of working memory performance. The use of effective strategies has been shown to improve performance on complex span tasks (Borella et al., 2017; Dunlosky & Kane, 2007; McNamara & Scott, 2001; Turley-Ames & Whitfield, 2003). However, there is some inconsistency between which strategies are effective, and under which circumstances these strategies are effective. Specifically, McNamara and Scott (2001) found no improvement on complex span measures when participants used a rehearsal strategy while Turley-Ames and Whitfield (2003) found improvement on complex span measures when participants used a rehearsal strategy. Additionally, Turley-Ames and Whitfield (2003) found the rehearsal strategy effective for participants with a low WMC, but less effective for participants with either average or high

WMC. The results of the present study are consistent with McNamara and Scott (2001) as the rehearsal strategy did not significantly increase WMC in comparison to the control group, but the results are inconsistent with Turley and Whitfield's (2003) conclusion that the rehearsal strategy is optimal for low spans.

The absence of support for the strategy mediation hypothesis may be due to task differences between the WRAML2 verbal working memory subtest and other complex span tasks used by previous studies of the strategy mediation hypothesis. Borella et al. (2017), Dunlosky and Kane, McNamara and Scott (2001), and Turley and Whitfield (2003) all used complex span tasks that were scored by the number of items remembered in the correct serial order. For the WRAML2, no points are awarded when a single interfering response is present in either the repeated list of animal words or nonanimal words even when other items are in the correct serial order (Sheslow & Adams, 2003). Additionally, the WRAML2 has a discontinue rule of two consecutive scores of zero on to-be-remembered word lists, which can greatly reduce overall WRAML2 score. Consequently, there is a potentially higher cost for errors in inhibiting previous to-be-remembered items during the WRAML2 verbal working memory in comparison to other complex span tasks.

Although there was not a significant interaction between strategy condition and training condition, the participant group who received visual strategy instructions had the highest average WRAML2 score with or without WM training. This pattern may be attributed to the strategic allocation hypothesis, and the

suggestion that greater WMC enables the use of effective strategies (Dunning & Holmes, 2014; Turley-Ames & Whitfield, 2003). The strategic allocation hypothesis explains the relation between WMC and strategy use by asserting that participants have greater WMC because they allocate working memory to effective strategies while inhibiting or ignoring irrelevant information (Turley-Ames & Whitfield, 2003). In the present study, the participants in the no training condition had greater WMC than participants in training condition based upon the prescreen WRAML2 score. This confounding group difference may have interacted with the effectiveness of the visual strategy instructions in the no training group; participants in the no training group who receive visual strategy instructions during the pretest scored the highest on the WRAML2 than all other conditions and time periods. Therefore, the benefits of higher WMC and the effective visual strategy may have enhanced the practice effect in this group.

The pattern of WRAML2 scores according to time, strategy, and training is consistent with the compensation effect and magnification effect described by Borella et al. (2017). Specifically, Borella et al. (2017) suggested that working memory training minimizes individual differences in WMC because low spans improve with training while high spans benefit less from the training. In contrast, strategy training maximizes individual differences as low spans may struggle with the higher cognitive load from effective strategies while high spans can use strategies with less susceptibility to the higher cognitive load (Dunning & Holmes, 2014; Titz & Karbach, 2014; Turley-Ames & Whitfield, 2003). Although the

present study did not train participants in memory strategies, the present study did manipulate the instructions to encourage the use of specific strategies. Figure 4 shows a pattern consistent with the magnification effect during the pretest and compensation effect during the posttest. During the pretest, participants were given the strategy instructions, and thus the strategy condition may have magnified the differences between groups. During the posttest, the differences between groups are less pronounced, which could be a possible result of the compensation effect through WM training. Because the present study screened participants for low WMC according to standardized WRAML2 scores, the magnification effect of strategy instructions during the pretest may be less than if a wider range of participants were included in the study. Although caution must be employed with any interpretation of null results, the present study is at least consistent with the magnification effect as a result of strategy and the compensation effect as a result of WM training.

