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Mediating and Moderating Mechanisms for Individual Differences in Working Memory and Reading Comprehension

by

Charles Parker

Thesis

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of the requirements for the degree of

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To the Graduate Faculty:

The members of the committee appointed to examine the thesis of Charles Parker find it satisfactory and recommend that it be accepted.

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September 9, 2015

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RE: regarding study number IRB-FY2016-70 : Mediating and Moderating Mechanisms for Individual Differences in Working Memory and Reading Comprehension

Dear Mr. Parker:

I have reviewed your request for expedited approval of the new study listed above. This is to confirm that I have approved your application.

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Sincerely,

Ralph Baergen, PhD, MPH, CIP
Human Subjects Chair

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Abstract

Research (e.g., Turley-Ames & Whitfield, 2003) has consistently found correlations between working memory span (WM) and higher order cognitive function (HCF), such as reading comprehension. However, the reasons for why individual differences in (WM) span occur and manifest across HCF tasks calls for further investigation. The present thesis study investigates whether the cognitive processes of resistance to proactive interference, inhibitory control, and metacognition have a mediating role on working memory span and its relationship to reading comprehension. The present study also evaluated the potential moderating effect of rehearsal strategy during an operation span task on the proposed mediation model. Resistance to proactive interference was measured using a Proactive Interference Release Task; inhibitory control was measured using a stop-signal task; and metacognition was assessed using the metacognition awareness inventory (MIA). Participants were assigned to operation span task groups in strategy and no strategy conditions. Although the moderated mediation model failed to achieve significance, metacognitive knowledge, specifically aspects of declarative knowledge, significantly mediated the relationship between WM and HCF. A greater awareness of declarative knowledge yielded a stronger relationship between WM and HCF. The findings are discussed in regards to development of techniques to improve working memory performance.

Keywords: working memory, strategy, inhibitory control, proactive interference, metacognition

Mediating and Moderating Mechanisms for Individual Differences in WM and Reading Comprehension

Working Memory is " …the contents of short term memory (STM) plus the limited-capacity controlled attention process associated with the central executive that can be used to maintain some set of those STM units as the focus of attention" (Engle, Tuholski, Laughlin, & Conway, 1999 p. 310). In other words, working memory is the memory system which can keep a limited amount of information active in attention. Moreover, it is often thought as the information we are able to process and store simultaneously. Working Memory is an important cognitive process due to its relation to higher order cognitive functions (Engle, 2002).

Working memory has been correlated with many other cognitive processes. Working memory is predicative of "general intelligence" and "fluid intelligence" (Engle et al., 1999; Kane, Hambrick, & Conway, 2005; Unsworth, 2010). Individuals with greater working memory abilities also have better attentional control (Schmiedek, Oberauer, Wilhelm, Süß, & Wittmann, 2007). Further, working memory predicts other higher order cognitive functions such as reading comprehension (Turley-Ames & Whitfield, 2003), verbal ability (Daneman & Merikle, 1996), and language comprehension (Just & Carpenter, 1992). The consistent correlations between working memory and the aforementioned cognitive functions suggest that it is central to executive functioning, and therefore responsible for many of the abilities attributed to executive function (Baddeley, 1992).

Also, neuroimaging studies have shown that working memory tasks produce activation within the frontal lobe; similar activation is observed during the performance of executive functioning and control tasks (Carpenter, Just, & Reichle, 2000; Kane & Engle, 2002; Olesen, Westerberg, & Klingberg, 2004; Osaka et al., 2004). However, working memory capacity is not equivalent across all individuals, as individual differences in working memory ability exist (e.g., Engle, 2002; Rosen & Engle, 1998).

Working memory performance is defined in terms of one's span: the number of items one can hold in memory within a given attention limit (Engle, 2002). Span is not directly due to item storage, but it is directly linked to the ability for one to maintain attention. In individual difference studies, individuals who are in the upper quartile of working memory performance are referred to as high spans, while those in the bottom quartile are typically referred to as low spans. High spans are characterized as having greater attentional control than low spans, which results in increased ability to recall items from memory. A low span has poor attentional control and suffers from poor recall of items (Engle, 2002).

Research has provided consistent support for high spans outperforming low spans on cognitive tasks (Cowan & Saults, 2013). Individual differences in WM manifest across various higher order cognitive processes (Engle, 2002). High spans have been shown to perform better on tasks of reading comprehension (Budd, Whitney, & Turley, 1995; Engle, Cantor, & Carullo, 1992; Just, Carpenter, & Woolley, 1982; Turley-Ames & Whitfield, 2003), language comprehension (Daneman & Merikle, 1996), and measures of fluid intelligence (Unsworth & Engle, 2005). However, the source of individual differences in working memory is still of considerable debate. One way to possibly understand the cause of individual differences may be to investigate cognitive mechanisms which may have a mediating role on working memory and its relationship to higher order cognitive functions. In other words, can other cognitive mechanisms account for the relationship between working memory span and higher order cognition? An answer to this question would help further our understanding of relevant mechanisms and/or the processes responsible for individual differences in working memory function.

Working memory and possible mediators

Since working memory is an integral part of executive function, it is possible that other cognitive mechanisms act as mediators for working memory and its relationship to higher order cognitive function. The cognitive mechanisms of proactive interference resistance (Carroll et al., 2010; Kane & Engle, 2000; Rosen & Engle, 1998), metacognition (Autin & Croizet, 2012; Elosúa, García-Madruga, Vila, Gómez-Veiga, & Gil, 2013), and inhibitory control (Bunting, 2006; Hasher, Zacks, Rose , May, & Cythia, 1999; Lustig, Hasher, & Zacks, 2007) have all been implicated as possible mediators of working memory and its relationship to higher order cognition. In the present study, a cognitive mediator will be defined as any cognitive mechanism which is responsible at least in part for the relationship between working memory and higher order cognitive function (Hayes, 2009).

The purpose of the present study was to investigate whether select cognitive mechanisms play a mediating role in determining an individual's working memory capacity and help explain its relationship to higher order cognitive function. More specifically, do any of the cognitive mechanisms identified above mediate all, or part of, the relationship with working memory span and higher cognitive functions?

In order to understand if a mediating relationship exists, each potential cognitive mediator was studied separately and evaluated against the current understanding of working memory's relationship with higher order cognitive function, namely reading comprehension (Turley-Ames & Whitfield, 2003). The following sections will review each potential mediator in order to make a case for why it was considered as a potential mediating mechanism as well as the rationale for how the proposed study examined the impact of the identified mechanism. The first cognitive process which will be investigated is proactive interference.

Proactive Interference

Interference has a long and well-documented history of being closely related to working memory (Cowan & Saults, 2013; Rosen & Engle, 1998; Salthouse, Siedlecki, & Krueger, 2006; Unsworth, 2010). There is significant support within the literature for the idea that a large amount of the variance observed within working memory, including individual differences, can be attributed to interference control (Bunting, 2006; Unsworth, 2010). Although there are two primary types of interference (i.e., retroactive and proactive), proactive interference has been identified as being culpable for individual differences within working memory (Bunting, 2006; Cowan & Saults, 2013; Kane & Engle, 2000; Rosen & Engle, 1998). Proactive interference occurs when previously stored information interferes with present information. Proactive interference can occur during encoding and/or recalling of to-be-wanted information (Underwood, 1957). An example of this would be a student trying to recall a Spanish word on a test, but instead the student recalls French words he/she learned in a previous semester.

Proactive Interference has been implicated in assessments of working memory capacity. The buildup of proactive interference has been thought to directly affect performance on working memory tasks, often leading to reduced recall of to-be-remembered words. The ability to manage proactive interference may affect the cognitive capacity of an individual, making –it-difficult to focus his/her attention on words that need to be remembered (Engle, 2002). For example, in a reading span task, it has been found that when proactive interference is reduced, the participant is likely to perform better on a working memory task (Lustig, May, & Hasher, 2001; May, Hasher, & Kane, 1999).

May et al., (1999) and a subsequent follow-up study by Lustig et al., (2001) directed participants to perform a working memory span task, followed by reading a story, and then completing a filler task. The working memory span task was the reading span test in which participants were instructed to read a series of unconnected sentences, with the goal to remember the last word in each sentence. When participants finished reading all of the sentences in a given set, they were instructed to recall the last word of each sentence they read. Set sizes ranged from two to five sentences. Participants then completed the digit symbol subtest of the Weschler Adult Intelligence Scale, which served as the filler task. Upon completion of the filler task, participants were asked to recall the story. Lustig, May, and Hasher, evaluated how proactive interference in the span task affected participants' ability to recall details of the story.

Proactive interference was created through the administration of the working memory task (in these experiments it was a reading span task). When the number of sentences in a set size systematically increased, proactive interference increased. As a means of reducing proactive interference, the span task was administered in descending order (Lustig, May, & Hasher, 2001); trials were presented starting with the largest set of to-be-remembered words (i.e., 5) and decreased to smaller sets (i.e., 2). Proactive interference was reduced also in the same experiment by giving participants in a separate group a break mid-way through the descending reading span task. Proactive interference was reduced in the descending condition because it allowed participants to use decreasing amounts of capacity as they progress through the experiment. Results showed that participants in the low proactive interference groups (i.e., descending and break) recalled more of the story than those who were in conditions thought to produce greater proactive interference (i.e., ascending and no break).

Kane and Engle (2000) also found that individuals with low working memory capacity were affected by proactive interference more than high spans when performing a proactive interference release task. However, high spans were more susceptible to proactive interference when they were instructed to perform a cascading finger task. The finger cascade task consisted of participants tapping their fingers in a specified pattern while performing the working memory task. It was theorized that high spans experienced reduced capacity because they were unable to focus their attention on both tuning out the interference and performing the finger cascade task. The cognitive load created by trying to focus on two tasks led to a decrease in performance. High spans appeared to be using their attentional resources not only to focus on the to-be-remembered words but also to engage in an active process of blocking out the buildup of interference. Low spans did not suffer the same decrease in performance on the proactive interference release task during the finger cascading task because they were not under the same cognitive load; in other words, they were not trying to actively tune out or manage interference. Low spans were simply unable to focus on the task of recalling the to-be-remembered information and simultaneously block out interference even before the finger cascading task was introduced. Thus, it was concluded that high spans may have greater working memory capacity because they were actively resisting proactive interference through attentional control.

Rosen and Engle (1998) also suggested that proactive interference plays a role in individual differences in working memory. In a series of span tasks, high spans experienced fewer intrusions than low spans. They also found that high spans were more active in their suppression of previous information than low spans. Due to actively suppressing no longer relevant information, high spans took longer to respond on span tasks, yet they produced higher recall scores, indicating they suffered less from proactive interference than low spans. Other experiments have shown how proactive interference resistance influences working memory span scores and working memory performance.

Cowan and Saults (2013) performed a series of memory span tasks along with a probe recognition task. Participants were given a study list of words varying from three to eight words. They viewed each word for 1.5 seconds before a new word was presented. Once the task was completed, participants were given a new task. Participants were shown a series of words, including test words, and they had to recall whether they had seen the word or not on a previously viewed list. In the proactive interference condition, the recognition words were semantically similar to the words in the previously viewed list, while the recognition words were entirely different from the list in the no proactive interference condition. For example, if the study list was composed of vegetable names, the proactive interference group may have seen the word “cucumber,” while the no proactive interference group may have seen the word “door.” Results showed high spans recognized whether the test word was on the list faster than low spans when the study list contained 4-5 items. However, on a study list containing 6-8 items, reaction times were roughly equivalent. Thus, it was not the ability to store more items that facilitated high spans' performance but rather the ability to tune out proactive interference. High spans could resist interference created from a study list of 4 to 8 items, while low spans were unable to do so.

Taking into account the literature on proactive interference and working memory, it can be safely concluded that susceptibility to proactive interference has an impact on working memory performance. The susceptibility, or the way in which one manages proactive interference, could be a limiting factor of working memory capacity (Bunting, 2006; Cowan, Johnson, & Saults, 2005; Cowan & Saults, 2013; Engle, 2002; J. Jonides & Nee, 2006; Kane & Engle, 2000; Lustig et al., 2001; May et al., 1999; Rosen & Engle, 1998). It is, therefore, important to investigate proactive interference and other cognitive mechanisms which may mediate working memory's relationship to higher order cognitive functions.

In an attempt to further breakdown potential cognitive mediators of working memory and higher cognitive function, the present study also examined the cognitive mechanism of inhibitory control in working memory. Although similar to proactive interference resistance, inhibitory control was treated as a separate construct and as an independent potential mediator of working memory and higher order cognitive functions.

Inhibitory control

Inhibitory control is the ability to ignore irrelevant information (Darowski, Helder, Zacks, Hasher, & Hambrick, 2008). Inhibitory control involves a two part process: suppression and activation. In an inhibitory control task, the distractor information needs to be inhibited while the relevant information is activated.

Inhibitory control has been related to memory consolidation. Research by Jain and Kar (2014) observed that an inability to suppress irrelevant information prevents effective consolidation of items in short term memory. Hasher and Zacks (1988) also suggested that a significant decrease in inhibitory control explained why working memory performance decreases with age. As individuals age, the faculties that inhibit irrelevant information diminish, and the individual becomes more susceptible to distraction and interference (Jain & Krar, 2014).

Inhibitory control is the focus of the controlled attention model of working memory capacity. In this model, individual differences are due to the inability for one to inhibit shifts in attention. This inability to properly shift attention allows for a buildup of proactive interference. Thus, a low span is unable to properly shift attention away from previous information as he or she attempts to learn new information; high spans, on the other hand, use attention control processes which result in more successful inhibition and greater working memory performance (Engle et al., 1999; Kane & Engle, 2000; Kane, Kathryn, & Engle, 2001). Hasher and Zacks (1988) have proposed a model which links inhibitory control to working memory capacity. They suggested that as humans age inhibitory control begins to diminish, and working memory capacity decreases as a result (Hasher & Zacks, 1988).

