COGNITIVE CONSEQUENCES OF WORKING MEMORY TRAINING ON A TYPICALLY DEVELOPED POPULATION

A Thesis

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by

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Recent studies have demonstrated that cognitive enhancement training methods
directed at working memory can improve the symptoms of disorders characterized by
deficits in executive functioning such as Attention Deficit-Hyperactivity Disorder.
Although additional studies have explored the effects of training on other populations
such as the older adults and those who have experienced a stroke, they have not
extensively examined whether or not training can improve working memory for typically
developed populations. Additionally, the underlying mechanisms impacted by the
training have not been elaborated on. Two studies seek to address whether or not working
memory can be trained in a population of college students, by examining how three
constructs of working memory: interference control, the focus and scope of attention, and
cue dependent retrieval, are impacted by working memory training.
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INTRODUCTION

Recently, there has been an increase in research exploring the area of cognitive enhancement (Atkins & Reuter-Lorenz, 2008; Dahlin, Stigsdotter Neely, Larsson, Bäckman & Nyberg, 2008; Eack, Hogarty, Greenwalk, Hogarty & Keshavan, 2007; Hayward, Das & Janzen, 2007; Hogarty, Greenwald & Eack, 2006; Jaeggi, Buschkuehl, Jonides & Perrig, 2008; Klingberg, Forssberg & Westerberg, 2002; Klingberg, Fernel, Olesen, Johnson, Gustafsson, Dahlstrom, Gillberg, Forssberg, & Westerberg, 2005; Olesen, Westerberg, & Klingberg, 2004; Persson & Reuter-Lorenz, 2008; Thorell, Lindqvist, Bergman Nutley, Bohlin & Klingberg, 2009; Westerberg, Hirvikoski, Forssberg, & Klingberg, 2004). The primary goal of this field is to examine new and better ways of improving the strength, speed and/or the endurance of a variety of mental processes. Potential applications of this enhancement range from improving the functional capabilities of a typically developed population, to providing an alternative to medication for some mental illnesses.

One area in particular has shown promising results for the use of cognitive enhancement as a treatment option: Attention Deficit-Hyperactivity Disorder (ADHD hereafter) (Klingberg, Westerberg & Forssberg, 2002). Recent meta-analyses of studies of ADHD have suggested that the neuro-cognitive impairments can be subdivided into
four domains, Motivation, Motor Control/Timing, Attention and Executive Functioning, (Nigg, 2006).

The domains of Motivation and Motor Control/Timing, and the constructs that are subsumed under these headings demonstrated modest to trivial impairment. Within these analyses, Attention encompasses perceptual selection, reflexive orienting and the alerting and vigilance systems. Of these, only alerting and vigilance displayed substantial deficits in people with ADHD.

Seven constructs are reported in these meta-analyses under the domain of executive functioning (Nigg, 2006). Of these seven, interference control, set shifting and activation demonstrated, at most, modest impairment. Response inhibition showed a substantial deficit in ADHD.

Of particular relevance for the current study are the final three constructs of executive functioning. Verbal working memory, planning and spatial working memory demonstrated moderate to severe impairment, with the deficits in spatial working memory showing a meta-analytic effect size of 1.00, the highest of any neuropsychological impairment included in the analyses. These three constructs can be grouped under the heading of Working Memory (WM hereafter).

Perhaps one of the most well known WM theories was proposed by Baddeley and Hitch (1974). Initially, this theory suggested that the construct of WM was comprised of three subcomponents, the visuospatial sketchpad, the phonological loop, and the central executive. This theory has since been expanded to include an episodic buffer component.
**Baddeley’s Model**

The phonological loop is comprised of phonological storage and articulatory rehearsal mechanisms. Phonological storage is necessary to explain phenomena such as the phonological similarity effect, where participants recalling visually presented consonants would make more errors based on the acoustic similarities, such as replacing a C with a P (Conrad, 1964). This was extended to words by Baddeley (1966) where it was observed that words with similar acoustic properties were recalled with less accuracy than those with different acoustic properties.

The rehearsal component of the phonological loop is able to account for the observation of word length effects (Baddeley, 2007). Lists containing shorter words are more consistently recalled correctly than lists comprised of longer words. The idea is that information is being rehearsed subvocally and that there are limited resources available to accomplish this. As a result, shorter words can be rehearsed more quickly, allowing more of the list to be remembered than longer words, which would take more time to rehearse.

Spatial information and the serial order of both spatial and object-based visual information are retained in the visuo-spatial sketchpad (Baddeley, 2007). Smyth and Pendleton (1989) suggest that motor actions may also be stored in the sketchpad. In terms of visual information, the sketchpad can hold up to 4 objects or 16 features of objects, so long as those features are distributed across several objects (Vogel, Woodman & Luck, 2001). Vogel and colleagues (2001) propose a model of visuo-spatial WM that suggests encoding visual objects results in increased activation of neurons that code the features of that object. This model is consistent with evidence from neuroimaging and single cell recordings and has provided an interface between research on WM and attention.
(Baddeley, 2007). It has also provided evidence suggesting that attention may influence WM encoding.

Awh, Jonides, and Reuter-Lorenz (1998) also demonstrated that attention influences WM. In their study, spatial WM was impaired when participants were unable to attend to locations they were instructed to memorize and showed improved visual processing efficiency for locations held in WM. There are however limits this, as tasks that place a high demand on attention do not necessarily disrupt WM in the visual modality (Baddeley, 2007).

Baddeley (1996) has suggested that the central executive may consist of up to four subcomponents, the capacity to focus attention, divide attention, switch attention and link WM and Long Term Memory (LTM hereafter). The first three processes are directly related to attentional control and provide another connection between WM and attention. The suggestion that the central executive provides links WM to LTM has resulted in the inclusion of a fourth component to the model, an episodic buffer.

The episodic buffer bridges the gap between WM and LTM (Baddeley, 2000). This buffer binds perceptual information, information in other WM stores, and information from LTM. It also serves as an interface for visual, verbal and other perceptual information with semantic and episodic memories from LTM. It also allows for accessing LTM for the purposes of both learning and retrieving information. The episodes generated by this buffer are the result of the integration of information from WM and LTM. They differ from their LTM counterpart in that they serve as temporary traces (Baddeley, 2007).
**Working Memory Training**

Taking into consideration the deficits in WM found in people with ADHD and the effectiveness of cognitive enhancement strategies for impaired populations, we are left with the question: can WM be enhanced? Baddeley’s (2007) model provides a framework to interpret any changes in WM performance from cognitive training. For example, given that spatial working memory exhibits consistent impairment in an ADHD population, if enhancement is effective in improving spatial WM, what specifically is improving? Is the enhancement targeting the ability of the central executive to manipulate the information or allocate attention more effectively, or expanding the storage aspect of the visuo-spatial sketchpad or both? To address the question of whether WM can be improved, Klingberg and colleagues (2002) used a computerized training task.

Klingberg and colleagues (2002) had 14 children with a diagnosis of ADHD perform four WM tasks (30 total trials per task per day) 5 days a week over the course of 5 weeks. The participants were divided evenly between the treatment and control conditions. Training tasks included a visuo-spatial WM task in which circles lit up in a random sequence on a 4x4 grid, a backwards digit span task and a letter span task (both may be considered verbal working memory tasks). The final task was a go/no-go task involving choice reaction time. This was included as a measure of inhibition, which, according to the meta-analyses described above, demonstrated substantial deficit in people with ADHD. These meta-analyses also define inhibition control as functionally distinct from WM although both fall under the heading of executive function. Task difficulty (in terms of numbers of items to be recalled) was adjusted for all of the WM tasks for the treatment group. Control participants remained at a “low dose” of the
program in which the number of items to be recalled never progressed beyond two or three. Two to three items were chosen as a placebo dose because this amount falls well within the capacity limit suggested by Cowan (2001) which places an upper limit on WM at around four items.

The results of this study were analyzed in terms of five pre-test and post-test measures: a version of the visuo-spatial task they had used during training, the span-board, the Stroop task, Raven’s Colored Progressive Matrices and a choice reaction time task (Klingberg et al., 2002). The visuo-spatial task proceeded in the same manner as the training task, however, in the testing session, the task provided two trials at each difficulty level and continued increasing the number of items to be recalled until participants missed two consecutive trials.

The span-board task is a measure of visuo-spatial WM in which participants view an array of irregularly placed blocks, an experimenter then points to a number of blocks in a specific sequence. After a delay, participants are expected to replicate the indicated sequence (either in forward or reverse order) (Klingberg et al., 2002).

The Stroop task involves participants viewing a series of color words. These words are printed either in a color that corresponds to the word (e.g. the word “blue” printed in blue ink) or in a color that is incompatible with the color word (e.g. the word “blue” printed in red ink) (Klingberg et al., 2002).

Raven’s Colored Progressive Matrices is a nonverbal reasoning task comprised of multiple trial of varying difficulty which is used as a measure of fluid intelligence (Gf hereafter). On a given trial, participants view a pattern with a piece missing and must select the answer that would correctly complete the pattern from a variety of options.
(Klingberg et al., 2002). The importance of using this measure is that Gf is related to the ability to observe and learn patterns of relationships which is related to scholastic performance (Cattell, 1943).

Finally, the choice reaction time task would involve participants viewing a screen on which yellow circles would appear randomly in either the left or right location with a warning cue that appeared in both locations. Participants would respond to which side the yellow circle had appeared on with a left key press for the left side or a right key press for the right side (Klingberg et al., 2002).

Behavioral symptoms for hyperactivity as measured by the number of head movements over a 15-minute period were recorded. During this period, children were performing a continuous performance task. This is a measure of the alerting and vigilance system and requires no information storage (Klingberg et al., 2002).