A possible relationship between composite span score and strategy condition on the WRAML2 may be attributed strategy carryover effect to the span tasks. During the pretest, participants in the visual and rehearsal strategy conditions are introduce to the notion that strategy could improve their performance on memory tasks. By the posttest, participants in these two strategy conditions would be able to apply that idea to the span tasks. Figure 6 shows the nonsignificant trend of the control and visual strategy conditions increasing in WRAML2 score from pretest to posttest while the rehearsal groups

remains the same. Research (e.g., Borella et al., 2017; Dunlosky & Kane, 2007;

Turley-Ames & Whitfield, 2003) has shown that strategy instruction can improve

performance on complex span measures. However, McNamara and Scott

(2001) demonstrated that using the rehearsal strategy scored lower on complex

span measures in comparison to participants who used semantically grouped

strategies or mixed strategies. Therefore, the participants given the rehearsal

strategy on WRAML2 may have also used that strategy on the span tasks, and

thus scored less on the composite span measure. Dunning and Holmes (2014)

demonstrated that participants are more likely to use strategies after WM

training, and can develop effective strategies during the course of WMC

assessment. Therefore, participants in the no strategy condition may have

developed effective strategies during repeated testing on complex span

measures. Finally, participants in the visual strategy condition may have had the

highest score due to the applicability of the visual strategy to the rotation and

symmetry span components of the composite span score.   Kane et al. (2004)

found the rotation and symmetry span highly correlated to spatial factor of WMC.

According to strategy affordance hypothesis, strategy mediates the relationship

between WMC measures only when the same strategy is applicable to both

measures (Bailey, Dunlosky, & Kane, 2008; Dunning & Holmes, 2014). Because

the rotation span and symmetry are strongly related to spatial WMC, the

participants in the visual strategy condition may have scored higher on the

composite span due to the applicability of the visual strategy to two out of the three complex span measures used in the composite span score.

There are limitations in the present study regarding the implementation of the strategy and training conditions. The present study did not include a procedure to examine whether participants followed the strategy instructions. During the data collection of the present study, Borella et al. (2017) published a means of evaluating the use of a visual strategy by having participants evaluate the vividness of their mental images. Similarly, Turley-Ames and Whitfield (2003) had participants rehearse words aloud to verify the use of a rehearsal strategy, but this technique was not applicable to the administration of the WRAML2 verbal working memory subtest. In regards to the training conditions, the present study used a passive control group to compare to the training group. The comparison between passive control groups and WM training group is thought to increase the risk of spurious findings (Dougherty, Hamovitz, & Tidwell, 2016; Melby-Lervag, Redick, & Hulme, 2016). Additionally, participants who were not available for training scored higher on the prescreen WRAML2 than participants who were available for training. Consequently, this difference may have masked training gains relative to the control group.

Overall, the present study cannot make any strong conclusions about the effects of strategy and training upon WMC in low WMC populations. The present study found repeated exposure to the complex span measures produces a practice effect that increases score on these measures. Speculatively, strategy

use may magnify individual differences measured in baseline performance and may increase practice effects on a specific task. In contrast, WM training may minimize individual differences among participants. Future research across a wider range of WMC is needed to see if strategy consistently magnifies individual differences in WMC, and if WM training reduces these individual differences.
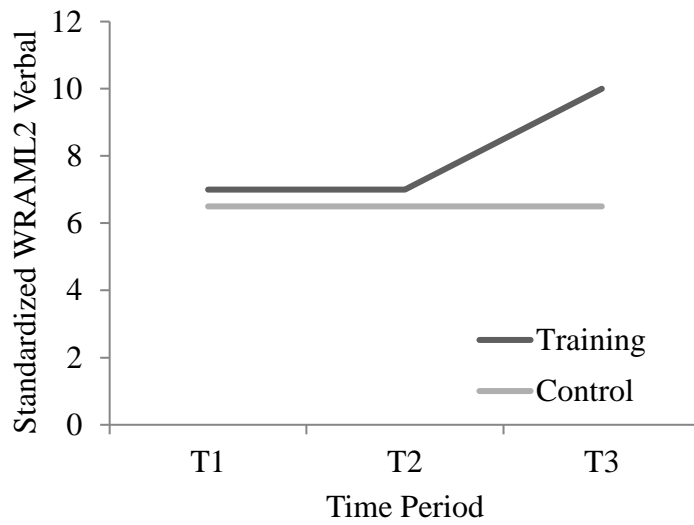
FIGURES