Inhibitory control is often associated with proactive interference (Bunting, 2006; Rosen & Engle, 1998). Individuals who successfully utilize inhibitory control are less likely to experience intrusive thoughts as they can actively suppress or inhibit previous learned information that has become irrelevant (Bunting, 2006; Cowan & Saults, 2013). In some previous research, inhibitory control is treated as a part of proactive interference as opposed to being assessed as a separate cognitive mechanism (Kane & Engle, 2000; Kane, Kathryn, & Engle, 2001; Rosen & Engle, 1998) and/or a byproduct of resistance to proactive interference.

While inhibitory control is frequently treated as a construct similar to proactive interference in the literature, inhibitory control includes a larger cognitive domain than that of proactive interference resistance. Inhibitory control has been implicated in processes such as impulsivity (Tabibnia et al., 2014), motor control (Schachar & Logan, 1990), memory regulation (Hasher et al., 1998; Lustig et al., 2007), attention (Crawford et al., 2013), and working memory (Lustig et al., 2001; Rosen & Engle, 1998). While inhibitory control has been linked to proactive interference management in the past (Kane & Engle, 2000; Kane et al., 2001; Rosen & Engle, 1998), recent research has demonstrated the processes are orthogonal to each other.

Friedman and Miyake (2004) evaluated the relationship between three inhibition-related functions: inhibition response, resistance to distraction, and resistance to proactive interference. In their research, inhibition response was the ability to suppress an automatic response; resistance to distraction was the ability to ignore irrelevant stimuli and focus on the given task; and resistance to proactive interference was the ability to prevent previously learned information from intruding upon information that was currently being learned.

Participants performed a series of tasks which tested each one of the aforementioned inhibition-related functions. When a structural equation model was performed on the three functions, no relationship between resistance to proactive interference and response inhibition (.18), nor resistance to distractor interference and resistance to proactive interference (-.03) was observed. However, resistance to distractor interference and response inhibition were highly correlated with each other (.68), suggesting that they were measuring a common mechanism. Thus, it was concluded that resistance to proactive interference was measuring a different aspect of cognition than the two other inhibition-related functions, namely inhibition response and inhibition to distractor interference.

A follow up study by Bissett, Evan Nee, and Jonides (2009) came to the same conclusions as Friedman and Miyake (2004). Bisset and colleagues (2004) used a task which combined proactive interference resistance with response inhibition. Participants were presented with four letters, and after a short delay (i.e., 3 sec), they were shown two of the previous four letters and were instructed to forget the two letters on display. After another delay (i.e., 1 sec), participants were shown another letter and were instructed to press the number “1” on the keyboard if the displayed letter was the one they were supposed to remember (i.e., one of the four letters not selected to be forgotten). On twenty percent of the trials, an auditory signal (i.e., loud tone) was played during the recall phase which indicated to participants to not respond to the presented stimulus. Based upon data analysis, it was concluded that the stop signal reaction times (i.e., the average time it took to inhibit the motor action) did not influence the susceptibility to proactive interference from the memory task. Participants were affected by proactive interference, as measured by the number of incorrect items, regardless of their ability to inhibit the response. These findings suggest that the ability to resist proactive interference is separate from an individual's ability to inhibit an action.

Lastly, neuroimaging studies have provided evidence that proactive interference resistance and inhibitory response control occur in two separate areas of the brain. Tasks that measure resistance to proactive interference initiate activation of the left inferior frontal gyrus, while tasks that require response inhibition activate the anterior cingulate cortex (Nelson, Reuter-Lorenz, Sylvester, Jonides, & Smith, 2003). Given the reports of the previous studies, it seems reasonable to conclude that inhibitory control should be examined as a separate potential cognitive mediator as we explore the relationship between working memory and higher order cognitive function.

Since the argument has been made for a distinction between proactive interference and inhibitory control, an inhibitory control task that minimizes interference was used in the present research. More specifically, the stop-start signal task was used, a common task for measuring response inhibition (Verbruggen & Logan, 2008). The stop signal paradigm has been empirically validated as a measure of inhibitory control as previously defined (Schachar & Logan, 1990).

The stop signal task measures inhibitory control through one's ability to stop his/her motor action during a task. The task involves an individual pressing a key when he/she see a particular symbol appear on a computer screen. During the task, the participant will hear an audible noise on some trials, signaling to him/her to not press the key. The participant must then try to stop the impulse to press the key when he/she hears the sound. As described, this task allows for one to measure an individual's ability to inhibit motor action through stop-start signal reaction time (SSRT; Verbruggen & Logan, 2008).

While the stop signal task is often used to measure and evaluate motor inhibition, it has also been linked to mental inhibition. For example, motor inhibition has been shown to be predictive of an individual's ability to inhibit previous thoughts from affecting current thought processes (Band, van der Molen, & Logan, 2003). The psychological disorder of Attention Deficit Hyperactivity Disorder (ADHD) has served historically as an example of how motor inhibition is linked with cognitive performance (Band, van der Molen, & Logan, 2003).

ADHD is a psychological disorder which is characterized by abnormal impulsivity, the inability to sustain attention, and hyperactivity (Barkley, 1997). Schachar and Logan (1990) conducted a study in which they tested children who had been diagnosed with attention deficit disorder (ADD) and ADHD using the stop signal paradigm. When compared to healthy control children, children with ADHD exhibited decreased inhibitory control. In Barkley's (1997) model of ADHD, motor inhibition is directly linked to four parts of executive function (i.e., working memory, self-regulation, internalization of speech, reconstitution). Barkley hypothesized that deficits in these four areas of executive control lead to poor motor control and inhibition. Following Barkley's model (1997), as well as the prior use of the stop-signal paradigm within the literature for similar purposes (Schachar & Logan, 1990; Schachar, Tannock, Marriott, & Logan, 1995), the stop signal task will be used to assess inhibitory control through motor inhibition.

While inhibitory control and proactive interference have both been studied within the context of working memory, other cognitive processes also deserve to be investigated in order to form a more comprehensive understanding of potential mediators of individual differences in working memory and its relationship to higher order cognition. Thus, the present study also evaluated the role of metacognition as an individual difference related to the relationship of interest.

Metacognition

Metacognition is defined as one's own awareness of their mental states and/or cognitive thought processes (Flavell, 1979; Schraw, 2009; Schraw & Dennison, 1994; Schraw & Moshman, 1995). Schraw and colleagues (1994, 1995, & 1998) propose that there are two parts of metacognition, consisting of metacognitive regulation and metacognitive awareness.

Metacognitive regulation is the way in which we monitor or control our own cognitions (Fernandez-Duque, Baird, & Posner, 2000; Sperling, Howard, Staley, & DuBois, 2004). By contrast, metacognitive awareness is our attentiveness to our own thoughts and mental processes. For example, imagine an individual who has high metacognitive ability trying to remember a twenty item list. The individual will likely try to utilize one or more different strategies to help remember all the items on the list. Such an individual may try to visualize an image of each item on the list, use a mnemonic device to remember each item, and/or repeat each item on the list over and over again. Further, an individual may try a variety of techniques until he/she finds a method that is effective given the task. Then, an individual will likely use this preferred technique when asked to remember items in the future when he/she is in similar situations.

Beyond the study of working memory, metacognition has been researched in educational settings. In children, it has been theorized that metacognition facilitates correct strategy choice and can enhance performance. Research suggests that a child with high metacognitive ability is more likely to use multiple cognitive strategies (e.g., mnemonic devices, rote rehearsal) to facilitate learning of new material. These strategies may include rehearsing new material, connecting it to real life examples, and/or seeking further elaboration (Pintrich & de Groot, 1990). Children who are high in metacognitive ability are more likely to engage with the material they are learning by connecting what is new with what they already know, leading to greater comprehension of the material (McNamara, 2011).

Metacognition also involves the integration of feedback into the cognitive schemata of the student. The cognitive schema is the mental representation and organization of the learned material into a coherent framework (Tuckey & Brewer, 2003). Via feedback, such as whether their answer was correct, students are given a chance to alter the way they represented previously learned information, as a means of enhancing subsequent performance (Butler, Karpicke, & Roedinger, 2008). In one study, students completed a multiple choice test and then received feedback on half of their answers. After answering each question and before receiving feedback, students judged how confident they were in their answer being correct. After a brief distractor task, students were tested on the same information presented on the first test, but instead of multiple choice responses, the questions allowed for free recall responses (i.e., open-ended questions). Students who received feedback on correct answers and had low confidence in their response demonstrated better recall when tested again compared to students who did not receive feedback for answers and had low confidence (Butler, Karpicke, & Roediger, 2008).

Within the working memory literature, metacognition has been theorized to be a mediator of the relationship between working memory and other higher order cognitive tasks (Swanson & Trahan, 1996). For example, Swanson and Trahan (1996) compared normal readers with disabled readers on measures of working memory, reading comprehension, and metacognition. These researchers found that differences in disabled readers' reading scores were predicted by metacognitive ability, while differences in normal readers were predicted by working memory ability. The authors concluded that metacognition may mediate the relationship between working memory and reading ability for some groups of individuals, namely low spans.

Further, Dunlosky and Kane (2007) investigated whether conscious strategy use influences individual differences in working memory span. Although the term metacognition is never directly referenced in the study, Dunlosky and Kane (2007) asked participants to pay attention to their own thoughts and evaluate their own mental processes. Dunlosky and Kane (2007) reported higher working memory performance to be positively correlated with greater awareness and use of cognitive strategies.

By extension, Austin and Croizet (2014) hypothesized that working memory performance could be increased by mentally reframing a previously difficult task. More specifically, they theorized that the difficulty level of the task could produce interfering thoughts, which in turn, would inhibit the performance of the working memory system. Austin and Croziet (2014) had sixth graders perform an anagram task which was impossible to complete given the time constraints. Mental reframing of the task was manipulated by telling one set of students at the conclusion of the study that failure to solve the task was “part of the process of learning;” the other set of students were not told anything at the conclusion of the task. Students, who had the difficult task positively reframed, performed better on the working memory span task under high cognitive demands (i.e., more to-be–remembered words) than the group who did not receive positive reframing. The reframed group also outperformed a third group who just took the working memory span task without attempting the anagram task beforehand; this group performed at a level equivalent to the no reframing group. Austin and Croziet (2014) also observed a boost in working memory performance, due to cognitive reframing, transferred to reading comprehension performance.

While the benefits of high metacognitive ability have been well documented, studies have found that most individuals within the population possess lower levels of metacognitive ability (Butler et al., 2008; Hertzog et al., 2009; Karpicke, Butler, & Roediger, 2009). An example of poor metacognitive ability can be seen in the study habits of students. The testing effect is a phenomenon in which performance on a test is increased by completing practice tests on the same topic (Roediger & Karpicke, 2006). These testing benefits are well known among teachers and students, but a survey of 177 students revealed that 77% of students did not use self-testing as a means to study material from a textbook (Karpicke et al., 2009). The results of this survey revealed that most students lacked the metacognitive awareness to connect the known benefit of the testing effect to their own study habits.

Together, the research suggests that there may be a relationship between metacognitive ability and performance on cognitive tasks, such as working memory span tasks and/or tests of reading comprehension. However, the exact nature of the relationship between working memory and metacognition is still not clear. Whitebread (1999) theorized that improvements in metacognitive awareness may enhance performance in the same way increased working memory capacity often results in better performance on tasks of higher order cognition. Perhaps, metacognition acts as a mediator to the relationship between working memory and higher order cognitive function. Thus, increasing metacognitive ability may enhance the relationship between working memory and higher order cognition.

In the present study, the potential role of metacognition as mediator between working memory and higher order cognitive function was investigated. In order to study metacognition, thoughts and attitudes about one's own metacognitive abilities must be quantitatively measured. Although self-assessment is not ideal, it is a reasonable first step in understanding the fundamental relationship between individual differences in working memory and metacognitive awareness.

There are several different methods for assessing metacognitive awareness, many of which fall into two larger categories of think out loud protocols and self-assessment (Saraç & Karakelle, 2012). Think out loud protocols require an individual to perform a cognitive task out loud while being videotaped. The participant's metacognitive behaviors are, then, scored or coded. Think out loud protocols provide a strong quantitative and qualitative picture of metacognition. However, due to the need to record and code each participant's behavior, think out loud protocols are time consuming to administer, and it is often difficult to achieve satisfactory inter-rater reliability (Saraç & Karakelle, 2012).

Self-assessment measures are self-report questionnaires which ask the participant to answer questions on a Likert scale regarding what they think or know about their own cognitive processes (Saraç & Karakelle, 2012; Schraw & Dennison, 1994). Although not as detailed as think out loud protocols, self-assessments require the participant to provide information about their own metacognitive awareness in a cost and time effective manner.

One other popular method of self-assessment is collecting judgment of learnings (JOL) or confidence ratings from participants. First collected by Arbuckle and Cuddy (1969), JOLs require the participant to judge/rate how well he or she thinks he or she knows previously learned information. For example, in an experiment of memory a participant may be given information to study. Then, JOLs are collected from the participant in the form of predictions about their learning and compared to actual memory performance as an assessment of judgment accuracy. High congruency between JOLs and actual performance is considered an indicator of high metacognitive ability. If a participant can accurately evaluate his/her own comprehension of the to-be-learned material, then he/she can accurately assess their own process of learning, indicating metacognitive awareness (Ariel & Dunlosky, 2010).