Performance on the visuo-spatial task, the span board, the Stroop task and Raven’s Colored Matrices showed significant improvements for those in the treatment condition (Klingberg et al., 2002). The authors note that this is of particular interest because these tasks were not directly related to any training tasks beyond the fact that they are believed to draw on aspects of WM. This suggests that the effects of the training can generalize to other tasks. However, given that the visuo-spatial task was a version of the training task and the span board shares a number of similarities to the visuo-spatial task these results should be interpreted with caution.

Comparison of the pre- and post-test measures for this experiment also suggests that hyperactive behavioral symptoms were reduced as a result of the treatment. That is to say, the number of head movements made following treatment was significantly reduced.
It is perhaps unsurprising that the choice reaction time task did not show improvement, as the program did not change the difficulty in either the treatment or control conditions for tasks completely unrelated to WM, so even if there had been any observed differences, they could have been due to practice alone. Upon closer inspection, the improvements on the span board task may not be as informative as was suggested. The span board and the 4x4 grid exercise are quite similar, differing only in the fact that the targets on the span board are irregularly placed as opposed to the grid configuration of the training task. The low sample size of seven participants per group in a between subjects design is also a potential drawback.

Training effects, like those reported by Klingberg et al. (2002) have been observed in subsequent studies. Klingberg and colleagues (2005) used a more rigorous training program, again consisting of both visuo-spatial and verbal working memory tasks consisting, for 90 trials per day. The training program would again be performed five days a week for five weeks.

The results of this study suggest participants exposed to the adaptive training demonstrate improved performance on outcome measures such as the span-board, digit span, Raven’s Colored Matrices and the Stroop task. Additionally, these training effects were still observed at a follow up session three months after the completion of training and posttest. Taken together, these studies support the position that training WM in children with ADHD will provide stable improvements to executive functions.

While these results indicate a promising improvement in WM for an impaired population, it does not address the question of whether or not this type of enhancement can benefit unimpaired populations. To explore this, Klingberg et al. (2002) performed a
second experiment using four healthy adult male participants. This study used treatment and outcome measures identical to their Experiment 1, with the exception that no behavior measures (head movements) were recorded and the advanced version of Raven’s Progressive Matrices was used in place of the colored children’s format.

All participants were given a full treatment level of the training tasks (Klingberg et al., 2002). The results suggest that even in unimpaired populations WM could be improved, as scores on all outcome measures showed significant increases. These results are questionable as the sample size for this group was only four and portions of the data for two of the participants (the go/no-go task) were lost. Additionally, the control group to which these participants were compared was the control group from Experiment 1 (children with a diagnosis of ADHD). The obvious maturational differences between these groups, combined with the potential differences between a typically developed population and one with a diagnosis of ADHD renders the results of a comparison between these groups unclear.

Olesen, Westerberg and Klingberg (2004) found further support for the effectiveness of WM training. In this study, they compared fMRI scans of adults while they performed working memory tasks before, during, and after training. The results showed that those in the training group increased their performance significantly on the Spanboard, Digit Span and Stroop Tasks from pre to post test.

These results are less straightforward in terms of the overall effectiveness of training. While the training did improve the performance on all outcome measures, the training group only demonstrated higher performance compared to the control group on the Stroop task (Olesen et al., 2004). That is to say, the tasks which aimed to measure
WM capacity directly (Spanboard and Digit Span respectively) did not show improvement. This raises some concern over the ability of the training to manipulate WM. The sample size of this study was eight (three of which comprised the control group). With such a limited sample size, it is possible that the training was effective, however there were too few participants to detect the effect.

Evidence from the fMRI scans from Olesen and colleagues (2004) suggests that areas in the medio-frontal gyrus and superior and inferior parietal cortices exhibit increased activation both during the performance of training tasks and following training during performance on outcome measure tasks. These areas have been linked to WM function and changes that result from this type of training may support the idea that this enhancement is inducing greater plasticity in these areas.

The results of Klingberg et al. (2002) and Klingberg et al. (2005) provide some support for the effectiveness of this type of treatment for children with ADHD. These studies also illustrate a relationship between WM and Gf in that performance on Raven’s Progressive matrices is improving with improvements on WM outcome measures such as the Spanboard and Digit Span (Klingberg et al, 2002; Klingberg et al. 2005, Olesen 2004). This evidence suggests that WM may serve as a predictor of scholastic achievement. Although this evidence supports the position that executive functioning in general and WM in particular, can be improved via cognitive enhancement, many questions are still unanswered.

Given the questionable nature of the data regarding WM enhancement in unimpaired adults, we are still left to wonder if this type of training is effective at improving these abilities in this population. The functions of the brain areas in the
imaging studies have not been explicitly mapped to specific mechanisms within the domain of working memory. This raises the question of which, if any, mechanisms are being affected by this training? A number of theories of WM exist that could explain these changes. We will now discuss three of these theories that may help explain what is happening during training.

**Executive Attention and Interference Control**

Interference arises when a stimulus triggers conflicting responses (Garforth, McHale & Meehan, 2006). Resolving this conflict has generally been ascribed as one of the functions of controlled attention, specifically the Supervisory Attentional System (SAS hereafter). To accomplish this, the SAS biases response selection toward the appropriate action in a given context by increasing activation of the appropriate (and potentially less active) response option (Kane & Engle, 2000).

Individual differences in WM capacity may be the result of differences in the ability to control attention to overcome interference, based on the belief that the central executive relies heavily on attention to the point that it has even been described as analogous to the SAS (Baddeley & Hitch, 1994). Therefore, WM plays an important role in the resolution of interference (Kane & Engle, 2000). Given that WM may underlie the maintenance of information in the presence of interference, this function plays an important role in higher order cognition such as Gf. This relation arises from the observation that individuals with low WM spans and individuals with low Gf are more susceptible to interference than high span or high Gf counter parts (Borkowski, 1965; Rosen & Engle 1998).
Given that attention is incorporated in WM, and is believed to be important in overcoming interference, WM should be a reliable predictor of resistance to interference (Kane & Engle, 2000). Work by Kane and Engle (2000) support this. Individuals with low WM spans consistently showed greater interference effects than those with high spans. This effect was observed both in tasks that required a heavy demand on attention and those in which it was not necessary.

Kane and Engle (2000) also found that people with high WM spans exhibited greater vulnerability to interference when their attention was divided. This suggests that they draw on controlled attention to overcome interference; this was not the case with low span individuals. The failure of low spans to make use of attention at either encoding or retrieval may explain their susceptibility to interference such as the results of work by Underwood Boruch and Malmi (1978) which demonstrated that those able to recall more words in interference tasks also demonstrated higher WM spans.

To further examine the attentional control component, Kane and colleagues (2001) compared people on an operation span and antisaccade task. Antisaccade tasks require participants to foveate to a specific location (the position opposite of the cued location) and maintain the task goals on-line in the face of environmental distracters. The operation span task was used to establish WM span. Differences were observed between high and low spans on antisaccade trials, but not prosaccade trials. Attentional control is not necessary for successful completion of prosaccade trials, therefore it is unsurprising that both high and low span individuals could perform equally well. Here individual differences in the ability to maintain the goals became evident, which supports the stance that attention is tied to WM.
Kane et al. (2001) suggest that the performance of the high span individuals is due to their ability to maintain the task goal in spite of the interference presented by onset cues in the antisaccade trials. It is also important to note that low span individuals showed difficulty in switching between prosaccade and antisaccade trials. This further supports the position that high spans are maintaining task goals while low span individuals suffer. This observation led to an extension of the view of attentional control.

Now, attentional control allows for flexibility in response to environmental stimuli (Kane et al., 2001). To accomplish this, a heavy emphasis was placed on the involvement of inhibition of irrelevant responses and representations. This may be a critical factor in determining outcomes on measures of Gf such as the Raven’s Progressive Matrices where suppression of competing but irrelevant response options and representations of the pattern are required to respond correctly.

Evidence from negative priming tasks has also supported this view. High span individuals demonstrate negative priming while low spans do not (Kane et al., 2001). Kane et al. claim that high span individuals are relying on attentional control to inhibit prior distracters. High span people were differentially slowed in cases where to-be-ignored letters from previous trials became the to-be-remembered letter of the current trial.

From this perspective, the outcome measures and the training tasks involved in WM training studies such as Klingberg et al. (2002), Klingberg et al. (2005) and Olesen et al. (2004), would be divided into two categories, simple span tasks which draw on Short Term Memory (STM hereafter) and complex span tasks which draw on WM. The training tasks, the digit span and span board are considered STM measures. Kane and
Engle (2002) explain that these types of tasks are similar to WM tasks, however they do not require the additional processing involved in a WM task proper, and do not exhibit a significant link to Gf when WM is controlled for.

This framework proposed by Kane and Engle (2002) suggests that WM relies on STM in addition to executive attention. The observed changes in the digit span and span board (both simple span tasks) used by Klingberg et al. (2002) could be a result of improvements to STM rather than WM proper. The change would be related more strongly to STM than WM because the task does not require the use of executive attention to complete successfully which is a critical factor in distinguishing WM from STM.

In contrast, WM tasks makes use of all of the processes required by the STM tasks, however there is a greater demand in a WM task (requiring the use of executive attention rather than simple storage) because of the presence of an embedded additional task that interferes with the primary one. The Stroop task and Raven’s Matrices would be truer measures of WM because there is a second task embedded within the measure. For the Stroop task, participants must overcome the interference caused by the requirement of the task goal of naming the ink color which conflicts with the prepotent response of naming the word (Kane & Engle 2002). That is, when presented with words in a more natural setting, participants would be inclined to read and respond to the word rather than the ink color. This strategy produces correct results on congruent trials, but is ineffective for the incongruent trials. Therefore, in order to respond correctly on all trials, including incongruent ones, the requirement of responding to ink color must be maintained over the course of every trial.
To explain the effectiveness of Raven’s Progressive Matrices in measuring WM capacity, Kane and colleagues (2001) suggest that the components of WM can be further subdivided into domain specific storage and domain general aspects. Domain specific storage is analogous to the visuo-spatial sketchpad and phonological loop described by Baddeley and Hitch (1994). Domain specificity refers to the modality by which information is being encoded and maintained. Domain general aspects are then analogous to the central executive. The emphasis here is an attentional component to the central executive that allows it to maintain the information on line, an aspect that Kane and Engle (2001) consider to contribute heavily to Gf.