Figure 1. Predicted outcomes of n-back training on standardized WRAML2 Verbal Working Memory as a function of time period.
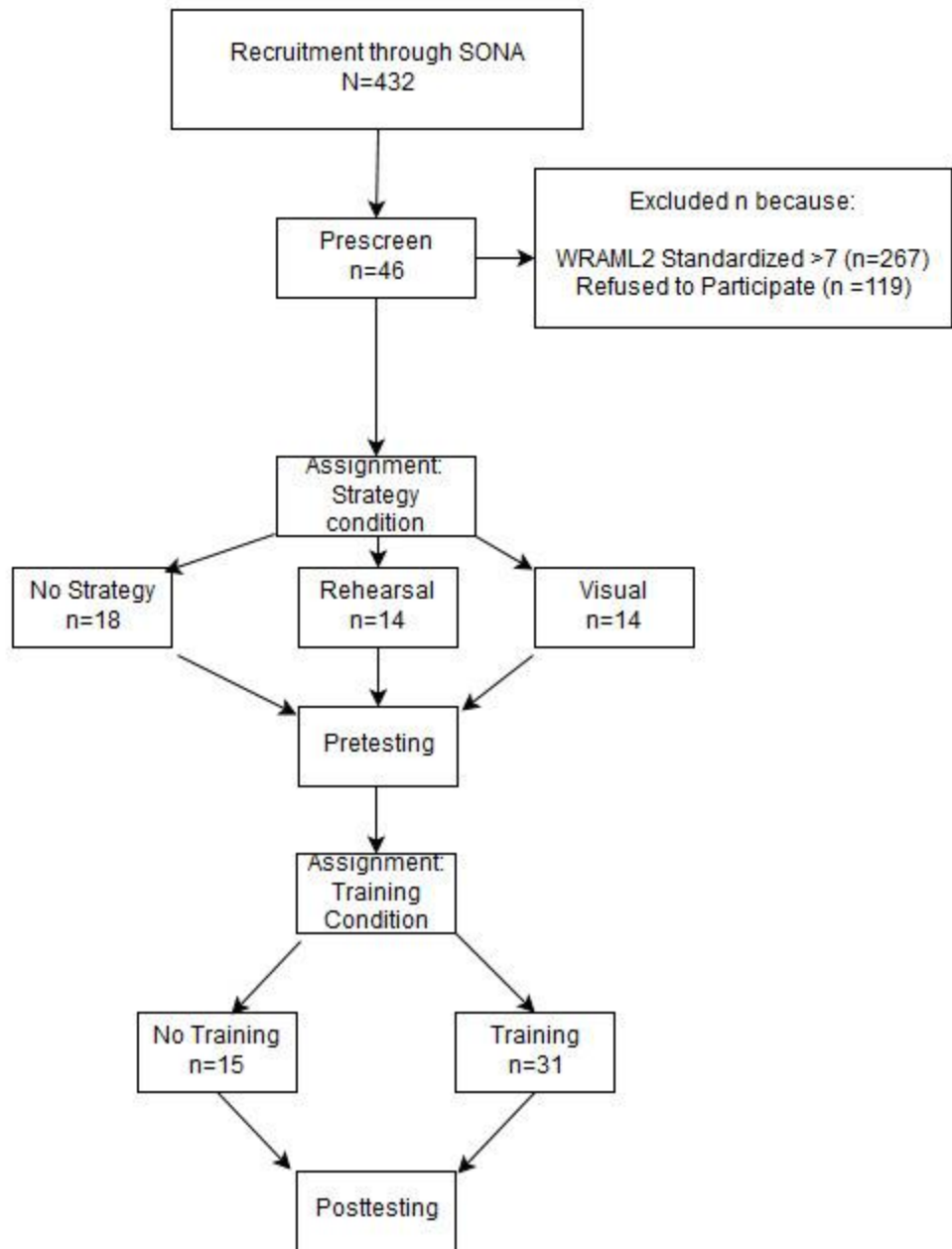
Figure 2. Participant Flow Chart
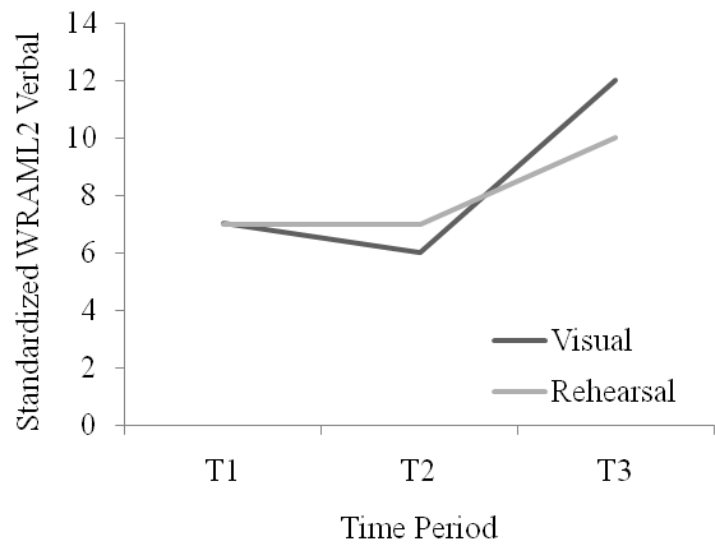
Figure 3. Predicted outcomes of n-back training on standardized WRAML2 Verbal Working