However, JOLs were not used in the present study because working memory is a time and load sensitive resource. Asking participants to predict their own performance before recall on a time based working memory task could present significant problems and introduce significant confounds and/or error variance. Having participants complete a JOL task before recall of to-be-remembered information would likely create interference and artificially lower assessment of working memory span performance. Therefore, in the present study we employed the use of a self-report questionnaire, more specifically the Metacognitive Awareness Inventory, otherwise known as the MIA (Schraw & Dennison, 1994). As this is a preliminary investigation into whether the relationship between working memory and higher order cognitive function is mediated by metacognitive awareness, the MIA provided important information about whether metacognition deserve further consideration in addressing the questions outlined in the present study.

While it is proposed that the cognitive mechanisms of proactive interference management, inhibitory control, and metacognition maybe responsible, at least in part, for individual differences, we further propose that the use of a working memory strategy can influence individual differences in working memory performance as well. As such, we investigated how the use of a strategy impacts the potential mediators and influences individual differences in working memory and higher order cognitive function. Thus, one of the fundamental questions of this study was: does strategy use moderate the relationship between working memory and other higher order cognitive processes such as reading comprehension? If so, how does this influence the more basic cognitive mechanisms associated with working memory and higher cognitive function?

Strategy Control

Strategy control is the intentional manipulation of cognitive heuristics or actions used to enhance performance on a given task. Strategy control has been applied to the study of individual differences in working memory capacity (e.g., Klinberg, Forssberg, & Westerberg, 2002; McNamara & Scott, 2001; Turley-Ames & Whitfield, 2003). As previously noted, working memory has been correlated with many measures of high order cognitive function (e.g., Engle, 2002). Thus, it is hoped that by teaching working memory management strategies performance and processing gains will transfer to higher order cognitive functions performed by individuals. Thus, the goal in teaching strategy control techniques to low spans would be to assist them in better utilizing their working memory capacity and enhancing performance on higher order cognitive tasks.

Working memory training has been shown to have an effect on higher order cognitive function, but there is considerable debate as to whether these functions generalize to other higher order cognitive tasks outside the domain of the specific training (Melby-Lervåg & Hulme, 2013; Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2012). Most of the debate has focused on whether far transfer can occur with strategy use. Far transfer is when learned information “transfers” to a novel context or situation. This is opposed to near transfer in which the acquired knowledge is “moved” to a similar situation or context (Perkins & Salomon, 1992). An example of near transfer would be an individual using knowledge acquired from doing practice math problems at home and to a math test at school with similar problems. Conversely, far transfer would be an application of a skill acquired from the math problems to an entirely different problem set, such as items on an analytic reasoning task.

Turley-Ames and Whitfield (2003) investigated whether working memory capacity could be increased through the use of a control strategy. In one condition, low span participants were taught to use repetition on an operation span task. Once well practiced in the strategy, participants showed a remarkable increase in performance on the operation span task, and those scores correlated strongly with Nelson–Denny reading comprehension scores. Thus, the increase in working memory spans scores yielded a stronger positive correlation with the reading comprehension score with training on the

OSPAN as compared to the control group. This is critical because it may suggest that higher order cognitive processes can be enhanced by teaching individuals a strategy to facilitate working memory resources which then may transfer to other higher order cognitive tasks.

Dunlosky and Kane (2007) also found a significant correlation with strategy use and performance on a span task. Participants completed a span task, with one group being prompted before the task to think about the strategies they could use to remember the item, knowing they would have to recall the strategies they used upon completion of the task. Another group of participants were instructed to think about strategies before performing the span task, but these participants were not told that they would have to report their strategy use at the end. A third group of participants was not prompted to do anything before the task. Upon completion of the span task, participants in all groups reported what, if any, strategies they used to aid them in remembering the to-be-remembered information. In the end, participants who utilized a strategy or a combination of strategies had higher scores on the span task, even if they were not explicitly prompted ahead of time to think about strategy use. Low span individual reported less use of a strategy than those with higher spans. Dunlosky and Kane (2007), like Turley-Ames and Whitfield (2003), also reported that high span individuals were more likely to report the use of a strategy. Thus, it was purposed that individual differences in strategy use were due to individual differences in working memory capacity. Individuals with high working memory abilities were better able to handle the cognitive load associated with using a strategy on a working memory task.

In another experiment (Klingberg, Forssberg, & Westerberg, 2002), children with ADHD were trained daily over the course of 5-6 weeks on different working memory tasks. The training tasks consisted of a choice reaction time task, letter span task, backwards digit span, and a visual-spatial working memory task. When retested, children who received training demonstrated a significant increase (as compared to pre-test results) on tests of working memory, a span board task, Stroop accuracy, and Raven's Matrices. Post-test scores showed improvement not only in working memory but other cognitive functions as well. More specifically, cognitive improvement was demonstrated by increased scores on the Stroop task (i.e., improvement in inhibitory control) and Raven's Matrices (i.e., improvement in fluid intelligence). Further, children produced fewer head movements as compared to baseline levels during the posttests which indicated a greater ability to focus and a decrease in ADHD symptoms (Klingberg, Forssberg, & Westerberg, 2002). Thus, results suggested that far transfer may be facilitated by working memory training.

Given the findings of Turley-Ames and Whitfield (2003) and Frosterberg, Kilinberg, and Westerberg (2001), one can hypothesize that far transfer to higher order cognitive functions may occur by teaching an individual how to properly use working memory management strategies. This hypothesis has been challenged by opponents who argue that individual differences observed in the aforementioned studies were due to error variance and not the experimental manipulation of strategy use (Shipstead et al., 2012). Proponents of the error variance interpretation argue that individual differences in working memory are not moderated by strategy use but rather are simply due to a corresponding reduction in error variance associated with standardized procedures.

Proponents of an error variance view also argue that, although individual differences exist, they are more biologically determined rather than being mediated by other cognitive factors and/or testing conditions (Engle et al., 1992).

Another argument against strategy is that is that low spans do not have the resources available in working memory to properly utilize strategies. Proponents claim that low spans are unable to correctly match situations with appropriate working memory management strategies. To do so, low spans would need higher or identical contextual match at both training and test (Shipstead et al., 2012). Morrison and Chein (2011) agree and argue that strategy use is to task specific and that transfer of strategy use does not occur unless the task is identical to the training conditions.

The results of studies such as Turley-Ames and Whitfield (2003), and Frostburg, Westerberg, and Klinberg (2002) argue that gains made from strategy use are not fully explained by the error variance hypothesis. In particular, Turley-Ames and Whitfield (2003) found that the rote rehearsal strategy condition had stronger correlations with reading ability scores (.79) than the control group in which participants were not trained to use an attentional control strategy (.47). The enhanced correlation with reading ability gives credence to the idea that strategy use can impact the relationship between working memory and reading ability. Thus, more investigation into strategy use is needed before performance increases can be written off as due exclusively to error variance.

Additionally, studies on latent learning have demonstrated that when trained in situations similar to real life scenarios individuals can apply learned information across situations (Idol & Jones, 2013). This consistent finding contradicts claims made by Morrison and Chein (2011), which deny far transfer occurring from strategy use and working memory performance on to other cognitive tasks. Further, McNamara and Scott (2001) present evidence in support of far transfer for strategy use when they observed a strong correlation between strategy use on an OSPAN test and performance on the verbal portion of the SAT. Strategy use was associated with higher scores on the verbal portion of the SAT. In another study focused on learning strategies among students, experimenters found that teaching strategies to students facilitated better recall of items from memory. Low achieving children whose teachers suggested strategy techniques (i.e., repetition of items) to them were more likely to use a strategy during recall, and these same students consequently recalled more items from a list of forty items (Moely et al., 1992).

Given the previous examples of far transfer associated with strategy control, the explanation that individual differences in working memory and reading ability are due exclusively to error variance may not be sufficient. Further investigation is needed to determine how strategy control influences the relationship between working memory and higher order cognitive function. Could strategy use act as a moderator for the proposed relationship? Importantly, could strategy training be used to enhance working memory performance more broadly? If so, how does strategy influence the effects of proactive interference resistance, inhibitory control, and metacognition?

Rational for present experiment

As described, researchers have theorized about a relationship between working memory performance and proactive inference resistance (Kane et al., 2001; May et al., 1999), metacognition (Karpicke et al., 2009; Roediger & Karpicke, 2006), and inhibitory control (Darowski et al., 2008; Hasher & Zacks, 1988). Thus, the aim of the present study was to look at whether these proposed mediators account, at least in part, for the relationship between working memory and higher order cognitive function. These mediators have all been identified by previous research as being related to working memory function. Thus, the goal is to determine if these processes influence the relationship between working memory and reading comprehension by mediation.

A mediated model between working memory and higher order cognition could elucidate why individual differences are observed consistently in relation to working memory and reading comprehension. Are the aforementioned mediators and moderators responsible for individual differences seen across working memory performance? Identifying cognitive mediators may help us better understand why individual differences exist and further our understanding of the relationship between working memory and other cognitive functions. Understanding the relationship is important because this knowledge could facilitate the development of techniques that may improve individual cognitive functioning across domains. Enhanced cognition, particularly working memory, may yield significant gains in areas such as reading comprehension and "intellectual" functioning, especially if far transfer is possible.

The present research also aimed to evaluate whether strategy use during working memory task performance can have a moderating effects on the proposed mediations. Does strategy use strengthen one of the mediational model pathways, creating an enhanced relationship between working memory and higher order cognition? If evidence of moderation is observed, then this could suggest that strategy use can facilitate far transfer effects (Morrison & Chein, 2011; Shipstead et al., 2012).

Hypothesizes

Given the previous rational, the following set of hypotheses were proposed for the present experiment:

Hypothesis 1. As a replication, working memory span will positively correlate with reading comprehension with and without strategy instruction.

Hypothesis 2. Proactive interference resistance with and without strategy instruction will meditate the relationship between working memory span and reading comprehension (see Figure 1).

2a. Rehearsal strategy use is hypothesized to moderate the relationship between working memory and proactive interference resistance, and/or the relationship between proactive interference resistance and reading comprehension when controlling for working memory span.

2b. Rehearsal strategy use will moderate the relationship between working memory and reading comprehension when controlling for proactive interference.

Hypothesis 3. Inhibitory control with and without strategy instruction will meditate the relationship between working memory span and reading comprehension (see Figure 2).

3a. Rehearsal strategy use is hypothesized to moderate the relationship between working memory and inhibitory control, and/or the relationship between inhibitory and reading comprehension when controlling for working memory span.

3b. Rehearsal strategy use will moderate the relationship between working memory and reading comprehension when controlling for inhibitory control.

Hypothesis 4. Metacognitive awareness with and without strategy instruction will meditate the relationship between working memory span and reading comprehension (see Figure 3).

4a. Rehearsal strategy use is hypothesized to moderate the relationship between working memory and metacognitive awareness, and/or the relationship between metacognitive awareness and reading comprehension when controlling for working memory span.

4b. Rehearsal strategy use will moderate the relationship between working memory and reading comprehension when controlling for metacognitive awareness.

Method

Participants

Participants were 236 students at Idaho State University. Students received course credit for their participation. All students were native English speakers; demographics of age, race, and gender were also collected. The tasks used in the present study relied heavily on correctly reading English words in a limited time frame; therefore, nonnative English speakers were excluded from the data analyses and replaced to meet the required sample size. Participants were randomly assigned to one of two conditions, either strategy or no strategy.

Power Analysis

A power analysis was conducted to determine the probability that the null hypothesis will be correctly rejected. The analysis assumed a medium effect size of .16 based on previous research by Turley-Ames and Whitfield (2003). With six predictors as determined by the moderated mediation models (see Figures 1, 2, 3), and a sample size of 240 participants, Cohen's power analysis tables estimated the power for the proposed study was approximately .9 (Cohen, 1988).

Materials

Operation Span Task. The operation span (OSPAN) task was used to measure working memory capacity for each individual. The OSPAN has been validated as a reliable and accurate measure of working memory capacity (α =.75, test-retest reliability = .67 - .81; Klein & Fiss, 1999). The version of the OSPAN used in the present research was an adaptation of Turner and Engle (1998) and has been successfully used in previous research (e.g., Turley-Ames & Whitfield, 2003). The OSPAN was programmed and presented using E-Prime 2.0 software.

For the OSPAN, an elementary math problem is represented for 8 seconds, displaying each part of the math problem individually (i.e., 5+3/2=__?). The participant must read aloud each part of the problem as it is revealed and provide an answer to the equation verbally after viewing the entire math problem. Then, the participant is presented with an unrelated to-be-remembered (TBR) word that needs to be recalled later. TBR words were randomly assigned to math problems.

For this task, participant had 8 seconds to read aloud the components of a math problem, report a solution, and read a TBR word. If the participant took longer than 8 seconds, the program automatically advanced to the next math-word problem. Participants were instructed to recall the TBR words at the end of a trial when given the instructions to "recall words." Participants wrote down words they recalled from that set on a blank page in an answer book they received at the start of the OSPAN. Before completing the actual OSPAN, participants completed 12 practice trials. Practice trials consisted of six sets with each set being compromised of two TBR words and math problems, and the other six sets each being compromised of three math-word problems. The participant had to correctly solve the math problems and recall the TBR words in three out of the last four sets in order to move on to the actual study OSPAN. If a participant was unable to pass the practice trials in three tries, his/her data was excluded. The OSPAN consisted of 15 sets. Following the method used by Turley-Ames and Whitfield (2003), the OSPAN trials increased in the size of operation word strings for each trial, starting at two and increasing to six operation words strings prior to being instructed to "recall words." Participants received a score from 0 to 60 based on the number of correct word-math problems.