Neuroanatomical evidence also supports this distinction. Kane and Engle (2002) suggest that this hierarchical view of WM corresponds to more specific brain areas. They propose that the domain specific aspects of WM are tied to posterior regions of the brain. This is accomplished by the connections of the prefrontal cortex, an area typically associated with WM function, to different posterior brain regions. These links form separate pathways, which may be tied to distinct WM systems. This position is further strengthened by the fact that these subregions of the prefrontal cortex respond to specific sensory modalities such as the auditory and visual systems. In contrast, the domain general aspects are tied most closely to the functioning of the dorsolateral prefrontal cortex an area typically associated with WM.

The interaction of the specific and general components is what Kane and colleagues (2001) suggest can explain the correlation between WM and complex cognition. The driving force behind this correlation is attention. If WM is construed in
this manner, then the capacity of WM could be measured by complex reasoning tasks such as Raven’s Progressive Matrices.

In Raven’s Matrices, the original pattern must be maintained and compared to response options. Kane and colleagues (2001) suggest that this type of “real world cognition” would be able to draw on the interface between the domain specific and domain general components of WM. The reliance on both domain specific and general components in this task could make it an effective measure of WM capacity.

Kane et al. (2001) suggest that domain general aspects of WM are highly predictive of performance in complex cognition. The evidence from this study further suggests that although domain specific components of WM may provide some predictive value for performance in domain specific tasks, domain general attentional aspects of WM are more strongly related to Gf. According to this, the limited utility of domain specific aspects to predict performance in tasks involving complex cognition could be due to the fact that domain general attention plays a role in the rehearsal and maintenance of the domain specific process.

The role of attentional control in resisting interference tries to illustrate an important link between WM and Gf. This theoretical approach could provide a possible explanation for the changes in scores on Raven’s Progressive Matrices seen in Klingberg et al. (2002) study. If WM was being improved by the training, then it would follow that Gf would also show improvement.

This view does raise a concern about the training. If the training tasks are simple span tasks, the mechanism that is being strengthened should be the STM component of WM. Although aspects of STM are involved in WM, training tasks lack an interference
component and therefore should not be impacting the domain general aspect as they
would not make use of the attention in rehearsal and maintenance. If the domain general
component of WM is not influenced by these tasks directly, it is unlikely that scores on a
measure of Gf would improve.

The training tasks are simple span tasks and therefore aimed at STM, how is it
possible that they are influencing WM capacity? One potential explanation is that
strengthening the domain specific stores and the subsequent interaction of these stores
with the domain general aspect is what drives the improvements observed in Klingberg
and colleagues (2002). Although we have mentioned that domain general aspects seem to
account for a larger portion of WM’s ability to predict Gf outcomes in this approach, it is
possible that training directed at the domain specific components allows the domain
general aspect to handle information more efficiently. This improved efficiency could
then explain why a simple span task is improving Gf outcomes.

**Focus and Control of Attention**

A second approach to WM also uses the distinction between storage and
processing. Here again, attention plays a prominent role in both aspects. The processing
component termed the “control of attention” subserves storage (Cowan, Fristoe, et al.,
2006). For WM, processing occurs when strategies such as chunking or rehearsal are
used to enhance the number of items within the WM store. The relation between control
of attention and WM was further elaborated by Redick and Engle (2006). They found that
individual differences in WM predict outcomes on executive function tasks on the
Attention Network Test (ANT) that are believed to involve controlled attention. This
relation corresponds closely to the executive attention approach. The aspect that
distinguishes these two theories is how storage in WM is addressed.

Cowan, Fristoe et al. (2006) suggest that storage in WM is limited to four items. They do, however, allow for individual and age related differences for this limit. Furthermore, they suggest that the construct that exhibits a similar restriction is the focus of attention. This view of the focus of attention allows capacity limits to exceed four items as items on the periphery of focus proper may also be captured to some extent.

The focus of attention (also called the scope of attention) has been measured in terms of a core capacity limit (Cowan, Fristoe, et al., 2006). This limit is defined as the number of items that may be recalled when rehearsal and grouping is controlled for or limited. Cowan et al. (2005) found that core capacity limits possess a predictive value for performance on both verbal and nonverbal intelligence tests, thereby linking WM span and Gf.

This relation between core capacity limits and intelligence suggests that this system is partially analogous to the domain general aspects described by Kane and Engle (2004). In fact, interference can play a vital role in examining the scope of attention, however according to Cowan, Fristoe et al. (2006) the difficulty of the task and the nature of the interference are of limited importance so long as strategy use is inhibited or blocked. They argue that controlling attention in this manner falls under the processing component they believe is necessary for rule maintenance and resistance to interference.

Cowan, Fristoe et al. (2006) tested this approach to WM in a number of ways. The first measure was a standard digit span. This type of task establishes that the focus of attention could be directed toward auditory stimuli and to estimate the size of the scope
of attention in this modality. The second task was modeled after the visual array proposed by Luck and Vogel (1997) and served as a visual counterpart to the digit span.

The third task involved a dual modality paradigm in which participants were told to attend to one of two streams of information (one auditory and one visual). Following the presentation, they reported the information from one of the two streams. The stream they were asked to report may not necessarily be the one they had been instructed to attend to (Cowan, Fristoe, et al., 2006). This measure is suggested to examine the role of controlling attention in WM. Poor performance reporting to be ignored information is taken as evidence for the process of controlled attention acting to inhibit distracting information. For this task, inhibition is a failure to encode the unattended stream so that attentional focus can be directed more efficiently to the attended stream.

Aptitude tests from the Stanford-Binet Intelligence Scale were also used to explore the relation between the scope of attention and intelligence. The vocabulary and pattern analysis subtests were used to measure verbal and visuo-spatial abilities. Individual differences on these tasks that correspond to high and low span individuals could further support WM as being a viable predictor of Gf.

The results of the dual modality task suggested that people with high spans are able to use attention to allow for enhanced encoding and storage of information (Cowan, Fristoe, et al., 2006). This is not the case for low span people who failed to demonstrate benefits as a result of attending to the stream they were reporting. From this, it was concluded that attentional control for lower span participants is used less efficiently in the service of memory.
The results of the aptitude tests indicate a strong correlation between the intelligence and the scope of attention as measured by the visual array task (Cowan, Fristoe, et al., 2006). This finding is consistent for both high and low span people. In contrast, only the high span participants exhibited a strong correlation between the intelligence measures and the benefit of attending to a specific modality in the dual modality task. This finding potentially redirects relationship between WM and Gf away from the control of attention to the storage related focus of attention. It may be that the improvements observed by Klingberg et al. (2002) from the training tasks are a result of improvements to storage abilities.

Friedman and colleagues (2006) offer conflicting evidence for storage driving the relationship between WM and Gf. They found that Gf is strongly correlated with the updating aspect of WM, but failed to find support for a relation between Gf and other aspects of WM. Cowan, Fristoe et al. (2006) were able to expand this correlation to include inhibitory aspects of WM. They demonstrated that the benefits of attending and responding to one modality for high span individuals showed a strong relationship with the Gf measures.

This view deals with the question of how the training tasks are improving WM in a different way. It may be that the training tasks are helping the participant to use strategies to greater effect or reduce interference. If so, then the focus of attention is being improved by virtue of reducing the load on controlled attention. Alternatively, these training tasks are simply taxing and expanding the storage based focus of control directly.
**Cue Dependent Retrieval**

The final approach discussed suggests that WM is composed of two stores that make use of attention and cue-dependent search (primary and secondary memory respectively) (Unsworth & Engle, 2007). This view argues that WM is needed when current task goals conflict with automatic processes and irrelevant information. Primary memory (PM hereafter) is a hypothetical construct that allows for the maintenance of a limited amount of information. Secondary memory (SM hereafter) is also a hypothetical store in which information that has been displaced from PM is held. Items from SM may be retrieved by means of a cue-dependent search process.

In PM, information is maintained by continuously allocating attention to the current task or item representations (Unsworth & Engle, 2007). Maintenance within the PM insulates those items from the effects of interference. As has been suggested with the other approaches, this aspect has a limited, but flexible capacity. The maximum number of items is believed to be four, although fewer items can be retained if the current task demands greater attention to fewer items. This view argues that individual differences are actually due to differences in the ability to retrieve task relevant information and actively maintain information in PM (Unsworth & Engle, 2007).

Unsworth, Schrock and Engle (2004) found support for the idea that individual differences are tied to the ability to maintain information in PM through the use of antisaccade tasks. High and low WM span people did not differ in terms of response times to prosaccade trials, however low span individuals exhibited marked decreases in response times when the additional demand of remembering the task goal interfered with the prepotent response of moving their eyes to the cued location (Unsworth & Engle,
This effect became even more apparent when prosaccade and antisaccade trials were intermixed within a block. In this instance, participants with low WM spans were more prone to error than those with high spans. This suggests that the lower WM span participants are either less able to maintain the task goals in PM or effectively retrieve them from LTM.

The need for cue-dependent retrieval arises when active maintenance of information is impeded (Unsworth & Engle, 2007). To recall task relevant information, a search of SM must be used. This search uses cues to delineate relevant and irrelevant information (Capaldi & Neath, 1995). These cues are internally generated context specific cues that focus the search (Raaijmakers & Shiffrin, 1980). Attention is necessary at this level to plan the search strategy, and select and combine appropriate cues (Unsworth & Engle, 2007).

Individual differences in cue-dependent retrieval come from differences in how effectively the context cues are implemented. In tasks requiring cue-dependent retrieval, each trial (after the first) is subject to interference (Unsworth & Engle, 2007). This is because context based cuing activates items from prior trials because the setting and context of performing the task has not changed. Given that the context between trials overlaps, this increases the overall number of items to be searched while reducing the effectiveness of the cues at the same time. These two factors lead to increased probability of previous trial items intruding into the internally generated set for the current trial.