Memory as a function of time period and strategy condition
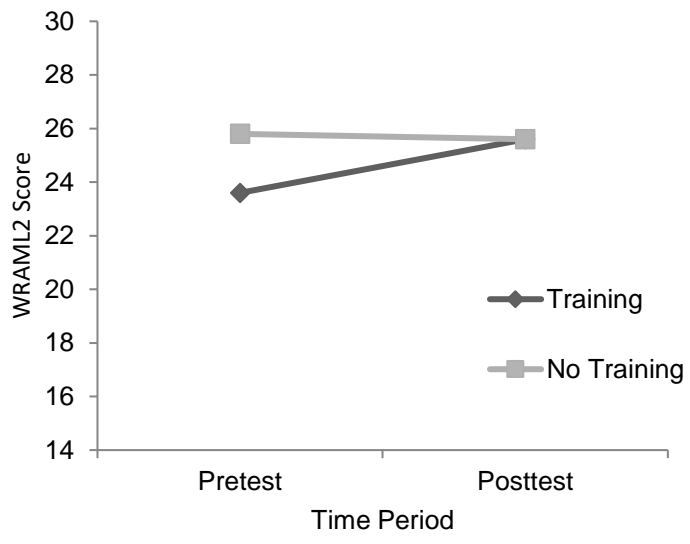
Figure 4. WRAML2 Score as a function of WM Training and Time Period
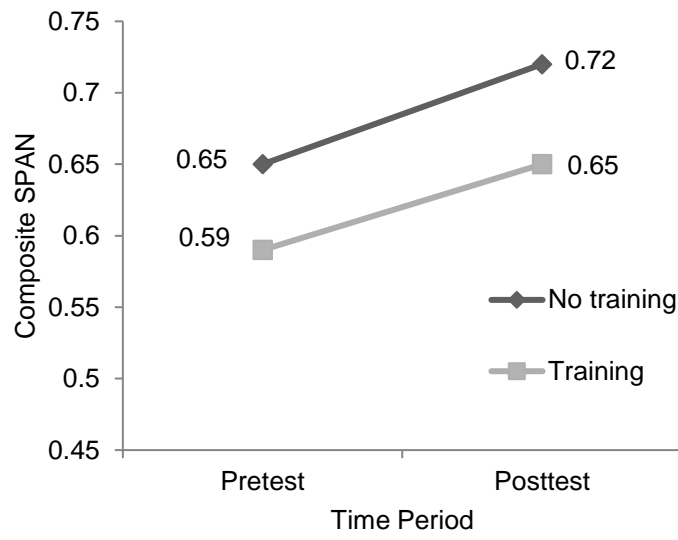
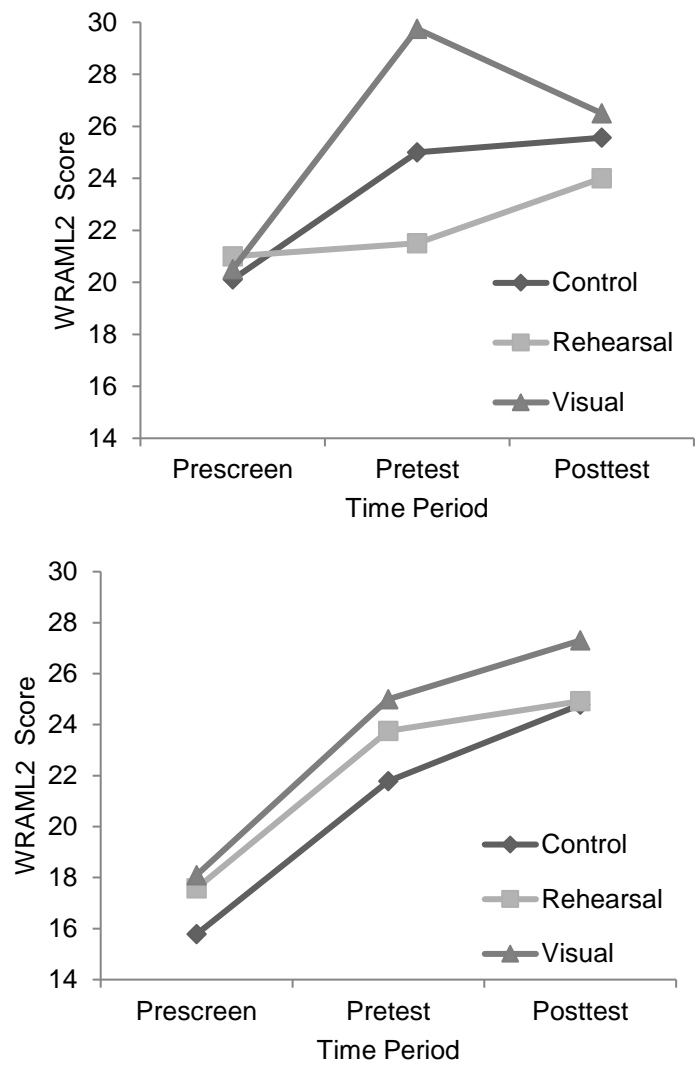*Figure 5*. Composite SPAN as function of time period and training.