Nelson Denny Reading Comprehension Test. The Nelson Denny, form G, is a reading comprehension task designed to measure verbal ability. The Nelson Denny consists of a vocabulary and comprehension section. Consistent with standardized administration, participants first completed the vocabulary section consisting of 80 items in which participants have to select the correct vocabulary word from a set of listed words (i.e., multiple choice) in order to complete a given phrase or sentence. Participants had 15 minutes to complete the vocabulary section (Brown, Fishco, & Hanna, 1993). Next, participants completed the comprehension section of the Nelson Denny. Participants read seven passages and answered comprehension questions pertaining to information in the text. Before reading all of the passages, reading rate for the participant was recorded. This was accomplished by telling participants to "stop" after one minute while reading the first passage. The line on which they stopped was then recorded as per standard instructions. The participant had 20 minutes to complete the reading comprehension section. The participant recorded their own answers on a self scorable sheet designed for the Nelson Denny.

Participants received one point for each correctly answered item with scores ranging from 0-80 on the verbal portion and 0-35 on the comprehension portion. A composite score was computed by multiplying the comprehension score by two and adding the result to the verbal score; composite scores could range from 0-150 (Brown, Fishco, & Hanna, 1993).

Proactive Interference Release Task. A proactive interference task was used to evaluate the participant's resistance to proactive interference. The release task was acquired from a public access script for E-Prime 2.0 software (MacWhinney, 2002). For each trial, the participant was presented with 3 TBR words, followed by 5 greater or less than math equations (e.g., 45 < 98). Participants then had to identify whether the equation was true or false by pressing the corresponding key (i.e., true = "T", false = "F") on the keyboard. After responding to the true/false problems, participants were then asked to recall the TBR words.

The TBR words for each trial were presented in groups of 3, with each word presented on successive but separate screens. TBR words in a given set were semantically related (e.g., tree, plant, and flower). The semantic category of the three words then switched to a new semantic category set after a predetermined number of trials. As participants progress through trials of a semantic category (e.g., fruits, vegetables), proactive interference builds due to new words being semantically similar to previous words. Participants were released then from the proactive interference when the TBR items switch semantic categories. For example, proactive interference would dissipate when participants switched from recalling types of tools to recalling colors, as all the previous words they had seen belonged to the same semantic category of “tools.” The proactive interference task was originally used by Wickens (1970, 1972, 1973). This particular task is similar to the task described by Wickens (1973). The task has been used within the literature several times following its introduction (e.g., Hasher, Chung, May, & Foong, 2002)

Stop-Signal Task. The stop-signal task is a computer task designed to assess inhibition control. The stop-signal task used in the present study was the STOP-IT task (Verbruggen & Logan, 2008). This stop-signal task measures motor inhibitory control. For the task, the participant completed a series of four trials (the first being practice) in which they had to press “z” on the keyboard when a white square flashed on a black background. When a white circle appeared on the black background, the participant pressed “/” on the keyboard. The keyboard presses served as a response to the stimuli. The pressing of the key in response to the square/circles served as the automatic response. However, the participant had to inhibit the key pressing response when the square/circle was presented with an audible beep.

Participants were given 1,250 msec to respond to each stimulus. As per standard procedures, there were 25% “stop” trials and 75% “non-stop” trials (Verbruggen & Logan, 2008). The task took approximately 15 minutes to complete. The participant performed the task four times, with the first time serving as practice. Stop signal reaction response time (SRRTs) was the variable used in the analyses. A SSRT for each participant was calculated by a complementary program ANYALZE IT, (Verbruggen &

Logan, 2008). A SSRT for each participant was determined by subtracting the mean stop-signal delay from the time it took to press the key (Verbruggen & Logan, 2008).

Metacognitive Awareness Inventory. Participants completed a self-assessment called the Metacognitive Inventory Awareness (MIA; Shraw & Dennison, 1994). The MIA is a 54 question assessment which assesses metacognition through two broad subcomponents of metacognition: knowledge of cognition and regulation of cognition. These components are further broken down into to 8 subcomponents (i.e., procedural knowledge, declarative knowledge, conditional knowledge, information management strategies, debugging strategies, planning, comprehension monitoring, and evaluation). The assessment enabled each one of these subcomponents to be scored; however, for the present study the focus was on the overall metacognitive awareness score. The MIA has psychometrically sound properties with items having strong intercorrelation (r = .54), and it has also been shown to be reliable across the factors of regulation and knowledge (α = .90; Schraw & Dennison, 1994). For a full description of the MIA and it psychometric properties, see Schraw and Dennison (1994).

Procedure

Participants completed the proactive interference release task first. The proactive interference release task was performed first in order to control for the transfer of strategy effects on the OSPAN in the rehearsal-strategy group. Transfer could occur by participants using a strategy (i.e., rehearsal) that was successful on the PI task and applying it to the OSPAN. Therefore, the proactive interference task was followed by the OSPAN.

Participants were assigned to one of two groups: strategy and no strategy groups. Participants in the no-strategy group performed the OSPAN as instructed with no additional instructions. The strategy group was given instructions on how to use a rehearsal strategy in conjunction with the span task. The rehearsal strategy instructions used in the present research were taken from Turley-Ames and Whitfield (2003) and read as follows:

> “When you are presented with a to-be remembered word, we would like you to rehearse that word aloud as many times as you can before going on to the next math operation. As additional words are added to a set, please rehearse aloud, not only the new word, but also other words presented previously in that set. In other words, each time you are presented with a new to-be-remembered word rehearse that word aloud and any previous to-be remembered words in that set as many times as you can (p. 451).”

Upon completion of the OSPAN task, participants completed three counterbalanced tasks (e.g., stop-signal, Nelson-Denny, and demographics). The Nelson-Denny reading comprehension test was administered as per the standardized procedures and took 35 minutes to complete. The stop-signal task took approximately 15 minutes to complete. The demographics questionnaire asked participants for age, grade, ethnicity, and whether they had any conditions that may affect performance on the task (see Appendix C). Lastly, participants completed the MIA (see Appendix D). The MIA was administered last in order to control for the possibility of priming participants to think differently during the task. For example, the MAI asks if participants critically evaluate what they have previously read. This question could potentially prompt participants to think more critically about their reading of passages on the Nelson-Denny than they would normally. Finally, participants were thanked for their time and debriefed.

Data Analysis

A correlation matrix was compiled in order to assess all possible correlations. This allowed for proper evaluation of the strength of the relationships between working memory, the cognitive mechanisms of interest, as well as the relationship between potential mechanisms of change. These relationships are important because they allow for the mediators to be evaluated and ensure that the mediators of interest are orthogonal constructs.

A moderated mediational analysis was performed with the PROCESS macro in SPSS. The PROCESS macro assessed whether each meditation model is moderated by strategy use. First, each cognitive mechanism was tested for mediation of the relationship between working memory span and reading comprehension. A mediation analysis determines whether the cognitive mechanisms of interest (i.e., resistance to proactive interference, inhibitory control, and metacognition) are responsible for the relationship between working memory span and reading comprehension scores. In other words, does a change in working memory span cause a change in the mechanism, which, in turn, produces a change in reading comprehension? The mediation model consists of three relationships referred to as pathways. The “a” pathway represents the relationship between working memory span and the mechanism of interest. The “b” pathway represents the relationship between the mechanism of interest and reading comprehension, while the “c’ ” pathway represents the relationship between working memory span and reading comprehension while controlling for mediation. The “c’ ” pathway is known as the direct pathway. Therefore, the goal of a mediation analysis is to determine whether the indirect pathways (i.e., “a” and “b”) are responsible for the direct (i.e., c’) pathway.

In order to assess a moderated mediation model, moderation by strategy use was tested for in the context of the mediation model. The moderation analysis determined whether the strength of the pathways in the mediation model was influenced by the presence of strategy during the working memory task. Specifically, does strategy use during the working memory task increase the strength of the pathways in the mediation model? Thus, a moderation analysis tested the effect that strategy has on each pathway in the mediation model, creating three moderated mediation models.

The first model tested whether proactive interference resistance mediated the relationship between working memory and reading comprehension, and whether strategy use moderated one or more of the pathways (see Figure 1). The second model tested whether inhibitory control mediates the relationship between working memory and reading comprehension, and whether one or more of the pathways are moderated by strategy use (sees Figure 2). The third model tested whether metacognition mediates the relationship between working memory and reading comprehension, and whether strategy use moderated any of the pathways (sees Figure 3).

The rational for testing all three pathways of the mediation for moderation is that there is currently no specific prediction with regards to where the moderation will take place. However, previous research (e.g., Turley-Ames & Whitfield, 2003) has supported the existence of strategy moderating the relationship between working memory span and reading comprehension (see Figure 4).

PROCESS calculated the model in two steps in order to test the hypotheses as described in the moderated mediation model. Each model was treated as independent of the other models in order to ensure the mediators did not correlate with each other (see Table 3). In the first model, working memory and strategy use predicted on to the mediator. The first step equation was as follows:

Predicted Mechanism= $\mathbf{B_{01}+B_{wms1}+B_{stategy}+B_{wms.strategy}}$. After the first step was tested the second step was tested to whether there was mediated moderation upon the b and c pathways of the model. The second step equation was as follows:

Predicted Reading Comprehension= $\mathbf{B_{02}+B_{wms2}+B_{mech}+B_{strategy}+ B_{mech.strategy} + B_{wms.startegy}}$.

PROCESS reported whether the mediation for each mechanism (i.e., resistance to proactive interference, inhibitory control, and metacognition) was significant. The macro produced a model summary listing the beta coefficients of the constant, working memory span, the cognitive mechanism (i.e., resistance to proactive interference, inhibitory control, and metacognition), reading comprehension, and the interaction term of each with the mediator. After the mediation output was evaluated, PROCESS displayed the indirect effects of strategy use on the pathways of the mediation model with bootstrapped confidence intervals. It showed the effect of strategy use on the direct pathway with bootstrapped confidence intervals. PROCESS utilized bootstrapping in order to test whether the product of a*b was significant for the mediation model. Bootstrapping is a resampling method of determining confidence intervals and testing the significance of a*b without assuming normal distribution of the sample. Bootstrapping yields greater power for significance testing than traditional methods such as the Sobel test (Hayes, 2013).

Results

Statistical Software

All statistical analyses were performed in SPSS version 22.0. PROCESS model 59 was used to test moderated mediation, while process model 7 was used to test the data for mediation. All tables and figures are included at the end of the document. In order to aid interpretation of the tables, the computational diagram of model 59 from Hayes (2013) has been included in Appendix B.

Participant Data

Participants in the strategy condition (N = 120) and no strategy conditions (N = 116) were each composed of statistically similar demographics (see Table 2). Participants in the strategy condition (*M* = 47.77, *SD* = 5.96) recalled more words on average than the no strategy condition (*M* = 43.43, *SD* = 7.24); *t* (234) = 5.03, p <. 001. The other dependent variables of inhibitory control, resistance to PI, metacognition, and reading comprehension did not significantly differ by condition (see Table 3). Table 4 shows the differences between span groups by condition. Span groups did not differ in mediator values despite significant differences in span score.

The demographic variables of education, gender, and ethnicity were examined in terms of their relationship to working memory span and Nelson Denny total. Educational level predicted working memory (*B* = 1.21, SE = .43, *p* = .01) and reading comprehension (*B* = 5.225, *SE* = 1.15, *p* < .001) scores. Tukey Post hoc analysis revealed that seniors (N= 20, *M* = 47.40, *SE* = 1.32) outperformed freshman (N= 101, *M* = 42.47, SE = .77) on the OSPAN. In additional, seniors (N= 20, *M* = 131, *SE* = 2.05) significantly outperformed freshman (N= 101, *M* = 111.90, *SE*= 2.01) and sophomores (N= 65, *M* = 116.94, *SE*= 2.66, $p > .05$) on the Nelson Denny. Since education regressed both on the OSPAN and the Nelson Denny, a Sobel test was performed to test for effects of mediation. The test was positive for mediation of the relationship between working memory span and reading comprehension by education level.

Gender did not significantly predict to working memory capacity (*B* = .217, *SE* = 1.01, $p = .83$) nor Nelson Denny scores (*B* = -.657, *SE* = 2.83, $p = .82$). Further, ethnicity predicted to Nelson Denny score (*B* = -9.936, *SE* = 3.96, $p = .01$) but not working memory capacity (*B* = -1.46, *SE* = 1.45, $p = .32$). It is important to note that in the present study only 29 participants identified as non-white, across all of the conditions, so power was restricted and limited the ability to make firm conclusions about the effects of race on the relationship between working memory and reading comprehension.

While ethnicity and gender were both found to correlate with either working memory and/or reading comprehension, including them in the moderated mediation models as covariates did not change the outcome of the models. Further, these covariates did not change the effect of strategy on the relationship between working memory and reading comprehension.

Correlations

Bivariate correlations were conducted between reading comprehension and all independent variables in order to evaluate the relationships between these variables (see Table 1). There was a significant correlation between working memory span and reading comprehension score ($r = .37$). The correlation was significant when groups were separated by strategy (*r* = .38) and no strategy (r =.40). The significance levels of these correlations replicate previous findings (e.g., Daneman & Carpenter, 1980). However, the strategy group did not yield a statistically stronger correlation between working memory span and reading comprehension when compared to the control group (see Table 1).

Further, SSRT was significantly correlated to reading comprehension (*r* = .39) and working memory (*r* = -.25). When broken down by strategy condition, the correlation between SSRT and reading comprehension was non-significant (*r* = -.15) for the strategy condition but was significant (*r* = -.27) for the no-strategy condition.

Proactive Interference Release

The PI release task was designed to increase PI as participants advanced further into the task. Therefore, it was expected that the number of correctly recalled items would decrease as the number of trials increased within a semantic category. Once the sematic category was switched, participants were expected to experience a release from PI, and the number of words recalled would increase until PI built up again due to repeated trials in the same semantic category.