In terms of WM capacity, low span individuals are more susceptible to intrusions of previous list items. This is because they are less able to constrain the search for relevant items to exclude an irrelevant set with similar contextual cues. Rosen and Engle
(1998) demonstrated that low WM span individuals were slower (compared to high span individuals) to learn additional lists of items when new lists shared cues with previous lists. This supports the idea that low span observers are less efficient in their ability to use cues to aid recall from SM.

Cue dependent retrieval from SM is examined in terms of complex span tasks (Unsworth & Engle, 2006). These tasks involve intermixing items that must be recalled with a distracting task. For example, the Operation Span task presents observers with a mathematical problem followed by an unrelated word. On a given trial, participants must solve the mathematical operation and then try to retain the word for later recall. The subsequent trials will follow the same pattern. New information (in the form of the math problems) is displacing the words from PM into SM. This is not true for the last trial in a given set because no new operations are presented to displace the final word.

In contrast, simple spans lack a distracting task intermixed with recall. A digit span such as that used by Klingberg et al. (2005) is a simple span task. These tasks are less effective at examining cue dependent retrieval because they rely on a combination of recall from PM and SM (Unsworth & Engle, 2006). Items in a simple span are only displaced from primary memory by other items that must be recalled; therefore target list items can be thought of as existing fully within both stores. Variability on these simple span tasks is believed to relate most strongly to PM which inconsistently correlates with Gf making this a less desirable measurement (Unsworth & Engle, 2006).

This approach to understanding WM would suggest that the training tasks are having a different type of impact than previously described. The repetitive nature of the tasks and the similar contexts across trials may give participants greater experience with
overlapping contexts. This experience may help them develop strategies or cues that can be used to effectively discriminate task relevant information in the face of the weaker contextual overlapping information. The more effective cues then allow people to more effectively delimit the search set, thereby producing the observed increases to WM span in terms of number of items recalled. Another possibility is that training on simple span tasks is overloading PM and therefore displacing items into SM. Training then would require the participant to gain more experience with retrieval from SM.

**Present Experiments**

In light of these frameworks for understanding WM and the results of the training studies, a number of questions remain unanswered. If WM can be enhanced in an impaired population, is it possible to observe the same training effects in a typically developed population? That is, can WM be improved in an adult population where it is believed to already be operating at optimum efficiency? Klingberg et al.’s (2002) Experiment 2 offer some preliminary findings to suggest that training is effective for this population, however the low sample size and loss of data demands a closer look.

Olesen et al. (2004) offer evidence that WM training is improving activation in brain areas associated with WM. However, the function of these areas has not been explicitly defined. If WM can in fact be improved through training, what exactly is being impacted by these training tasks, controlled attention, focus of attention or cue-dependent retrieval? The present study seeks to address these questions through two experiments.
EXPERIMENT 1

The purpose of Experiment 1 was to examine the relationship between WM training, executive attention, the control of attention and cue dependent retrieval. To explore these relationships, several simple and complex span tasks were used.

Simple span tasks have only a list of stimuli for the participant to recall. In contrast, a complex span is composed of two tasks per trial, one that requires recall of the correct serial order of a list and an additional unrelated task. The two components are intermixed such that a participant performed the unrelated task between presentations of the to be recalled items.

The simple span tasks were a digit span, letter span and word span tasks. Participants were only exposed to the stimuli they needed to recall for a given trial. The complex span tasks included a comprehension span, a spatial span, a sentence span and operation span tasks.

We predicted that participants in the treatment condition would demonstrate enhancement on the simple span tasks because they most closely resembled those used in training. Failure to find enhancement on these tasks would constitute a failure to replicate previous research in this area.

Each of the three frameworks, executive attention, control of attention and cue dependent retrieval also predict that the treatment group would demonstrate enhancement on the complex span tasks. Failure to find enhancement would suggest that the
mechanisms described by these approaches are not affected by training. A second explanation would be that although one or more of these mechanisms is enhanced via training, the outcome measures were not sensitive to the type of change that occurred.

**Method**

*Participant.*

Forty undergraduate students from the University of Notre Dame were invited to participate in this study. Of the initial 40 participants, 33 completed pre and post test assessments and were included. Participants ranged in age from 18 to 24. Participants were randomly assigned to either the treatment (17 participants) or control conditions (16 participants).

*Compensation*

Incremental monetary compensation for involvement was provided. Those in the treatment condition received $15.00 for competing the first week of the program, $25.00 for completing the second and so on, up to $55.00 for completing the fifth and final week of training. Treatment condition participants that completed the pre and post test sessions and all five weeks of the program received a bonus of $25.00 for a maximum total of $200.00. Those assigned to the control condition received $20.00 for completing pre and post test sessions set 5 weeks apart.

*Intervention*

Participants made use of the RoboMemo[R] training program developed by Cogmed Cognitive Systems AB, Stockholm, Sweden (Klingberg et al., 2005). This program is presented on a personal computer and involves a variety of working memory tasks in both visual and verbal modalities. Participants took part in 8 of the 10 exercises.
each day, completing a total of 115 trials per training session. Datalink, Data Room, Rotating Dots, Stabilizer and both Input Modules were present on all training days. Rotating Datalink, Asteroids, Decoder and Corrector are alternated in and out of the program at different intervals in order to maintain the upper limit of 115 trials per day (e.g. Decoder would be presented the first five days of training and be alternated out for Corrector for five days).

Visual Datalink

In this task, participants were presented a 4x4 grid of red dots that simulate light emitting devices (LEDs). For each trial, these LEDs produced a specific pattern. Once the pattern had been displayed, participants were required to replicate it by clicking on the appropriate LED in the grid in the serial order in which it was presented. Responses were made using a computer mouse to point at and click on the appropriate LED. This task consisted of 15 trials per training day.

Rotating Datalink

For this task, participants were presented a 4x4 grid of simulated LEDs. Prior to the onset of the trial, the grid rotated 90 degrees to the right. The pattern was then presented. Once the pattern was completed, the grid rotated 90 degrees to the left (back into the original orientation). Participants were then required to click on the appropriate LEDs to complete the pattern observed in the presentation in the now rotated orientation. This task consisted of 15 trials per training day.

Data Room

In this task, participants were presented with a simulated three dimensional environment. Here 2x2 grids of simulated LEDs were presented on the upper, lower, left,
right and far “walls” of the environment. During each trial LEDs illuminated in a specific pattern. Participants then recalled the correct serial position of each LED that illuminated during the presentation portion. To respond, participants clicked on the LEDs in the order in which they had been presented. This task included 15 trials per training day.

**Rotating Dots**

In this task, participants viewed a simulated rotating wheel with 10 LEDs along the perimeter. This wheel rotated at a steady pace through both stimulus presentation and response period. During presentation, the LEDs lit up in a specific pattern. After presentation had completed, participants responded in the typical manner by clicking on the appropriate LED in the correct position of the pattern. This task had 15 trials per day.

**Asteroids**

During this task, participants were given a scene of a small asteroid field in orbit around a planet. During the stimulus presentation and response phases, the asteroids moved randomly throughout the field. This allowed the asteroids to, at various points, partially occlude other asteroids or collide with them setting them on differing trajectories. Participants were told that these asteroids were dangerous to the planet and that some would be targeted to be destroyed. The asteroids that are targeted illuminated in a specific pattern. In order to respond, the participant clicked on the asteroids that lit up in the correct serial order in which they were illuminated. This task was comprised of 15 trials per day.

**Stabilizer**

Participants observed a simulated handset device that consists of a circular configuration of 11 LEDs and a center display. During stimulus presentation, participants
heard a series of spoken letters. As each letter is presented, an LED on the “handset” lights up to correspond to the letter. Each LED lights up in a sequence starting at the lower left and moving clockwise through the circular array. Once the letter string had been presented, a single letter appeared in the center of the “handset.” The participants responded by clicking on the LED that corresponded with that letter. This exercise would consist of a total of 15 trials per training day.

**Decoder**

In this task, participants first observed a series of simulated LEDs organized in a line across the top portion of the display. Beneath each of these LEDs are three black squares. Participants heard a series of letters spoken aloud. Again a single LED would light up to correspond with each of the letters. When the stimulus presentation ends, each column of black squares would be filled with white letters. One of these letters corresponded to the letter that was spoken when the LED at the top of that column had been lit up. Participants responded by clicking on the correct letter choice for each column. This task would include 10 trials per day.

**Corrector**

For this exercise, two parallel rows of LEDs appear separated by a single row of black boxes. Participants were presented with a string of letters. Each letter corresponded to one illuminated LED on the top row starting at the left and moving right. Once this letter string finished, a second string was presented. This series of letters was tied to the bottom row of LEDs again with one letter corresponding to one LED. The second letter series was identical to the first with the exception of one letter. Participants were then required to respond by clicking on the black box located between the two rows of LEDs.
that corresponded to the letter that differed between the two series. After making their selection, participants clicked on the button marked “done.” This task includes 10 trials per day.

**Input Module**

Participants are presented with a series of auditory digits and a 3x3 grid of digits, 1 through 9. This grid appears in a touch tone telephone dialing pad configuration. When the corresponding number is spoken, the number on the number pad lit up. Spoken digits are randomly selected, with replacement, so that spans higher than nine can be accommodated. Once the series of numbers finished, participants clicked on the number pad in the reverse order from the spoken list. This task includes 15 trials per day of training.

**Input Module With Lid**

This task is identical to the Input Module with one important difference. During presentation, the number pad in the standard Input Module is occluded by a lid. This lid is then retracted during the response phase to allow participants to respond in the same manner as they had for Input Module. This manipulation removes the visuo-spatial aspect present in Input Module without lid and restricts this task to auditory working memory. This task includes 15 trials per day.