Figure 6. WRAML2 score as a function of Strategy, Training, and Time Period. The top panel displays changes over time for the no training group, and the bottom panel displays changes over time for the training group.
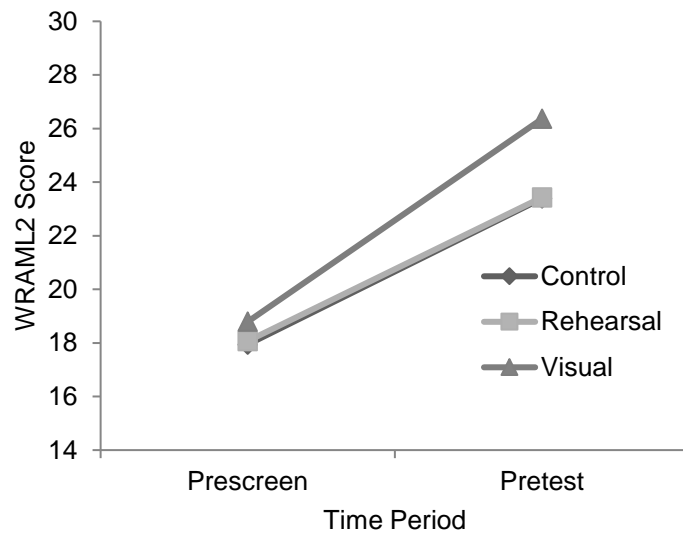
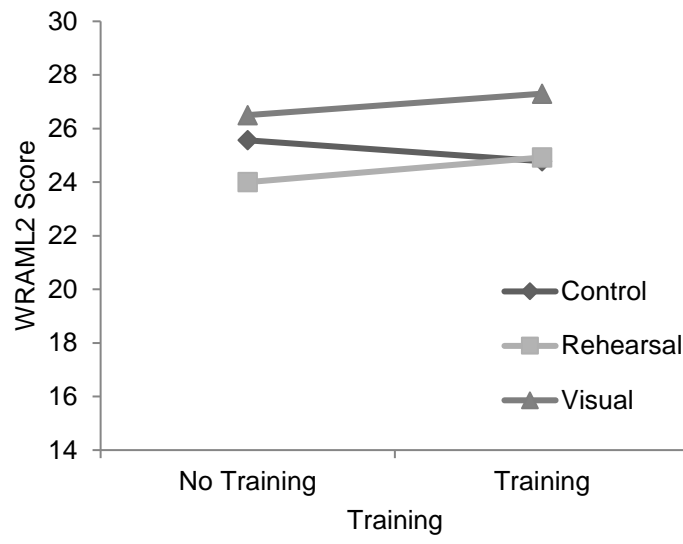*Figure 7.* WRAML2 score as function of time period and strategy.