There is evidence to suggest that the task did not produce a sufficient amount of proactive interference to yield significant differences in number of words recalled as trials increased within a semantic category. The number of words recalled on each trial within a semantic category were compared using a within subjects ANOVA. The results from the ANOVA indicate that there was a significant difference between words recalled on each trial within a semantic category (see Table 5 for ANOVA results). However, the average number of words recalled did not always decrease in each successive trial (see Figure 5). Thus, while the change in number of words recalled across trials in a semantic category was significant, the effect size was not sufficient to produce a noticeable difference in word recall performance, nor was the direction of change consistent with that of proactive interference (see Figure 5).

There is evidence that PI build up occurred across trials as well. Participants displayed an increase in the number of words recalled when participants switched to a new semantic category. Switching semantic categories released participants from the build-up of PI on previous trials (Wickens, 1972). The category switch occurred after every fourth trial (Trials: 5, 9, 13, and 17). Paired sample t-tests were performed between the number of words recalled on the last trial of a semantic category and the number of words recalled on the first trial of the next semantic category. All t-test results were significant ($p < .001$) except for the first release trial ($p = .236$). See Table 6 for results.

In addition to using number of words recalled, reaction time was used to further investigate the efficacy of the task. The difference in reaction time between the response time on the last trial and the response time on the first trial of a new semantic category was calculated. This calculation represents processing time under PI and no PI. Prior studies have demonstrated that as PI increases, the time spent trying to recall information increases as well (Jonides & De Nee, 2006). It, therefore, stands to reason that participants would behave accordingly with a decrease in time spent recalling words when released from PI. However, participants did <u>not</u> experience a decrease in response time for every point of PI release (see Table 7). Due to the inconsistency in the reaction time data, an index based on the number of words recalled was used as the variable of interest to test resistance to PI in the moderated mediation model.

In order to properly apply the results of the PI release task to a mediation model, a novel index of resistance to PI was created. This index was created by calculating the change in performance after release. Change in performance was operationalized as the number of words recalled on the first trial after release subtracted from the number of words recalled on the last trial before release. This calculation yielded the number of words recovered by the participant after being released from PI. An overall change in performance score was then calculated for each participant by averaging the four change in performance scores (see Table 8). This overall change in performance scored served as the release from PI index. Thus, the resistance to PI index represented the average number of additional words the participant was able to recall after being released from PI. Consequently, a large index indicated poor performance while under PI and a stronger performance when PI was absent. Similarly, a lower PI release index would indicate greater resistance to PI as performance on recall did not change as a result of PI build up.

Data from 236 participants was analyzed for moderated mediation of working memory and reading comprehension as a result of PI and strategy use (see Table 9 for group scores by condition). The overall model of working memory predicting to Nelson-Denny total score was significant; F (5, 230) = 10.35, p <. 001, R^2= .18. Working memory span regressed onto average PI release was non-significant; b = -.02, SE = .01, p = .09, 95% CI [-.05, .004]. Average PI release was also not predicative of total Nelson-Denny score; b = -5.2, SE = 8.62, p = .54, 95% CI [-22.18, 11.78]. The effect of working memory span on reading ability was non-significant as well; b = .85, SE = .59, p = .15, 95% CI [-.32, 2.01]. The total variance accounted for by the model was 18.4%. A bootstrap estimation of 10,000 samples was used to test direct and indirect effects in the model. There was no evidence of mediation of the relationship between working memory and reading comprehension by resistance to proactive interference.

The index of moderated mediation failed to achieve a difference in equality between the strategy and no strategy group; *B* = -.06 *SE* = .07, 95% CI [-.25, .05]. The index of moderated mediation is a numerical representation (which can be compared to zero) of the interaction between indirect effects of the moderator and the mediator. A significant confidence interval from the index of moderated mediation would indicate an interaction between the effects of mediation and the moderator, meaning moderation would be present. Thus, it was concluded that the relationship between working memory and reading comprehension was not moderated by strategy use on the OSPAN in the present study. Strategy use also failed to moderate the pathways related to resistance to proactive interference in the complete model. See Table 9 for summary of results.

Inhibitory Control

Data from 236 participants was analyzed for moderated mediation of inhibitory control. In order to account for multicollinearity, total scores on OSPAN (*M* = 43.83, *SD* = 7.27) and SSRTs (*M* = 289.01, *SD* = 66.7) were mean centered. The overall model of working memory predicting to Nelson-Denny total score was significant; F (5, 230) = 10.63, $p < .001$, R^2=.19. Working memory span regressed onto inhibitory control was non-significant; *b* = -.03, *SE* = .02, *p* =.14, 95% CI [-.07, .01]. Inhibitory control was also not predicative of total Nelson-Denny total score; *b* = 1.19, *SE* = 5.81, *p* = .83, 95% CI [-10.26, .12.65]. Furthermore, the effect of working memory span on reading ability was non-significant; *b* = .97, *SE* = .6, *p* = .11, 95% CI [-.21, 2.15]. The total variance accounted by the model was 19%. A bootstrap estimation of 10,000 samples was used to determine confidence intervals. The index of moderated mediation failed to achieve a difference in equality between the strategy and no strategy group; *B* = .07 *SE* = .11, 95% CI [-.12, .31]. Therefore, the relationship between working memory and reading comprehension was not mediated by inhibitory control nor moderated by strategy use on the OSPAN. See Table 10 for summary of results.

Metacognition

Data from 225 (11 were removed due to failure to complete the full questionnaire) participants was analyzed for whether moderated mediation occurred with metacognition and strategy. Metacognition (*M* = 193.5, *SD* = 20.04) scores were derived from the sum of all answers per standardized procedures (Schraw & Dennison, 1994). Similar to the previous models, the overall model of working memory on Nelson-Denny total score was significant; F (5, 219) = 11.75, $p < .001$, $R^2 = .21$. Working memory did not predict to metacognitive awareness; *b* = .02, *SE* = .06, *p* = .75, 95% CI [-.11, .15]. Metacognitive awareness did not significantly regress upon Nelson-Denny total score; *b* = 1.44, *SE* = 1.91, *p* = .45, 95% CI [-2.31, 5.2]. The total variance accounted for by the model was 21%. A 10,000 sample bootstrap estimation was used to test indirect effects. The index of moderated mediation was non-significant for the model; *B* = -.01 *SE* = .07, 95% CI [-.15, .14]. Metacognition did not mediate the relationship between working memory and reading ability, and strategy did not moderate any of the pathways in the hypothesized mediation model. See Table 11 for a summary of results.

The MAI is made up of 8 subscales, which assess specific components of metacognition (i.e., declarative knowledge, procedural knowledge, conditional knowledge, information management strategies, planning, comprehension monitoring, debugging strategies, and evaluation; Schraw & Dennison, 1994). Since the previous model of mediated moderation failed to achieve significance, strategy was dropped as a possible moderator when analyzing the subcomponents. The subscales were examined as possible mediators of the relationship between working memory and reading comprehension as a means of assessing the metacognitive explanation in more depth. The subcomponent of declarative knowledge (N = 234, *M* = 30.8, *SD* = 3.78) was the only component which significantly mediated the relationship between working memory and reading ability (see Figure 7). The total effect of the model was significant; F (2, 231) = 36.02, $p < .001$, $R^2 = .24$. No other significant effects were observed ($p > .05$).

Additional Analyses

The significant correlations between SSSRT, working memory capacity, and Nelson Denny (see Table 1) indicated that inhibitory control may mediate the relationship between working memory and reading comprehension. When the strategy interactions were removed from the model, there was a significant mediation of the relationship between working memory and reading comprehension by inhibitory control (see Figure 8). Resistance to PI and metacognition were also run for simple mediation without the strategy interactions. Resistance to PI did not predict to working memory capacity (*B* = -1.96 *SE* = 1.06, *p* = .07) but did significantly regress on to reading comprehension (*B* = -6.28 *SE* = 2.93 *p* = .03). Despite a significant “b” pathway, mediation was not present (Sobel = 1.40, SE = 8.81, *p* = .16). Metacognition did not regress onto working memory capacity (*B* = .02 *SE* = .02, *p* = .55), but it did regresses significantly onto reading comprehension (*B* = .15 *SE* = .07, *p* = .03). However, metacognition also failed to significantly mediate the pathway between working memory and reading comprehension (Sobel = .91, SE = .003, p = .36).

Discussion

The present experiment investigated whether specific cognitive processes mediated the relationship between working memory and reading comprehension. Furthermore, we sought to investigate whether the use of a rehearsal strategy during OSPAN performance would enhance the correlation between working memory and reading comprehension. None of these hypotheses were supported by the present experiment. Resistance to proactive interference, inhibitory control, and general metacognition did not mediate the relationship between working memory and reading comprehension. Strategy use on the OSPAN failed to yield a stronger correlation between working memory and reading comprehension. While the proposed model of moderated-mediation was not supported, mediation was found among a sub-component of metacognition. More specifically, declarative knowledge mediated the relationship between working memory and reading comprehension. The following discussion will address these findings in detail followed by a discussion of future research and limitations of the present study.

Critical Findings

Resistance to Proactive Interference. Resistance to proactive interference did not mediate the relationship between working memory and reading comprehension. This finding is counter to previous studies (e.g., Kane & Engle, 2000) which have suggested that the mechanism driving individual differences in working memory is one’s ability to resist the buildup of interference (see Engle, 2000 for review). However, as previously stated, the PI task failed to elicit a significant amount of proactive interference. PI was detected in the task, but it was not at a sufficient level to impact performance on the task. Therefore, PI build-up within each semantic category was not able to capture potentially meaningful individual differences. All participants, regardless of working memory span, were able to manage the PI successfully that they experienced during the task.

Inhibitory Control. Inhibitory control was also not found to be a significant mediator of the relationship between working memory and reading comprehension, despite previous findings suggesting that greater inhibitory ability is linked with greater working memory abilities (e.g., Friedman & Miyake, 2004). Significant correlations were observed between SSRT, working memory, and reading comprehension, suggesting that a relationship between these cognitive processes exists. The present experiment, thus, indicates that the observed relationships between these three variables are not explained by mediation as proposed.

If mediation is not responsible for the relationship between inhibitory control, working memory, and reading comprehension, then the mechanism driving the relationship is still up for debate. Recent work in cognitive neuroscience has suggested indirectly that a third cognitive process may be responsible for the relationship between working memory and inhibitory control. Traditionally, inhibitory control and working memory have been thought to share neural networks in the frontal cortex (Aron, Robbins, & Poldrack, 2004). However, more recent research suggests that the neural networks responsible for inhibitory control may be diffused throughout the frontal cortex (Aron, 2007; Aron & Poldrack, 2006; Rubia et al., 2001). Areas associated with inhibitory control include the right inferior frontal cortex (Rubia, Smith, Brammer, & Taylor, 2003), left frontoparietal regions (Rubia et al., 2001), and the left frontal gyrus (Jonides, Smith, Marshuetz, Koeppe, & Reuter-Lorenz, 1998). These additional areas of activation could indicate that other cognitive processes may be active, processes such as verbal working memory (Jonides et al., 1998), attention orienting, and/or task monitoring (Aron, Robbins, & Poldrack, 2004).

The STOP-IT task (Verbruggen & Logan, 2008) used in the present study was treated as a prototypical inhibitory control task. Yet, researchers have recently questioned whether all inhibitory control tasks activate the same brain regions (Mostofsky et al., 2003; Simmonds, Pekar, & Mostofsky, 2008). The areas of activation within the right inferior cortex have been known to change depending on the type of inhibitory task being used (Aron, Robbins, & Poldrack, 2004). For example, inhibition tasks, such as the Stroop task, elicit diffuse activation across the left prefrontal cortex (Adleman et al., 2002), while go/no-go tasks typically elicit more localized responses in the left interior frontal lobe (Rubia et al., 2001). Furthermore, Rubin and colleagues (2001) found different areas of activation for go/no-go tasks and stop-it tasks. Go/no-go tasks were found to elicit activation in the left frontal lobe areas, while stop-it tasks were associated with activation in the right hemisphere of the brain.

Since areas of activation appear to change depending on the inhibitory control task, researchers have questioned whether working memory is active at the same level for all inhibitory control tasks. The task used in the present experiment is considered to be a simple stop-it task because participants hold only one set of actions (i.e., don’t press button upon hearing sound) within memory as they perform the task (Rubin et al., 2001). Simple stop tasks, such as this one, utilize highly localized areas within the supplementary motor area, whereas more complex go/no-go tasks, which require participants to remember several instructions at once, recruit neural networks from the dorsal lateral prefrontal cortex, a brain region crucial to working memory (Mostofsky et al., 2003; Simmonds et al., 2008). In conclusion, while the STOP-IT task used in the present experiment assessed inhibitory control, it may not have elicited activation in brain areas associated with working memory, possibly explaining the lack of mediation.

Metacognition. As reported, the total MAI score did not yield mediation of the relationship between working memory and reading comprehension. The overall metacognition awareness score failed to mediate, because only one subscale was a significant mediator. Since metacognitive awareness is represented by a composite of eight subscales (i.e., declarative knowledge, procedural knowledge, conditional knowledge, information management strategies, planning, comprehension monitoring, debugging strategies, and evaluation; Schraw & Dennison, 1994), non-significant subscales also contributed to the overall score and not just the one significant subscale.