**Outcome Measures: Simple Span.**

**Digit Span**

In this task participants viewed a series of digits, presented one at a time, on a computer screen. Once the presentation of the digit series finished, participants responded by recalling the digits in the order they had been presented. Responses were made by
typing in the digits they could recall one at a time into a response area on the computer screen. After a digit had been entered, the participant clicked the “next” button to enter subsequent digits. If participants could not recall any more digits they could proceed by clicking on the “done” box. Three trials were presented at each span length. The program terminated automatically if a participant is unable to correctly recall the items for any trial at a given list length. Spans would then be calculated in terms of the highest list length at which the participant was able to successfully complete a trial.

**Letter Span**

In the letter span task, a series of letters were presented one at a time on a computer screen. Once the presentation finished, participants responded by recalling the letters in the order they had been presented. Responses were made by typing in the letters, one at a time, into a response area using the computer keyboard. After a letter had been entered, the participant clicked on the “next” button to enter any subsequent letters. If they could not recall any more items they could proceed by clicking on the “done” box. Three trials per span length were presented. The program terminated automatically if a participant is unable to correctly recall the items at a given list length. Spans were calculated in terms of the highest list length at which the participant was able to successfully complete a trial.

**Word Span**

In this task, a series of words were presented, one at a time, in the central area of a computer screen. Once the presentation finished, participants responded by recalling the words in the order in which they had been presented. Responses were made by typing in the words, one at a time, into a response area. After each word was entered, the
participant would click on the “next” button to proceed. If participants could not recall any more words, they could click the “done” box to move on to the next trial. Three trials per span length were presented. The program terminated automatically if a participant is unable to correctly recall the items for any trial at a given list length. Spans were again calculated in terms of the highest list length successfully completed.

**Outcome Measures: Complex Span.**

**Sentence Span**

For the sentence span task, participants read aloud sentences presented on a computer screen. As with the other span tasks, sentences appeared one at a time at the center of the screen. In addition, participants were instructed to remember the last word of each sentence they read. As soon as they had finished reading a sentence, an experimenter pressed the space bar to proceed to the next trial, preventing any delay that would allow the participant to rehearse the word. When the last sentence at a given list length was completed, participants were prompted to recall the last word of each sentence they had read and enter it into a response box. Participants entered the words by typing them into the response space and click the “next” button in order to enter the next word or “done” to proceed to the next trial.

**Comprehension Span**

As with the sentence span, the sentences were presented centrally on the computer screen and participants were asked to read the sentence aloud and recall the final word of sentence. This task differed from the sentence span in that participants also had to determine whether the sentence they read made sense. An example of a nonsensible sentence might be: “It was the boy that the milk bought.” An example of a sensible
sentence might be: It was the money that the robber stole.” Participants pressed the left mouse button if the sentence made sense and the right button if it did not. The next sentence was presented once the participant had entered their decision. Entering recall responses would be handled in the same manner as the previous span tasks.

**Operation Span**

For the Operation Span task participants were asked to read aloud a mathematical operation presented on a computer screen. They then judged if the given solution was correct. Following the operation was an unrelated word to remember. An example of a trial item is “(10+2)/3=4 goat”, here participants would respond that the solution for the given operation is correct (using the same response method for deciding whether a sentence was nonsensical from the comprehension span) and then remember that the word to be recalled is “goat”. Responses were made in the same way as the other tasks.

**Spatial Span**

In the final complex span task, participants viewed a series of letters presented at different orientations and determined whether the letter was printed normally or if the letter was reversed. Participants clicked the left mouse button if the letter appeared normal or the right button if the letter was reversed. When all letters were presented, participants then recalled the orientation of each of the letters in the order they were presented. Responses were made by clicking on the location that most closely corresponded to the direction of the top of the letter at that serial position. See Figure 1 for a sample spatial span trial.
**Results and Discussion**

Analysis of the simple span tasks (Digit, Letter and Word Spans) were done using a 2(treatment condition) X 2 (pre/post test) mixed model ANOVA. The digit span task served as a measure of the effectiveness of training because of its similarity to the training tasks “Input Module” and “Input Module with Lid”. Additionally, the Letter Span is similar to the Stabilizer training task. A two way interaction between treatment condition and pre and post test sessions would provide evidence that participants in the treatment condition improved in terms of the number of items correctly recalled. This improvement may be attributed to practice effects and would replicate the findings of Klingberg et al. (2002) and Klingberg et al. (2005).

*Simple Spans*

**Digit Span**

The results showed a significant treatment condition by pre/post test interaction in the digit span task \[F(1,31)=14.72, p<.001\] which renders significant main effects less informative. Due to the presence of this significant interaction, simple effects of treatment condition were investigated within the pre/post test timing periods. Here a significant effect of treatment at post test\[F(1,31)=31.08, p<.001\] was observed, providing evidence that the training was driving the observed changes in number of items recalled on this task (See Table 1 and Figure 2). This finding replicates previous research regarding the efficacy of this training and near transfer.

**Letter Span**

The results showed a significant main effect of pre/post test time condition \[F(1,31)=7.38, p<.05\], however no significant main effect was observed for treatment
condition in this task \[F(1,31)=.90, p>.05.\]. Additionally, no significant interaction between pre/post test and condition was observed \[F(1,31)=1.41, p>.05\], this task is outwardly quite similar to the Stabilizer training task. This suggests that participants may be having difficulty in terms of near transfer of the skills gained during training to new tasks. A possible explanation of this is that subjects are developing a specific strategy to resolve training tasks that does not adequately generalize to untrained tasks. This is consistent with the findings of Thorell et al. (2009) that showed difficulty in near transfer tasks after training. This is also consistent with Ericsson, Chase & Faloon (1980) which also demonstrated that learning to remember long strings of digits did not result in better memory for letters (see Table 1 and Figure 3).

**Word Span**

The results showed a significant interaction of treatment condition by pre/post test time period \[F(1,31)=4.26, p<.05\] which renders the main effects less informative. Given the significant interaction, simple effects of treatment condition within the pre/post test time periods were explored. A significant effect of treatment \[F(1,31)=8.78, p<.001\] was observed at post test again providing evidence that training was improving the number of items recalled (see Table 1 and Figure 4) again supporting previous findings of near transfer from trained tasks.

**Complex Spans**

The complex span tasks (Sentence, Comprehension, Operation and Spatial span tasks) were also analyzed in terms of a 2 (treatment condition) X 2 (pre/post test) mixed model ANOVA. A significant two way interaction here would suggest that training is improving the number of items a participant is able to correctly recall. Failure to find a
significant interaction here could indicate that none of the three constructs is influenced by training. Alternatively, the measures used may not be sufficiently sensitive to detect the type of changes in these constructs that result from training.

These tasks may be associated with cue dependent recall, because the unrelated task is presumed to take up PM capacity and push to be remembered items into SM, therefore a significant interaction in the complex spans may suggest that training is improving the participant’s ability to use relevant cuing to recall more items from SM. Executive attention could also be related to performance on these tasks. In this case training may be affecting the ability to inhibit the distracting information presented in the interleaving task of the complex spans in service of better maintaining the target information. Focus of attention may also be related to performance on these tasks, with improvements indicating that the storage abilities of this construct have increased. Although improvements on complex spans resulting from training may indicate improvements in one or more of these constructs, the specific improvements and to which aspects would be unclear.

**Sentence Span**

The results demonstrated a significant main effect of pre/post test time period \([F(1,31)=10.01, p<.01]\) indicating that participants were improving spans from pretest to post test. No significant main effect was observed for treatment condition in this task \([F(1,31)=.01, p>.05]\). There was also no treatment by pre/posttest time interaction \([F(1,31)=.06, p>.05]\) suggesting that treatment was ineffective at improving performance on this task. Failure to find the interaction here may suggest that the participants are
unable to generalize the strategies from the simple span tasks they experienced during training to tasks that are dissimilar (See Table 2 and Figure 5).

**Comprehension Span**

The results here failed to demonstrate a main effect of treatment condition \[F(1,31)=3.37, p>.05\] suggesting the training is not able to generalize to this task. The results also failed to show a main effect of pre/post test \[F(1,31)=2.69, p>.05\]. No significant interaction was observed \[F(1,31)=1.11, p>.05\] which fails to support the idea that training is improving performance on this task. Neither the training nor pre/post test was able to improve performance on this task (See Table 2 and Figure 6).

**Operation Span**

The results here also failed to demonstrate a main effect of either the treatment condition \[F(1,31)=.22, p>.05\] or pre/post test \[F(1,31)=.12, p>.05\]. Again, no significant interaction was observed \[F(1,31)=.22, p>.05\]. This suggests that neither training nor practice effects were able to improve performance on this task (See Table 2 and Figure 7).

**Spatial Span**

The results here demonstrated a main effect of pre/post test time period \[F(1,31)=5.16, p<.05\] suggesting that performance improved over time. A significant main effect was not observed for treatment condition \[F(1,31)=.38, p>.05\]. No significant interaction was observed \[F(1,31)=.38, p>.05\] suggesting that the training was not able to improve abilities on this task (See Table 2 and Figure 8). No significant interaction was observed across all four complex span measures, which fails to support the idea that training is able to generalize to these types of WM tasks.
The Experiment 1 findings offer conflicting support for the findings of Klingberg et al. (2002) and Klingberg et al. (2005). The Digit and Word Span tasks demonstrated significant effects of training which supports the previous research. However, the present experiment failed to find a significant effect of training on the Letter Span task which is still very similar to the training task Stabilizer. This is surprising in that the Stabilizer, which is very similar to the Letter Span did not demonstrate near transfer, however it is consistent with the finding that strategies developed for learning one type of training task such as learning lists of digits will not result in better memory for letters (Ericsson, Chase & Faloon, 1980).