Figure 8. WRAML2 Score as a function of Strategy and Training.
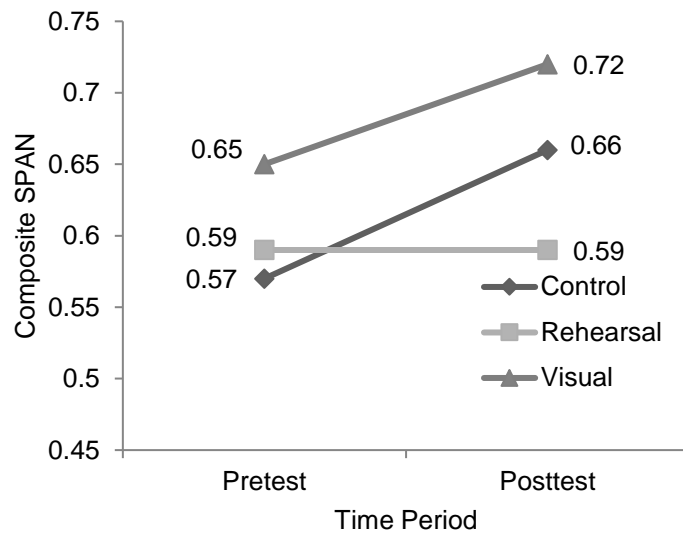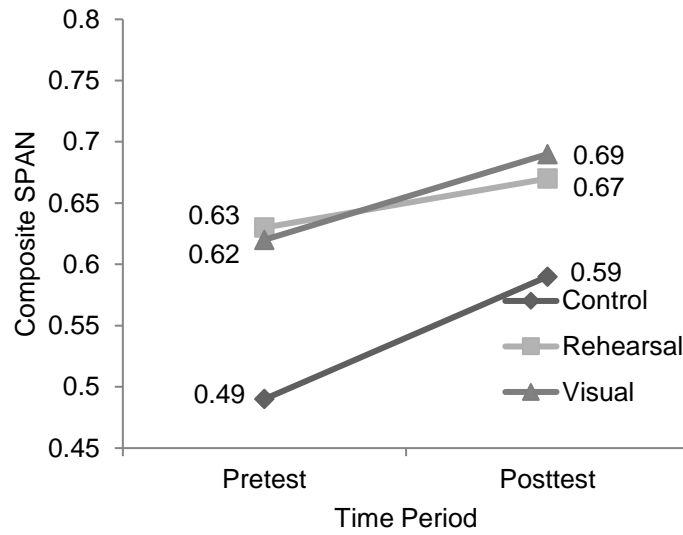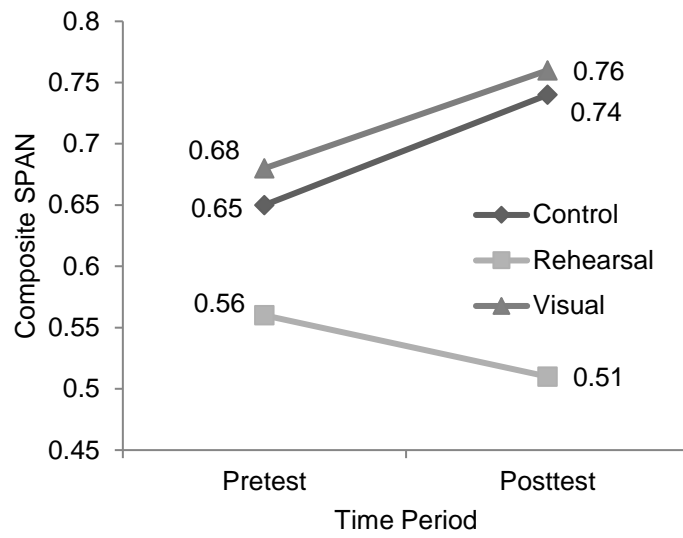
Figure 9. Composite SPAN as function of time period and strategy.

Figure 10. Composite SPAN as a function of Strategy, Training, and Time Period. The top panel displays changes over time for the no training group, and the bottom panel displays changes over time for the training group.

APPENDIX B

IRB APPROVAL

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

PI: Reimer, Jason

From: John P. Clapper

Project Title: Working Memory Tasks

Project ID: H-13FA-04

Date: 9/29/16

Disposition: Renewal Request

Your IRB renewal request is approved to include 300 participants. If you need additional participants, an addendum will be required. This approval is valid until 9/29/17.

Good luck with your research!

(signature)

John P. Clapper, Co-Chair
Psychology IRB Sub-Committee

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