Another possible reason for metacognitive awareness failing to mediate may be due to a task domain effect. The MAI task used in the present study may have been subject to a task domain effect. All of the other tasks used in this project were time-constrained, forcing participants to respond quickly to each test item. The MAI was untimed and allowed participants to select carefully their responses to each item. When participants are not under a time constraint, it is possible that they do not rely as much on working memory for processing (Baddely, 1992). In this case, participants may have relied upon long term memory to answer the questions by recalling multiple pieces of information from memory to help answer the question. Therefore, the untimed nature of the MAI may not have tapped working memory in the same way as time-dependent tasks do, further obscuring the relationship between working memory and metacognition.

Yet, the subcomponent of declarative knowledge was a mediator of the relationship between working memory and reading comprehension. Declarative knowledge is the factual information an individual knows about specific events or objects (Schraw, 1998), in this case about variables that effect memory. While studying the effect of declarative knowledge on memory, Schraw (1998) concluded that; "…good learners appear to have to have more knowledge about different aspects of memory such as capacity limitations, rehearsal, and distributed learning (Garner, 1987; Schneider & Pressley, 1989)." Thus, greater declarative knowledge may reflect an individual's use of strategy on memory tasks.

The knowledge one possess about his or her own memory may be essential to the relationship between working memory and reading comprehension. Since reading comprehension tasks demand working memory resources (Just & Carpenter, 1992), individuals with greater awareness of their memory system's strengths and weaknesses may be better equipped to handle the demands of a task. For example, an individual with low declarative knowledge may not know that rehearsing items are an effective way to keep information active in working memory. Thus, when demands are placed upon working memory, low span individuals may not use the correct strategy to alleviate the elevated demand on working memory. Conversely, high span individuals may approach the task with strategies that are more effective in maximizing working memory performance.

Strategy. Strategy did not moderate the pathways in the proposed mediation model as predicted. Although this may seem contrary to Turley-Ames and Whitfield (2003), there are factors which complicate a straightforward comparison of the two studies. First, Turley-Ames and Whitfield (2003) used a seven second time limit for completion of the word-problem, whereas the present study used an eight second time limit. An eight second time limit was utilized in order to help participants complete the math portion on each trial and increase participant inclusion rates in the study.

While one second may seem inconsequential, the difference in findings between the two studies suggests that the one second difference could be a source of variation. For example, previous research has indicated that high spans view the math problem and word for equal durations on each trial of the OSPAN, and low spans spend more time viewing the math problem when not instructed to use strategy (Turley-Ames, Thompson, & Parker, in prep.). Thus, when given more time, low spans in a no strategy condition may distribute their viewing times of the math problem and word differently, thus enhancing the performance of low spans in the no-strategy condition. Future research will be needed to examine the impact of strategy on the relationship between working memory, reading comprehension, and viewing time.

Future Research

The present study highlighted the need for at least three areas of future research. Future research should begin to evaluate the role of metacognition by using more analytical methods, such as those discussed in the introduction. Methods such as feeling-of knowing and confidence judgements would produce metacognitive data less dependent on self-reported ratings of self-knowledge. Using these methods, metacognition is determined by comparing a metacognitive judgement to an individual's observed score on an item (Dunlosky & Metcalfe, 2009). For example, in the present study, we could have asked participants to rate how confident they were in their answer after they responded to each question on the Nelson-Denny. The confidence ratings would then be compared to the participant's actual scores to assess whether participants were accurately gauging their own abilities.

Future research may also benefit from including a strategy questionnaire after completion of the OSPAN. Similar to Dunlosky and Kane (2007), participants would report their use of strategy upon completion of each math–word operation on the OSPAN. Having participants report what strategies they used would serve as a manipulation check, and it would allow for researchers to investigate whether participants are consciously using strategies to improve their performance on the OSPAN. By tracking strategy use, researchers can begin to evaluate whether strategies are a driving factor behind individual differences in working memory.

Future studies also need to investigate the relationship between working memory and reading comprehension, particularly the impact of declarative knowledge on the relationship. Educational research has demonstrated previously that metacognitive training is beneficial to enhancing both working memory performance and academic performance (Cain, Oakhill, & Bryant, 2004). Thus, in keeping with the findings of the present study, future research could focus on declarative knowledge training as it relates to working memory and reading comprehension. For example, a future study could train declarative knowledge by teaching participants' strategy use and how to apply it to tasks which rely on working memory. Participants could then be re-evaluated for far transfer by using working memory tasks different from the ones they were trained on. Since working memory training has been challenged by some researchers (Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2012), students may benefit from training that focuses on particular strategies or techniques that aid in remembering factual knowledge as opposed to strategies solely focused on improving working memory performance on a task such as the OSPAN. If increasing declarative knowledge improves working memory and reading comprehension, then a new avenue for teaching working memory could be explored.

Limitations

There are at least four limitations to the present study. One of the limitations was the tasks used to collect data. In order to reduce the total time of a session and potential for cognitive fatigue, a PI release task of short duration was used (Wickens, 1972). While successful in demonstrating the effect of PI on semantic categories (as per its original design), the PI release task was unable to induce a significant amount of proactive interference in a majority of participants. This made it difficult to assess whether PI mediates the relationship between working memory and reading comprehension.

Another limitation was the use of a self-report survey to assess metacognition. As such, participants were asked to accurately report their own abilities on the measurement. But, it could be a subject of debate as to whether an individual of low metacognitive awareness can accurately report their own mental awareness. Thus, the validity of MAI scores could be questioned for individuals of low metacognitive awareness.

As previously discussed, changes made to the timing of the OSPAN represent a significant limitation to the replication component of the study. An eight second trial interval was used to compensate for participants struggling to complete the math problem on each trial. However, by providing eight seconds on each OSPAN trial, the viewing behavior of low spans may have changed enough to artificially enhance their performance on the OSPAN. Thus, comparisons to Turley-Ames and Whitfield (2003) on the effect of OSPAN strategy on Nelson-Denny scores are difficult to assess.

Lastly, a carry-over effect may have occurred unexpectedly. All participants received the PI release task before completion of the OSPAN. The PI task was intentionally given before the OSPAN to prevent participants in the strategy condition from applying the rehearsal strategy to the PI task. However, the PI release task may have inadvertently served as a “mental warm up” for participants before completing the OSPAN. While not identical to the OSPAN, the PI release task was similar (i.e., maintaining items in memory while completing a distractor task) that could have served as a form of practice for participants. This practice then may have artificially enhanced score. For example, participants may have had a chance to test strategies (i.e., rehearsal) out during the PI task. If the rehearsal strategy worked on the PI release task, then participants may have applied this rehearsal strategy to the OSPAN. While we controlled for strategy use in the rehearsal condition, the no-strategy condition only ensured participants were not utilizing an observable strategy on the OSPAN. It is, therefore, theoretically possible that participants in the no-strategy condition utilized an unobservable (i.e., sub-vocal) rehearsal strategy on the OSPAN.

Summary

The aims of the present study were to investigate whether three cognitive mechanisms--resistance to proactive interference, inhibitory control, and metacognition--

mediated the relationship between working memory and reading comprehension. Furthermore, it was hypothesized that the use of a rehearsal strategy on the operation-span task would moderate the pathways of the various mediation models. Mediation of the relationship between working memory and reading comprehension was not supported in the present experiment, nor did strategy use moderate the pathways of the proposed mediation models. However, declarative knowledge mediated the relationship between working memory and reading comprehension. The implications of the present study suggest that more research is needed in determining how certain mechanisms, such as inhibitory control, overlap and influence working memory performance. The results also suggest that future training in strategy utilization may be a way to enhance working memory performance.

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Table 1

Correlations by Condition

		Correlations								
Condition	**Variable**	**OSPAN Word**	**OSPAN Math**	**OSPAN Total**	**SSRT**	**Word PI**	**Time PI**	**MAI**	**Vocabulary**	**Reading**
Combined (N=236)	**OSPAN Math**	.206**								
	OSPAN Total	.905**	.538**							
	SSRT	-.169**	-.257**	-.254**						
	Word PI	-.092	-.132*	-.120	.103					
	Time PI	.034	-.029	.037	-.018	.118				
	MAI	.044	-.023	.040	.048	.015	-.047			
	Vocabulary	.321**	.252**	.342**	-.183**	-.141*	.039	.130		
	Reading	.338**	.184**	.348**	-.216**	-.120	-.007	.169*	.687**	
	ND Total	.367**	.245**	.386**	-.212**	-.139*	.024	.148*	.910**	.897**
Strategy (N=120)	**OSPAN Math**	.332**								
	OSPAN Total	.926**	.579**							
	SSRT	-.177	-.231*	-.249**						
	Word PI	-.140	-.204*	-.174	.226*					
	Time PI	-.044	-.031	-.040	.006	.057				
	MAI	.036	.048	.059	.123	-.001	-.055			
	Vocabulary	.319**	.167	.299**	-.129	-.191*	.057	.138		
	Reading	.339**	.132	.317**	-.167	-.129	-.031	.146	.697**	
	ND Total	.379**	.189*	.360**	-.154	-.172	.014	.156	.897**	.912**
No Strategy (N=116)	**OSPAN Math**	.128								
	OSPAN Total	.871**	.550**							

SSRT	-.154	-.282**	-.260**							
Word PI	-.001	-.075	-.021	-.037						
Time PI	.170	-.045	.172	-.082	.346**					
MAI	.085	-.075	.061	-.037	.021	-.033				
Vocabulary	.373**	.313**	.434**	-.238*	-.104	.017	.123			
Reading	.371**	.228*	.414**	-.268**	-.110	.054	.194*		.682**	
ND Total	.403**	.290**	.461**	-.273**	-.111	.061	.141		.922**	.883**

Correlation is significant at the 0.01 level (2-tailed).

Correlation is significant at the 0.05 level (2-tailed).

SSRT=Stop-signal reaction time

PI word= Average number of increase in words recalled after release from PI

PI word= Average change in reaction time following release from PI

Table 2
Demographics

	Condition	
Demographic	**Strategy (N=120)**	**No Strategy (N=116)**
Age	21.7 (4.98)	22.69 (6.35)
Freshman	46.20%	39.70%
Sophomore	26.60%	28.40%
Junior	16%	19.80%
Senior	7.60%	9.50%
Other Grade	3.40%	2.60%
Female	67.20%	65.80%
Male	32.80%	34.20%
White	85.80%	89.70%
Hispanic/Latino	7.50%	2.60%
Native American	3.30%	1.70%
Native Hawaiian/Pacific Islander	0.80%	0
Middle Eastern/Arabic	0	0.90%
Other Ethnicity	2.50%	5.20%

Average age is listed with standard deviation in parentheses
Percent is derived from the total number of respondents to each question
No Significant differences between groups $p > .05$

Table 3

Average Scores by OSPAN Condition

	Condition		
Variable	**Strategy (N=120)**	**No Strategy (N=116)**	**Total (N=236)**
OSPAN Word	47.77* (5.96)	43.43* (7.24)	45.64 (6.96)
OSPAN Math	56.53 (3.42)	56.3 (4.57)	56.42 (4.02)
OSPAN Total	46.18* (6.32)	41.33 (7.47)	43.80 (7.31)
SSRT	286.07 (67.68)	292.05 (65.82)	289.01 (66.70)
Word PI	.22 (.45)	.31 (.44)	.26 (.45)
Time PI	2194.74 (7045.42)	1671.74 (2699.46)	1937.67 (5363.81)
MAI	192.57 (20.17)	194.51 (19.95)	193.52 (20.04)
Vocabulary	60.07 (10.19)	60.78 (11.48)	60.42 (10.83)
Reading	28.23 (5.53)	28.1 (5.50)	28.21 (5.50)
ND Total	116.50 (19.7)	117.08 (20.78)	116.78 (20.20)

* significantly different $p < .001$

SSRT=Stop-signal reaction time

PI word= Average number of increase in words recalled after release from PI

PI word= Average change in reaction time following release from PI

Standard deviations in parentheses

Table 4

Average scores by Working Memory Span Group and OSPAN Condition

	Condition					
	Strategy (N=120)			No Strategy (N=116)		
Variable	**Low (N=42)**	**Medium (N=40)**	**High (N=39)**	**Low (N=39)**	**Medium (N=38)**	**High (N=39)**
OSPAN Word	41.98 (4.98)*	48.45 (2.28)*	53.45 (3.1)*	36.51 (6.55)*	43.42 (2.5)*	50.35 (3.38)*
OSPAN Math	54.19 (4.0)*	57.15 (2.52)	58.47 (1.66)	53.31 (6.08)*	57.34 (2.52)	58.28 (2.44)
OSPAN Total	39.19 (4.16)*	47.18 (1.32)*	52.87(2.27)*	33.10 (4.56)*	41.66 (2.18)*	49.22(3.15)*
SSRT	304.69 (77.42)	280.43 (64.59)	271.43 (55.16)	307.6 (67.34)	288.31 (57.86)	280.15 (70.06)
Word PI	0.29 (.51)	0.19 (.42)	0.16 (.39)	0.35 (.43)	0.19 (.44)	0.37 (.45)
Time PI	2508.88 (3998.26)	2790.33 (11467.22)	1220.58 (1362.67)	1482.63 (1835.21)	1071.43 (2202.95)	2445.76 (3598.3)
MAI^	192.37 (21.98)	190.11 (20.94)	195.39 (17.2)	194.26 (20.81)	193.14 (21.95)	196.14 (17.13)
Vocabulary	56.95 (9.57)**	59.86 (10.04	63.71 (10.08)	54.33 (11.4)**	62.47 (11.69)	65.59 (8.17)
Reading	26.79 (5.48)**	27.68 (5.16)	30.42 (5.42)	25.85 (5.69)**	28.79 (4.99)	29.92 (5.08)
ND Total	109.86 (20.25)**	115.88 (17.3)	124.5 (19.04)	106.08 (20.66)**	119.37 (20.67)	125.85 (15.99)