Previous research has also demonstrated improvements on tasks such as the Stroop task and Raven’s Progressive Matrices as a result of training. That observation suggested training was able to generalize improvements to more dissimilar tasks. Experiment 1 tried to extend this finding to a variety of untrained complex span WM tasks. Findings from Experiment 1 however, failed to demonstrate any training effects on these types of tasks, which conflicts with the results of Klingberg et al. (2002) and Klingberg et al. (2005). A possible explanation for this lies in the fact that even simple span tasks did not fully replicate their findings. Failure to replicate may suggest that the measures used in Experiment 1 were too coarse to detect the kind of changes that occur as a result of the training. An alternative explanation may be that the training is not effective at improving WM skills in this age group. Alternatively, the dosage, that is the duration or frequency of training, may need to be adjusted to compensate for the needs of a typical population as the intensity is already maintained at optimum levels by the adaptive nature of the tasks.
It is possible that the observed improvements of Klingberg et al. (2002) and Klingberg et al. (2005) were due to the fact that training was restoring the impaired ADHD population to a more optimal developmental trajectory such as that exhibited by a typically developed population. If this were the case it would follow that a high functioning adult sample such as the one employed in the present experiment would fail to show improvements as they are already operating at their optimal level.

An additional concern is that these tasks may not adequately isolate the constructs of interest: executive attention, focus of attention or cue dependent retrieval in a manner that could detect subtle changes in any one construct. Experiment 2 sought to disentangle the relationship between training and these processes.
EXPERIMENT 2

Experiment two explores the relationship between training tasks and executive attention, the focus of attention and cue dependent retrieval by using measures designed to isolate each of these constructs. First, a digit span task was used to assess the effectiveness of the training. The digit span was selected because it is similar to some of the training tasks and allowed us to replicate the results of Klingberg and colleagues (2005) and the training effects observed in Experiment 1.

Atkinson and Shiffrin (1968) further suggest that a digit span task is a good measure of general working memory. The task involves remembering lists of digits presented in the auditory modality. The benefits of this are that digits are over-learned and derived from a limited set which avoids confounding WM span with language deficits that may be observed in word or sentence span tasks.

The second task was a visual array modeled after Luck and Vogel (1997). This was used to assess changes in the capacity of the focus of attention. The visual array is particularly well suited to examining focus of attention as the task lacks a controlled attention component. This is due to the fact that rehearsal is not necessary and interference is limited because only one decision (is the cued item the same or different from a previous display) needs to be made on any trial (Cowan, Fristoe, et al., 2006).

Finally, a dual modality task was used to examine which of the three constructs plays a critical role in training. Participants were instructed to attend to a stream of
information, either visual letters or auditory numbers. They then respond to either the attended or ignored stream. The ignored list competes for WM storage and the participants’ ability to selectively attend to a specific modality. This is a measure of the ability to overcome interference.

If the scope of attention is improved by training, a significant treatment by pre/post test time period interaction would be expected for both the auditory span and visual array tasks. Improvements in number of items recalled for the training group in all conditions of the dual modality task would also indicate increases to the scope of attention. In contrast, if training targets executive attention, performance on attended conditions of the dual modality task should show increases in number of items recalled, while ignore conditions should demonstrate a decrease in number of items recalled. This would suggest a benefit to attending to an information stream and a cost to ignoring a particular stream. The cost/benefit differences, taken together, would indicate that controlling attention to inhibit distracting information had been improved.

Finally, observing benefits only in the ignored condition of the dual modality task suggests that the improvements are a result of cue dependent retrieval. This is due to the belief that the ignored stream would not be actively maintained, therefore, the ignored information is displaced from PM to SM, requiring cue dependent retrieval to be accessed.
Method

Participants

Thirty graduate and undergraduate students from the University of Notre Dame were invited to participate in this study. Of those participants, only 27 completed pre- and posttest measures and were included in the study. Participants ranged in age from approximately 18 to 24 and were randomly assigned to either the treatment (15 participants) or control conditions (12 participants).

Compensation

Incremental monetary compensation for involvement in the proposed study was provided. Those in the treatment condition received compensation as outlined in Experiment 1 up to a total of $200.00. Those assigned to the control condition received $20.00 for completing pre and post test sessions set 5 weeks apart.

Intervention

The intervention used was identical to that of Experiment 1.

Outcome Measures

The present study was interested in comparisons within individuals and will administer tests in a standard order starting with an auditory digit span, followed by a visual array task and ending with a dual modality measure, involving auditory digits and visual letters (Cowan et al., 2005). These measures have been used to test a variety of populations ranging from children to young adults (Luck & Vogel, 1997; Cowan, Naveh-Benjamin, Kilb & Saults, 2006). In addition, the visual array task has been used by Cowan, Naveh-Benjamin and colleagues (2006) to examine signal detection ability which may subtend observed deficits in the vigilance system of patients with ADHD. All three
Auditory Digit Span

For this measure, all participants received identical lists of digits. The task began with a set of six 3-digit lists. These first six trials served as practice. Following practice, participants were presented with the experimental trials. These were blocked in sets of three trials per list length. Experimental trials began with a length of three digits (like the practice trials) and continued up to 15 digits in length (Cowan et al., 2005).

Each trial began with a white fixation cross in the center of the screen on a black background. This cross remained onscreen during stimulus presentation and was replaced by the words “report answer” when the complete digit list had been presented. Lists were presented 500 ms after the fixation cross (a stimulus onset asynchrony [SOA] of 500 ms). Each list was presented over speakers, read in a male voice, at a rate of 250 ms per word. Participants were instructed to listen carefully to the list and respond only when prompted.

Responses were made by using the number keys on a keyboard to enter the digits in the correct serial order. Once participants finished responding they pressed the “enter” key. No cues were given to indicate the appropriate number of digits in a given list. After responding, participants press the space bar to progress to the next trial.

Span was measured in terms of the longest list length at which participants could correctly recall the serial position for all digits in at least one trial. For example, if a participant correctly recalled all the digits in one trial at list length 8 and then incorrectly
responded to all three trials at list length 9, their span would be 8, regardless of performance on any subsequent trials (i.e. list length 10 and above).

**Visual Array**

This measure used the paradigm described by Luck and Vogel (1997). In each trial, a participant observed two displays, presented sequentially with an intervening delay. Participants were asked to remember as much as possible from the first display (the recall display hereafter) in order to compare it to the second display (comparison display hereafter). Once the comparison display was presented, participants were asked to decide whether the comparison display matched the recall display.

Each trial began with a fixation display; a gray box in the center of the screen, which subtended 9.8 x 7.3° of visual angle. A fixation cross, presented in white, appeared in the center of this box. The fixation display was presented for one second, before the recall display (1000 ms SOA).

A recall display contained all of the elements of a fixation display, however 4, 6, 8 or 10 colored squares, each subtending 0.74° x 0.74° of visual angle appeared within the gray box. Square colors were randomly selected (with replacement) from the options of red, yellow, green, blue, purple, black and white. The location of each square was randomly generated, however no element of the display (colored square or fixation cross) could be within 2° of visual angle (center to center) of any other display element. Recall displays remained on screen for 250 ms, after which the colored squares disappeared and participants once again observed a fixation display.

The second fixation display remained onscreen for 1000ms before the onset of the comparison display. In a comparison display, the number of colored squares and their
location were identical to the recall display it was paired with. A single square in the comparison display appeared with a black circle around it. This circle subtended 1.48° of visual angle. Participants were informed that if any of the items in that display had changed color, it was the cued square. Cued squares were equally likely to be either the same or different from the recall display and were randomly selected. Responses were made using a response box for which a left key press denoted that the cued item had changed color and a right key press indicated that the item had not changed color.

This measure consisted of 256 trials; 64 trials at each display size (4, 6, 8 or 10) of which 32 would be “same” and 32 “different”. Experimental trials were not blocked by display size and participants were given four practice trials at the beginning to familiarize them with the task.

Dual Modality Task

This measure was composed of four subtasks, an auditory digit span, a visual letter span, a presentation of both modalities with the instruction to attend to auditory information and one in which both modalities are present and participants are instructed to attend to the visual modality. List lengths for this measure were determined for each individual based on the results of auditory span performance. That is, list lengths were equal to a participant’s auditory span minus 0, 1, 2, and 3 items. The subcomponents of this task were blocked such that participants proceeded through a block of auditory only trials, then visual only, then both modalities, with instructions to attend to the auditory stream, then a block with instructions to attend to the visual stream. The block types then repeated in reverse order.
For the auditory only blocks of this task, participants were instructed to listen carefully to the list of numbers being presented. They were asked to press the “z” key with their little finger each time they heard an even number. The list of digits (1-9) were presented in random order without replacement (for spans up to 9 and with replacement only after the ninth digit for spans greater than 9) for 500 ms. By presenting the lists without replacement until they exceeded a span of 9 the chances of artificially inflating a participants’ span due to chunking of repeated digits was minimized.

The embedded detection task of pressing the “z” key ensured that participants are attending to the desired stream. Given that there is only one stream presented in the auditory and visual only tasks, this manipulation is not extremely informative and was used primarily to ensure that participants are complying with the instructions. For the sake of consistency, across all aspects of this task, it will be employed in the single modality streams as well. Stimuli were presented in lists of two trials at the participants span minus 0, 1, 2, and 3. Once the participant completed eight trials, the order reversed, such that participants were presented with two trials of span minus 3, 2, 1 and 0 for a total of 16 trials.

The visual span aspect of this task followed the same basic principle and stimuli presentation procedure as the letter span. Participants viewed a series of letters (A, C, E, F, H, I, L, O and R) in white on a computer screen for 1000 ms per letter. Once the letter stream completed, they were prompted to report the letters in the same order in which they were presented by entering them using the keyboard. When the participant entered all the letters they could recall, they pressed the “enter” key and then pressed the space
bar to proceed to the next trial. For the detection portion of this task, participants were asked to press the “z” key every time a vowel was presented.

The final two portions of this task combined the previous two so that both auditory and visual stimuli were presented on a given trial. The same visual and auditory stimuli from the previous two portions were used here. Note that since auditory stimuli are presented for 500 ms and visual for 1000 ms, the auditory stream did not begin until halfway through the visual list so that the presentation of both stimuli would end at the same time.

In the “attend auditory” condition, participants were instructed to ignore the visual letter stream and only attend to the auditory digit stream. To ensure that participants complied with this instruction, they were asked to press the “z” key each time they heard an even number. Once stimulus presentation was complete, participants were asked to either report the auditory or visual stream. Responses were made in the same manner as in either the visual or auditory only portions of the task. The instruction to report auditory (or visual) appeared randomly on half of the trials in a given block in which both modalities were present.

The second block for a given attend condition, when both information streams were present, was the inverse of the first. That is, if in the first block of attend visual, the reporting instructions for the first trial were to report the auditory stream, the first trial in the second block would have the report visual instruction. This is done so that each participant was exposed to both possible conditions for a given trial position.
Results and Discussion

Digit Span

The data for the auditory span task was analyzed using a 2(treatment condition) x 2 (pre/post-test) mixed model ANOVA. The expected result would be a two way interaction. This reflects the belief that participants in both conditions started at roughly equated baseline levels. If the treatment is having an impact, participants given the training tasks should demonstrate higher performance relative to their pre-test recall scores and the post-test scores of the control participants. This change would be indicative of the idea that the training is effectively enhancing performance on tasks similar to the training tasks. This interaction would replicate the findings of Klingberg et al. (2002) and Klingberg et al. (2005) and suggest that training effects can be observed in an unimpaired adult population. Failure to find this interaction would suggest that participants are already operating at the optimum level and that training is ineffective. The implication of this would be that training done by lower span individuals is simply enhancing them to match the population norm.

The results indicate that there was a significant interaction between treatment and pre/post test time periods [F(1,25)=9.51, p<.01] which renders the main effects less informative. In light of the significant interaction, a test of simple effects for treatment condition within the pre/post test time periods was performed to explore the nature of the interaction. A significant effect of the treatment condition at posttest was observed [F(1,25)=8.60, p<.01]. This provides evidence that training improved performance on near transfer tasks as has been observed in previous research and Experiment 1 (see Table 3 and Figure 9).
Visual Array

The visual array task was also analyzed in terms of a 2 (treatment condition) x 2 (pre/post test) mixed model ANOVA. Here an interaction would suggest that the training is impacting the scope of attention. That is, given attention is believed to be limited to four plus or minus one item, training may increase that limit. A failure to find a significant interaction would suggest that the training tasks do not impact the scope of attention and that it may be eliminated as being influenced by the simple span tasks used in the training. This may also suggest, in terms of the larger finding, that if these tasks are improving impaired groups, the scope of attention is not necessarily an appropriate framework to examine these deficits.

The results demonstrated a significant main effect of treatment [F(1,25)=5.00, p<.05] with the controls having superior spans, additionally a significant main effect of pre/post test [F(1,25)=8.96, p<.01] was observed with higher spans at post test. The findings failed to indicate a significant interaction [F(1,25)=.24, p>.05] which would have provided evidence for the effectiveness of the training on improving the scope of attention (see Table 4 and Figure 10).

Dual Modality

Data from the dual modality task was analyzed in terms of 3(attend condition) x 2(treatment condition) x 2 (pre/post-test) repeated measures ANOVAs. The first ANOVA examined the relationship between the three potential report auditory conditions (auditory alone, attend and ignore). The second ANOVA would examine the relationship between the three potential report visual conditions (visual alone, attend and ignore).
If executive attention is affected by training a three way interaction would be expected. That is to say, participants would be expected to perform best when a single modality is presented because information streams were not competing. If training impacts the ability to selectively attend to a particular stream then, there should be a benefit of the attend condition relative to the ignore condition. Participants would be better able to recall the items of the stream that they were instructed to attend to and so interference from the other modality would be reduced. This could also result in a corresponding reduction in the number of items recalled when the instructions are to report the ignored stream. These effects would also be expected in the second ANOVA for the visual modality.

In contrast, if the focus of attention is receiving the primary benefit of training, the results of the dual modality task should demonstrate increased storage across modalities and instruction sets. That is to say, in responding to single modality presentations, responding to the attended modality and responding to the unattended modality participants should demonstrate an increase in the number of items recalled. This would suggest that the focus of attention had been increased because more information was being held within this store.

Finally, if cue-dependent retrieval is receiving the primary benefit of training, the pattern of results would indicate an overall improvement in the number of items recalled in an ignore condition. According to this view, information in the ignored stream should not be actively maintained; this would mean that the information is being displaced from PM into SM. Therefore improvements in overall number of items recalled in this
condition alone would indicate that cue-dependent retrieval has been improved via training.

For this analysis two participants were eliminated due to incomplete data. In the visual modality, the results indicated a significant interaction \([F(1,23)=40.10, p<.01]\), rendering main effects less informative. In light of the significant interaction, a test of simple effects was performed. A significant effect of treatment was observed \([F(1,22)=493.29, p<.01]\) providing evidence that training is improving the ability to attend information in the visual modality. The pattern of results for this analysis is consistent with improvements to focus of attention. As seen in Figure 12, the treatment condition demonstrated improvement across all attend conditions. This would suggest that the capacity of focus of attention has improved.

In the auditory modality, a significant two way interaction of treatment by pre/post test was observed \([F(1,23)=4.15, p<.05]\). The presence of this interaction warranted an investigation of simple effects. Tests of simple effects revealed that there was a significant effect of treatment \([F(1,23)=614.46, p<.01]\) providing evidence the treatment was improving performance. Additionally, there was a significant main effect of the attend condition \([F(1,23)=94.41, p<.01]\). As Figure 11 demonstrates, the pattern of results is consistent with improvements to cue-dependent retrieval. This is due to the fact that participants are improving spans on the ignore condition. Improvements to the ignore condition suggests better cue-dependent retrieval because the information from the ignored stream has been pushed into SM by the attended stream and is retrieved to PM by a cue-dependent search process.
The effects observed in the auditory condition of the dual modality task reflect the pattern of results expected if cue dependent retrieval were being impacted by the training. The ignore condition showed higher spans following training consistent with the belief that information displaced from PM was being retrieved effectively from SM. The visual condition of the dual modality task showed results more consistent with an increase in focus of attention as an increase of span was observed for all three attention conditions. The significant main effect of attend condition is unsurprising and supports evidence that attending to a single stream of information promotes recall (see Tables 5 and 6, and Figures 11 and 12).
GENERAL DISCUSSION

The present study offers a number of important contributions to our understanding of WM and cognitive enhancement. Although training studies have demonstrated that it is possible to improve WM performance as a result of these intervention tasks, the use of an impaired population had left the question of whether or not training effects can be generalized to other populations unresolved. This study sought to address and expand on this by using an unimpaired adult population for both the treatment and control conditions.

The findings from Experiment 1 demonstrated that training was only partially effective at improving the abilities of an adult population. In terms of simple span tasks, participants showed improved performance on the Digit and Word Span tasks as a result of the training. However, the performance enhancement did not carry over to the Letter Span task. This observation suggests that in a typically developed adult population training effects do not readily generalize to untrained tasks even in the instance of Letter span tasks which are very similar to the Stabilizer training task. Although this contrasts with the findings of Klingberg et al. (2002) and Klingberg et al. (2005), it is consistent with previous findings from Ericsson and colleagues (1980). They demonstrated that learning to remember long lists of digits did not improve the performance on letter recall tasks which suggests that this type of task may be difficult to generalize to as an outcome.
A second contribution is that the enhancements seen in previous training studies may not simply be limited to improving WM abilities of an impaired population up to more typically developed levels. Successful improvements in the current population demonstrate that WM training can enhance this cognitive ability beyond the expected trajectory for a normal population. The inconsistent improvement observed in Experiment 1 suggests that enhancement in for a typically developed adult population should be interpreted cautiously, however. These inconsistent findings do not necessarily negate the possibility of improving cognitive abilities beyond a typically developed trajectory across a wider array of tasks.

Future studies may extend the present findings to other tasks and typically developing child populations. It may be that enhancement may be more readily and consistently observed in children and young adults who have not yet reached adult proficiency in WM.

Recall that the present study also sought to examine the relationship between training tasks and three approaches to understanding WM: executive attention, focus of attention and cue dependent retrieval. Experiment 2 compared performance on a variety of tasks that sought to isolate and eliminate some of these competing theories as possible explanations for the mechanism of change that results from this training.

Evidence from Experiment 1 failed to demonstrate improvements in performance on complex span tasks. These tasks were chosen to measure WM performance across the three mechanisms discussed earlier. The failure of Experiment 1 to demonstrate significant improvements did not preclude the possibility that these changes were simply too subtle for measures designed to look at all three. Failure to improve inhibition which
may underlie these tasks is consistent with the findings of Thorell et al. (2009). They were unable to train inhibition directly or in tandem with WM training. Experiment 2 tried to address the potential shortcoming of too coarse of measurements.

Recall that the findings from Experiment 2 showed a significant improvement on the Digit Span task indicating that training had been successful at improving a near transfer task and replicate the training effects of Experiment 1. The results of the Visual Array task however, failed to show the expected interaction. This finding failed to provide evidence that training was impacting the focus of attention in this population.

The results of the dual modality task indicated that cue dependent retrieval may be improved following training for the auditory modality. The ignore auditory/report auditory condition demonstrated an increase following training and was higher than the attend auditory/report auditory condition. This relationship suggests that the information from the auditory modality was being pushed out of PM and into SM and subsequently retrieved via cue-dependent retrieval.

The results for the visual modality of the dual modality task indicated instead that the focus of attention may be improving via performance. Following training, the spans for all three attend conditions showed improvement. An improvement across all attention conditions would indicate that the capacity of the focus of attention had improved. This finding conflicts with the evidence from the Visual Array task which failed to demonstrate enhancement in focus of attention following the training.