* Tukey post-hoc indicates significantly different from all spans; p < .001

** Tukey post-hoc indicates significantly different from high spans; p < .05

^ N (Strategy)= 41 for low, N=38 for medium, and N=36 for high due to incomplete questionnaire

^ N (Strategy)= 38 for low, N=36 for medium, and N=36 for high due to incomplete questionnaire

SSRT=Stop-signal reaction time

PI word= Average number of increase in words recalled after release from PI

PI word= Average change in reaction time following release from PI

Standard deviations in parentheses

Table 5

Results of Within Subjects ANOVA or the four Recall Trials With Each Category

Semantic Category	**Mean Square**	**F**	**df**	**p-value**	**eta^2**
1 (Fruit)	3.74	9.57	3.00	<.001	.04
2 (Tool)	13.02	27.00	3.00	<.001	.10
3 (Color)	2.12	.54	3.00	.10	.01
4 (Vegetable)	1.96	8.50	3.00	<.001	.40
5 (Tree)	2.12	7.49	3.00	<.001	.80

Table 6

Paired sample T-test Results Between Last Trial of a Semantic Category and the First Trial of the Following Category

Release From Set	M	SD	t	df	p-value	effect size
1 (Fruit-Tool)	-.07	.80	-1.38	235.00	.17	.14*
2 (Tools-Color)	-.63	1.15	-8.41	235.00	<.001	.07
3 (Color-Vegetable)	-.16	.63	-3.90	235.00	<.001	.25**
4 (Vegetable-Tree)	-.18	.72	-3.90	235.00	<.001	.26**

*p < .05

**p < .001

Note. Effect size is represented by Pearson correlation

Table 7

Average Change in Number of Words Recalled and Time to Respond Upon Release from a Set

	Condition					
	Strategy (N=120)		**No Strategy (N=116)**		**Total (N=236)**	
Release From Set	**Words**	**Time (ms)**	**Words**	**Time (ms)**	**Words**	**Time (ms)**
1	0.017	6460.19	0.13	4643.03	0.07	5567.01
2	0.5	4066	0.77	3928.66	0.63	3998.49
3	0.27	-4171.17	0.05	-4574.85	0.16	-4369.59
4	0.09	2423.92	0.28	2690.14	0.18	2554.77
Total Avg.	0.22	2194.74	0.31	1671.74	0.26	1937.67

Note. Negative number indicates an increase in response time

Table 8

Regression Coefficients with Standard Errors for the Model of Moderated Mediation with Words Recovered after PI Release as the Mediator. Theoretical Pathways are Included.

Variable		**Outcome**		
		PI Word Release		**ND Score**
Constant		1.21 (.64)**		71.42 (27.45)
WM	$\alpha_1 \rightarrow$	-.02 (.01)	$c_1' \rightarrow$	.85 (.59)
Strategy	$\alpha_2 \rightarrow$	-.43 (.38)	$c_2' \rightarrow$	-2.81 (16.12)
PI Word Release			$b \rightarrow$	-5.12 (8.62)
WM x Strategy	$\alpha_3 \rightarrow$	.01 (.01)	$c_3' \rightarrow$	-.191 (.376)
PI Word Release x Strategy			$b_2' \rightarrow$	.24 (5.46)
	R	0.16		0.43
		Index	**95% bootstrap CI***	
Moderated Mediation		-0.06	-.23 to .05	

*10,000 bootstrap sample used to determine CI

**p < .05

Standard errors in parentheses

Table format taken from Hayes (2016)

Table 9

Regression Coefficients with Standard Errors for the Model of Moderated Mediation with Inhibitory Control as the Mediator. Theoretical Pathways are Included.

Variable		**Outcome**		
		SSRT		**ND Score**
Constant		2.98 (.14)*		104.23 (17.39)*
WM	$\alpha_1 \rightarrow$	-.03 (.02)	$c_1' \rightarrow$	.97 (.6)
Strategy	$\alpha_2 \rightarrow$	-.06 (.09)	$c_2' \rightarrow$	15.44 (11.09)
SSRT			$b \rightarrow$	1.19 (5.81)
WM x Strategy	$\alpha_3 \rightarrow$	-.004 (.01)	$c_3' \rightarrow$	-3.19 (3.73)
SSRT x Strategy			$b_2' \rightarrow$	-.09 (.36)
	R	.26*		0.43
		Index	**95% bootstrap CI***	
Moderated Mediation		0.07	-.13 to .31	

*10,000 bootstrap sample used to determine CI

**p < .05

Standard errors in parentheses

Table format taken from Hayes (2016)

Table 10

Regression Coefficients with Standard Errors for the Model of Moderated Mediation with Inhibitory Control as the Mediator. Theoretical Pathways are Included.

Variable		**Outcome**		
		MAI		**ND Score**
Constant		18.83 (.45)		80.82 (36.94)
WM	$\alpha_1 \rightarrow$	.02 (.06)	$c_1' \rightarrow$	.86 (.59)
Strategy	$\alpha_2 \rightarrow$	.28 (.2846)	$c_2' \rightarrow$	8.17 (23.71)
MAI			$b \rightarrow$	1.44 (1.91)
WM x Strategy	$\alpha_3 \rightarrow$	-.002(.4)	$c_3' \rightarrow$	-.27 (.36)
MAI x Strategy			$b_2' \rightarrow$	-.14 (1.22)
	R	0.08		.46*
		Index	**95% bootstrap CI***	
Moderated Mediation		-0.005	-.15 to .13	

*10,000 bootstrap sample used to determine CI

**p < .05

Standard errors in parentheses

Table format taken from Hayes (2016)

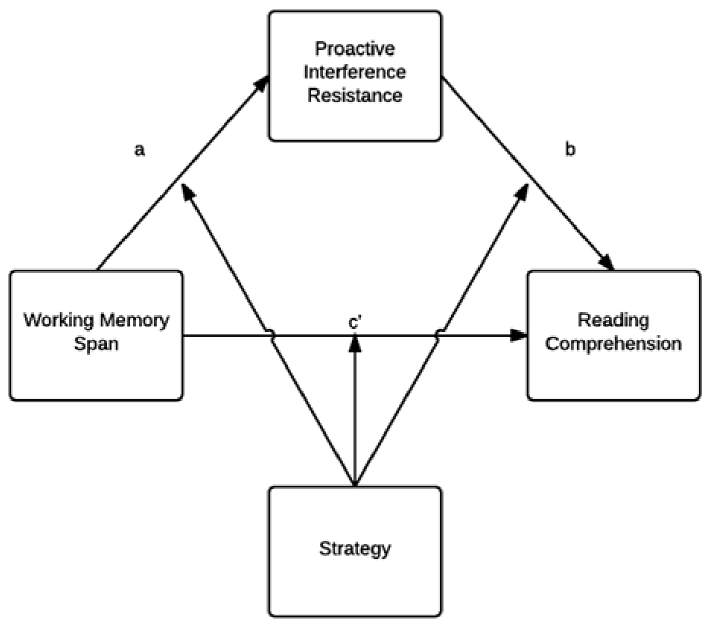


Figure 1. The Predicted Model for Proactive Interference Resistance Mediating the Relationship Between Working Memory and Reading Comprehension. The Model tested for Moderation by Strategy.

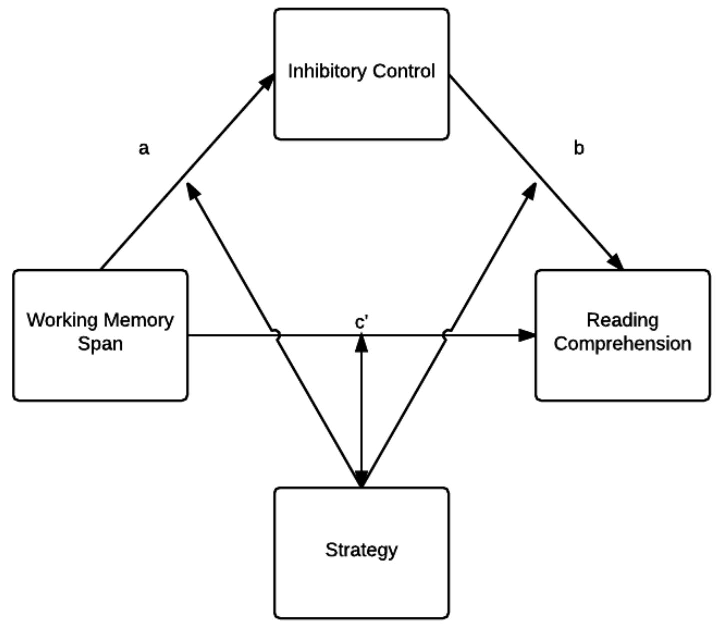


Figure 2. The Predicted Model for Inhibitory Control Mediating the Relationship Between Working Memory and Reading Comprehension. The Model tested for Moderation by Strategy.

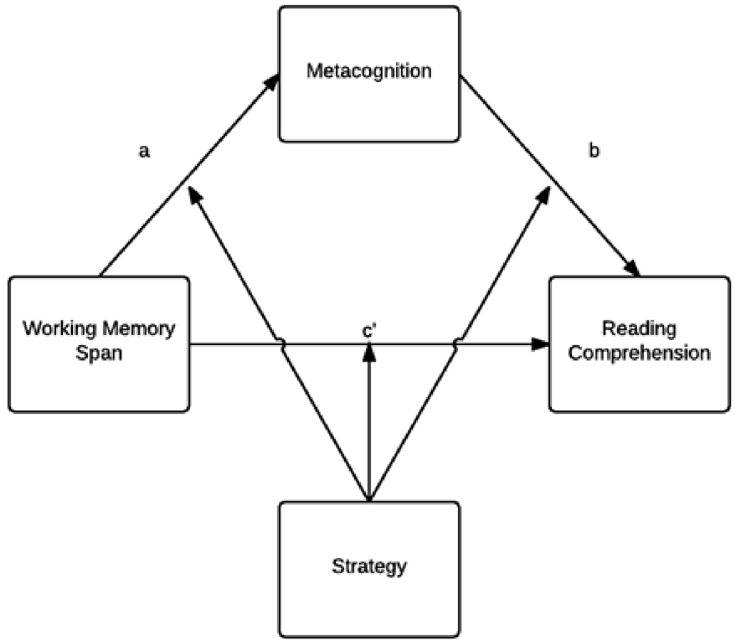


Figure 3. The Predicted Model for Metacognition Mediating the Relationship Between Working Memory and Reading Comprehension. The Model tested for Moderation by Strategy.

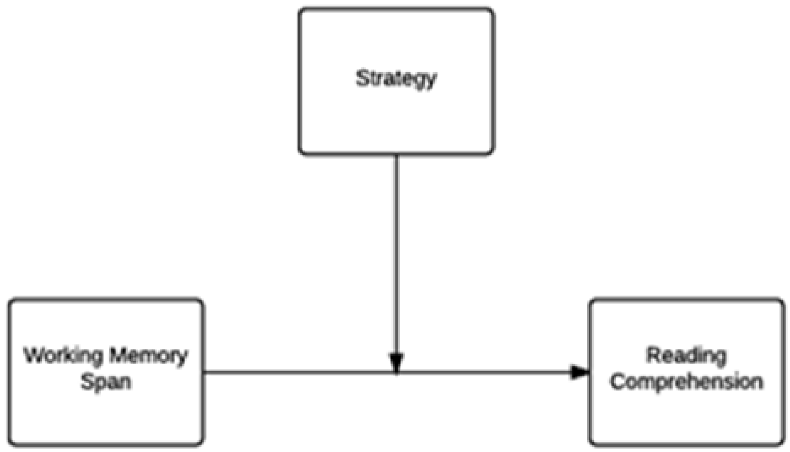


Figure 4. The Proposed Moderated Effect of Working Memory Span and Reading Comprehension by Strategy.

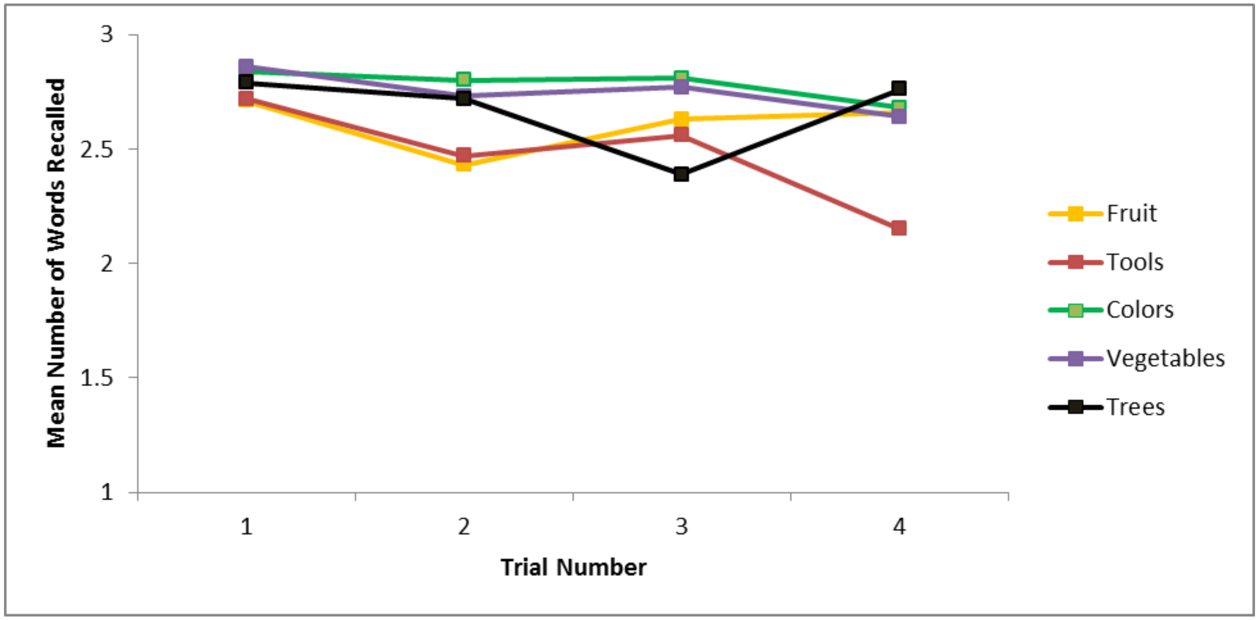


Figure 5. Average Number of Words Recalled per Trial for each Semantic Category in the PI Release Task. Participants were released on Trial 1 of a New Semantic Category.