There are a variety of uses for this information. The present study offers a better understanding of how these tasks are impacting WM and may guide future cognitive enhancement treatment paradigms to explore the relationship between training and focus.
of attention and cue dependent retrieval. Isolating these mechanisms extended the work of Klingberg and colleagues (2002) and Klingberg et al. (2005) by offering an explanation for what specific mechanism may underlie the ADHD symptoms that these studies reduced through training. Failure to find improvements to executive attention and interference control replicates Thorell et al. (2009) who were unable to train inhibition or generalize the effects of WM training to inhibition.

The training tasks used in the present study were adaptive in nature, that is, as participants were able to recall items consistently at a certain span length, the program would add items to the lists in order to tax the capacity of the trainee. It is possible, given the high functioning, typically developed nature of the sample for this study, that the training regime was not challenging enough to elicit training effects. An alternative approach may be that the duration of the training sessions may need to be adjusted upward for this population. Another possibility is that the number of training sessions was insufficient perhaps demonstrating a need for a greater number of training sessions for the effect to generalize. This explanation is not entirely satisfying in light of the work of Feng, Spence and Pratt (2007).

In their study, Feng and colleagues trained spatial abilities through the use of action video games. Their results indicated that both men and women could improve spatial attention after only 10 sessions lasting approximately 1 hour each. A critical aspect of their study was that spatial abilities were required for the treatment video game and the outcome measure, however the control condition which did not play an action oriented video game did not demonstrate improvements from simply playing video
games that did not tap into spatial attention. This further demonstrates that far transfer is
difficult for this population, but near transfer is readily observable following training.

Although the difficulty of the training may be an explanation for the lack of
improvements observed in the present study it is also possible that training is simply
ineffective for an unimpaired population. Previous studies have examined the efficacy of
training in terms of improving impaired populations, such as those with ADHD (Klinberg
et al., 2002; Klingberg et al., 2005) while other studies have examined populations which
may experience suboptimal cognitive abilities such as preschool populations (Thorell et
al., 2009). It is possible that this training may only serve to improve performance up to a
typically developed young adult level. In this case, the present study should have failed to
find training effects because the population is already considered to operate at an
optimum level.

Dahlin et al. (2008) examined the relationship between training and performance
on unrelated tasks. Their results indicated that transfer can occur if the training and
outcome tasks activate overlapping processing components and brain regions. They also
demonstrated that age related decline in the activation of the striatum mediated the
transfer of training tasks. These results offer important insights for the present study. If
the training tasks were not activating the same brain regions as the outcome measures it
could explain why we failed to find consistent improvements in performance on far
transfer tasks such as the complex span tasks of Experiment 1. The difficulty of transfer
is consistent with the observation of restricted transfer in older populations, but not with
younger populations. This may suggest that a critical period exists when training can
transfer more readily. If so it is likely that our college aged population is now past this
critical developmental period. It may also be possible that training is effective later in life at reducing age related declines which would not have set in on a young adult population.

In conclusion, the present study found that training WM using simple span tasks had significant effects on several of the trained tasks. These effects did not generalize to untrained tasks that were highly dissimilar such as the complex span tasks of Experiment 1 or the Visual Array of Experiment 2. This does not eliminate the possibility that training could generalize in this population. Changing the frequency and/or duration of the training dosage may allow training to more readily generalize to dissimilar tasks. Finding training effects following a modification to dosage in this age group would indicate that difficulty in training WM may change over the lifespan. It is also possible that the difficulty observing training effects in this population may arise from the fact that training tasks are activating different anatomical regions than the outcome measures. As Dahlin et al. (2008) demonstrated, transfer of training effects was related to the overlap of activation for training and outcome tasks. In this case, far transfer would be more difficult if the training tasks are not activating the same areas as the outcome measures or our population is beyond the appropriate developmental stage for this training to have the highest impact.
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**TABLE 1**

MEAN SIMPLE SPAN SCORES AS A FUNCTION OF TASK, PRE/POST TEST AND TREATMENT CONDITION.

<table>
<thead>
<tr>
<th>Task</th>
<th>Pretest Control</th>
<th>Pretest Treatment</th>
<th>Posttest Control</th>
<th>Posttest Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digit Span</td>
<td>8.38 (1.07)</td>
<td>7.82 (1.02)</td>
<td>8.25 (1.42)</td>
<td>9.59 (1.48)</td>
</tr>
<tr>
<td>Letter Span</td>
<td>7.31 (1.77)</td>
<td>7.75 (0.87)</td>
<td>7.35 (1.55)</td>
<td>8.47 (1.29)</td>
</tr>
<tr>
<td>Word Span</td>
<td>6.13 (0.87)</td>
<td>5.59 (1.02)</td>
<td>6.13 (1.46)</td>
<td>6.59 (1.09)</td>
</tr>
</tbody>
</table>
TABLE 2
MEAN COMPLEX SPAN SCORES AS A FUNCTION OF TASK, PRE/POST TEST AND TREATMENT CONDITION.

<table>
<thead>
<tr>
<th>Task</th>
<th>Pretest Control</th>
<th>Pretest Treatment</th>
<th>Posttest Control</th>
<th>Posttest Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentence Span</td>
<td>3.69(1.40)</td>
<td>4.38(.95)</td>
<td>3.71(1.26)</td>
<td>4.29(1.09)</td>
</tr>
<tr>
<td>Comprehension Span</td>
<td>3.19(1.01)</td>
<td>4.00(1.52)</td>
<td>4.18(1.37)</td>
<td>4.35(1.51)</td>
</tr>
<tr>
<td>Operation Span</td>
<td>4.00(1.78)</td>
<td>4.06(1.03)</td>
<td>4.18(1.65)</td>
<td>4.29(1.12)</td>
</tr>
<tr>
<td>Spatial Span</td>
<td>4.75(1.91)</td>
<td>5.19(1.18)</td>
<td>4.41(1.32)</td>
<td>5.00(.91)</td>
</tr>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------</td>
<td>----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Group</td>
<td>7.17(1.11)</td>
<td>6.67(.94)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training Group</td>
<td>7.20(1.08)</td>
<td>8.07(.92)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3

MEAN AUDITORY SPAN SCORES AS A FUNCTION OF PRE/POST TEST AND TREATMENT CONDITION.
<table>
<thead>
<tr>
<th>Display Size</th>
<th>Pretest Control</th>
<th>Pretest Treatment</th>
<th>Posttest Control</th>
<th>Posttest Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3.41(.43)</td>
<td>3.21(.61)</td>
<td>3.50(.76)</td>
<td>3.37(.51)</td>
</tr>
<tr>
<td>6</td>
<td>3.72(.77)</td>
<td>3.65(1.39)</td>
<td>4.92(.89)</td>
<td>3.72(1.40)</td>
</tr>
<tr>
<td>8</td>
<td>4.65(1.80)</td>
<td>3.65(1.22)</td>
<td>5.42(1.66)</td>
<td>4.44(1.55)</td>
</tr>
<tr>
<td>10</td>
<td>5.29(2.73)</td>
<td>3.72(2.09)</td>
<td>6.24(1.79)</td>
<td>4.23(2.51)</td>
</tr>
<tr>
<td>Task</td>
<td>Pretest Control</td>
<td>Pretest Treatment</td>
<td>Posttest Control</td>
<td>Posttest Treatment</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Auditory Only</td>
<td>2.62(.40)</td>
<td>2.57(.40)</td>
<td>2.62(.33)</td>
<td>2.88(.37)</td>
</tr>
<tr>
<td>Attend Auditory</td>
<td>2.81(.38)</td>
<td>2.69(.46)</td>
<td>2.97(.34)</td>
<td>2.57(.36)</td>
</tr>
<tr>
<td>Ignore Auditory</td>
<td>2.75(.59)</td>
<td>2.43(.54)</td>
<td>2.60(.46)</td>
<td>2.79(.49)</td>
</tr>
<tr>
<td>Task</td>
<td>Pretest Control</td>
<td>Pretest Treatment</td>
<td>Posttest Control</td>
<td>Posttest Treatment</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------</td>
<td>------------------</td>
<td>-----------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Visual Only</td>
<td>2.30 (.49)</td>
<td>2.36 (.56)</td>
<td>2.27 (.31)</td>
<td>2.71 (.37)</td>
</tr>
<tr>
<td>Attend Visual</td>
<td>2.65 (.35)</td>
<td>2.53 (.57)</td>
<td>2.60 (.27)</td>
<td>2.79 (.31)</td>
</tr>
<tr>
<td>Ignore Visual</td>
<td>1.81 (.53)</td>
<td>1.96 (.56)</td>
<td>1.97 (.62)</td>
<td>2.17 (.43)</td>
</tr>
</tbody>
</table>
Figure 1.
In the spatial span, participants must make a decision regarding the orientation of a letter which can either be presented facing the proper direction or it is the mirror image (left). Once the list of decision letters has been displayed, participants are then asked to recall the orientation of the top of each letter in the list (right).
Figure 2.
Mean digit span as a function of treatment condition in pre- and posttest time periods.
Figure 3.
Mean letter span as a function of treatment condition in pre- and posttest time periods.
Figure 4.
Mean word span as a function of treatment condition in pre- and posttest time periods.
Figure 5.
Mean sentence span as a function of treatment condition in pre- and posttest time periods.
Figure 6.
Mean comprehension span as a function of treatment condition in pre- and posttest time periods.
Figure 7.
Mean operation span as a function of treatment condition in pre- and posttest time periods.
Figure 8.
Mean spatial span as a function of treatment condition in pre- and posttest time periods.
Figure 9.
Mean auditory digit span as a function of treatment conditions and pre/posttest time period.
Figure 10.
Mean span measured by the visual array as a function of treatment conditions and display size for pre- and posttest time periods.
Figure 11.
Mean number of items recalled as a function of attend condition in pre/posttest time periods for the auditory modality portion of the dual modality task.
Figure 12.
Mean number of items recalled as a function of attend condition in pre/posttest time periods for the visual modality portion of the dual modality task.