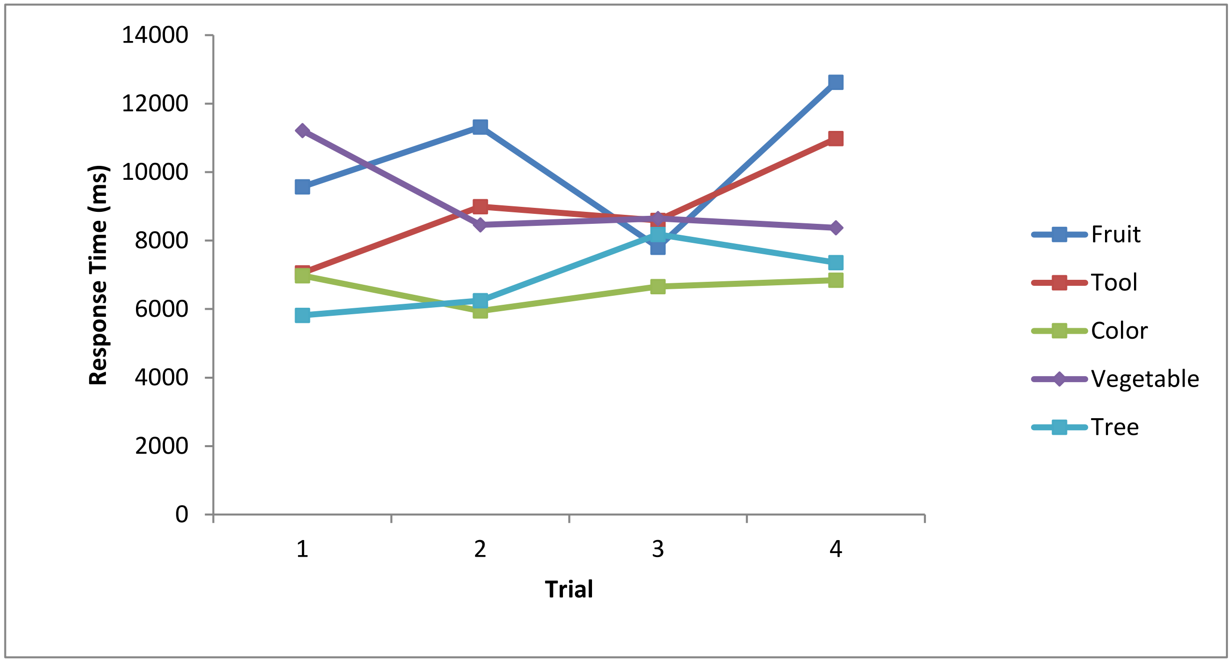


Figure 6. Average Response Time per Trial for each Semantic Category in the PI Release Task. Participants were Released on Trial 1 of a New Semantic Category.

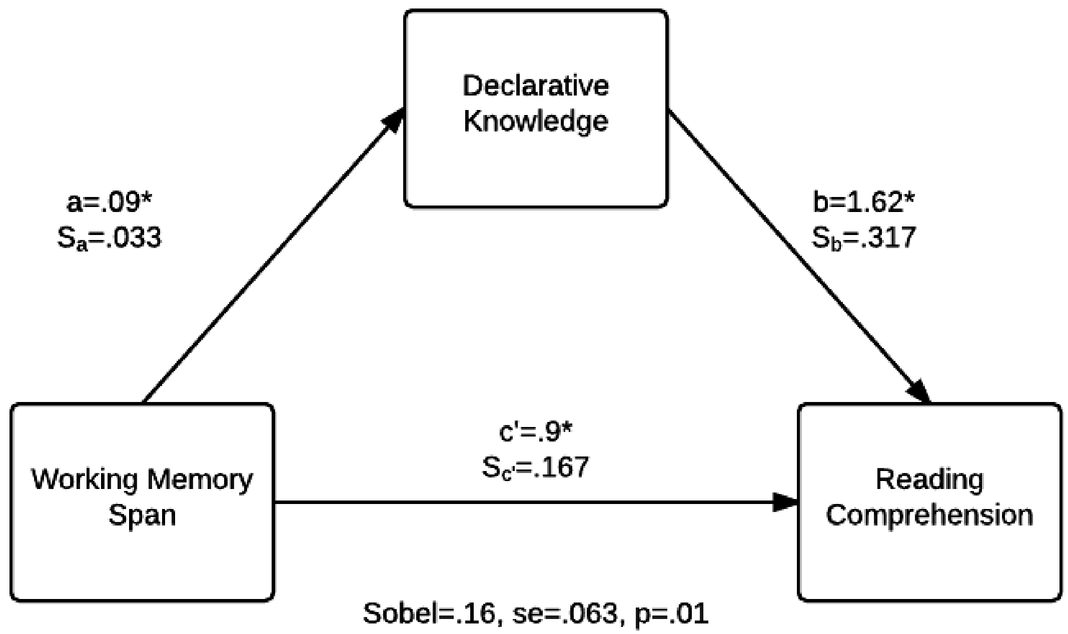


Figure 7. Mediation of Declarative Knowledge. *p < .05

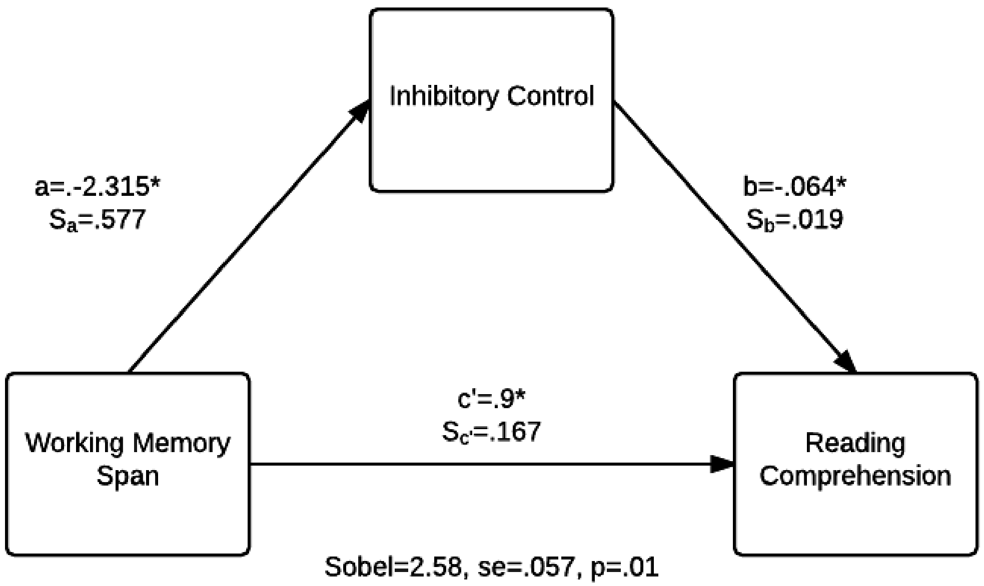
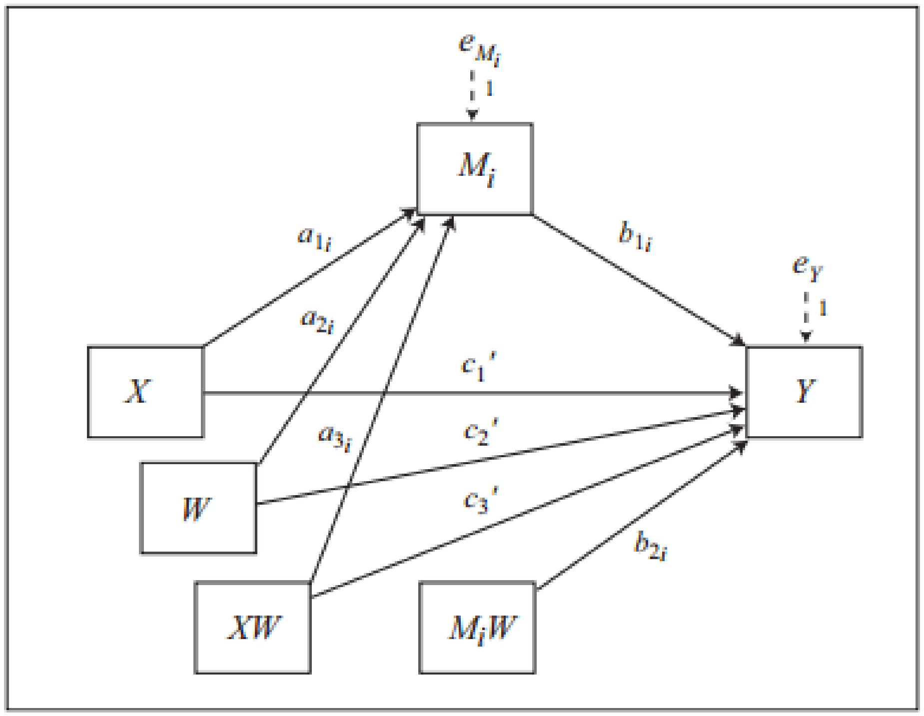


Figure 8. Mediation by Inhibitory Control. **p* > .05

Appendix A

Statistical Diagram



Conditional indirect effect of X on Y through $M_i = (a_{1i} + a_{3i}W)\,(b_{1i} + b_{2i}W)$

Conditional direct effect of X on $Y = c_1' + c_3'W$

Diagram from Hayes (2013)

Appendix B

Demographics Questionnaire

Participant #:________________________

Today's Date:____/____/____

1. Age:______ 2. Gender: Male / Female

3. Education (circle one)
    a. Freshman
a. Sophomore
b. Junior
c. Senior
d. Other: ________________

4. Race (Circle all that apply)
    a- Black b. White c. Hispanic/Latino

    d- Asian American e- Native American/Alaskan Native

    f- Other : _______ g – Native Hawaiian or Pacific Islander

    h- Middle Eastern/Arabic k – unknown/decline to respond

5. Have you ever been diagnosed with a psychological condition, such as depression or an anxiety disorder? (Please circle one)
    Yes No

If yes, please list:____

6. Have you ever been diagnosed with a learning disability?
(Please circle one)
    Yes No

If yes, please list:____

7. Is English your native language? (Please circle one)
    Yes No

If no, what is your native language? __________________________

8. Do you have any memory difficulties? (Please circle one)
    Yes No

If yes, please explain: ____

APPENDIX C

	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1. I ask myself periodically if I am meeting my goals.					
2. I consider several alternatives to a problem before I answer.					
3. I try to use strategies that have worked in the past.					
4. I pace myself while learning in order to have enough time.					
5. I understand my intellectual strengths and weaknesses.					
6. I think about what I really need to learn before I begin a task					
7. I know how well I did once I finish a test.					
8. I set specific goals before I begin a task.					
9. I slow down when I encounter important information.					
10. I know what kind of information is most important to learn.					
11. I ask myself if I have considered all options when solving a problem.					
12. I am good at organizing information.					
13. I consciously focus my attention on important information.					
14. I have a specific purpose for each strategy I use.					
15. I learn best when I know something about the topic.					
16. I know what the teacher expects me to learn.					
17. I am good at remembering information.					

18. I use different learning strategies depending on the situation.					
19. I ask myself if there was an easier way to do things after I finish a task.					
20. I have control over how well I learn.					
21. I periodically review to help me understand important relationships.					
22. I ask myself questions about the material before I begin.					
23. I think of several ways to solve a problem and choose the best one.					
24. I summarize what I've learned after I finish.					
	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
25. I ask others for help when I don't understand something.					
26. I can motivate myself to learn when I need to					
27. I am aware of what strategies I use when I study.					
28. I find myself analyzing the usefulness of strategies while I study.					
29. I use my intellectual strengths to compensate for my weaknesses.					
30. I focus on the meaning and significance of new information.					
31. I create my own examples to make information more meaningful.					
32. I am a good judge of how well I understand something.					
33. I find myself using helpful learning strategies automatically.					
34. I find myself pausing regularly to check my comprehension.					

35. I know when each strategy I use will be most effective.					
36. I ask myself how well I accomplish my goals once I'm finished.					
37. I draw pictures or diagrams to help me understand while learning.					
38. I ask myself if I have considered all options after I solve a problem.					
39. I try to translate new information into my own words.					
40. I change strategies when I fail to understand.					
41. I use the organizational structure of the text to help me learn.					
42. I read instructions carefully before I begin a task.					
43. I ask myself if what I'm reading is related to what I already know.					
44. I reevaluate my assumptions when I get confused.					
45. I organize my time to best accomplish my goals.					
46. I learn more when I am interested in the topic.					
47. I try to break studying down into smaller steps.					
48. I focus on overall meaning rather than specifics.					
49. I ask myself questions about how well I am doing while I am learning something new.					
	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
50. I ask myself if I learned as much as I could have once I finish a task.					

51. I stop and go back over new information that is not clear.					
52. I stop and reread when I get confused.					