8-2021

Inducing Proactive Control with High Load AX-CPT

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INDUCING PROACTIVE CONTROL WITH HIGH LOAD AX-CPT

A Thesis

Presented to the

Faculty of

California State University,

San Bernardino

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

in

Psychological Science

by

Mina S. Selim

August 2021

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ABSTRACT

A central hypothesis of cognitive control is that goal maintenance operates via two distinct modes: proactive control and reactive control (Braver, Gray, & Burgess, 2007). Individuals that tend to use proactive control will focus on actively maintaining goal-relevant information in memory, whereas individuals that utilize reactive control will store goal-relevant information and then retrieve it later when contextual cues reactive it. This theoretical framework for understanding the sources of variation in cognitive control is termed the dual mechanisms of control (DMC). When compared to high working memory capacity (WMC) individuals, low WMC individuals tend to utilize reactive control more often. However, some factors influence an individuals' bias towards one type of control over another. The purpose of the present study is to examine how different strategies are utilized by low vs. high WMC individuals under different task situations. Specifically, whether a shift in cognitive control will occur in low and high WMC individuals when the task favors one strategy method over another. A new version of the AX continuous performance task (AX-CPT) (termed the AX-CPT-color) was created where letter stimuli are presented in either the color red or green. Two rulesets are given with the AX-CPT-color, one ruleset without color match requirements and one ruleset with color match requirement. A switch from reactive to proactive control was observed when the color ruleset was being utilized. This switch occurred in both low and high WMC individuals in a mixed design study and was characterized by faster RTs and

fewer errors on AX and BX trials, but slower RTs and greater errors on AY trials in relation to the no rule condition. These findings could potentially assist in early intervention programs and aid in identifying individuals with deficits in order to provide them adequate resources to help improve in performance.

ACKNOWLEDGMENTS

I would like to thank Jason F. Reimer for his guidance and patience throughout this project. I would also like to thank Eugene Wong and Donna Garcia for their feedback and for helping me grow as a researcher.

TABLE OF CONTENTS

ABSTRACT iii

ACKNOWLEDGEMENTS v

LIST OF TABLES viii

LIST OF FIGURES ix

CHAPTER ONE: COGNITIVE CONTROL 1

Working Memory Capacity 1

Context Processing 2

Neurobiology of Cognitive Control 3

CHAPTER TWO: DUAL MECHANISMS OF CONTROL 5

AX Continuous Performance Task 5

Reactive Versus Proactive Control 7

CHAPTER THREE: MEASURING WORKING MEMORY CAPACITY 13

Complex-Span Tasks 13

CHAPTER FOUR: INDUCING REACTIVE AND PROACTIVE CONTROL 16

CHAPTER FIVE: SUMMARY AND HYPOTHESIS 18

CHAPTER SIX: METHODS 23

Subjects 23

Design 23

Apparatus 24

Operation Span 26

Reading Span 27

Symmetry Span.. 27
AX Continuous Performance Task with Color 29
Procedure 31
CHAPTER SEVEN: RESULTS.. 34
Effect of Working Memory Capacity, Rule Condition, and Color........ 36
AX Trials 37
AY Trials 38
BX Trials 39
CHAPTER EIGHT: DISCUSSION 50
Limitations.. 58
Conclusion 61
APPENDIX A. INFORMED CONCENT 63
APPENDIX B. INSTITUTIONAL REVIEW BOARD APPROVAL 66
REFERENCES 69

LIST OF TABLES

Table 1. Response Times and Error Rates 41

Table 2. Composite Scores 42

LIST OF FIGURES

Figure 1. Session One No Color Rule 43

Figure 2. Session Two Proactive Behavioral Index 44

Figure 3. Response Times for AX Matching Trials 45

Figure 4. Error Rates for AX Matching Trials 46

Figure 5. Error Rates for AX Mismatch Trials 47

Figure 6. AY Mismatch versus Matching Trials 48

Figure 7. BX Mismatch versus Matching Trials 49

CHAPTER ONE:

COGNITIVE CONTROL

Working Memory Capacity

Working memory (WM) has been studied extensively due to its relationship with a wide variety of skills that translate to real world tasks (Williams, Cohen, & Conway, 2008), as well as, its links to other cognitive processes that rely on WM to function (Gathercole, Alloway, Willis, & Adams, 2006). It has been described as the part of human cognition that gives us the ability to use limited amounts of information in order to solve complex cognitive tasks (Baddeley, 1992). Over the years, a great deal of research on WM has focused on its direct relationship with cognitive control. This is because in order to function, cognitive control relies on a number of WM components; such as, selecting and maintaining relevant information, protecting that information from inappropriate sources of interference, and updating it in accordance to goal relevant tasks (Braver, Gray, & Burgess, 2007). Although all of these mechanisms of WM are well defined in cognitive control, they substantially vary across tasks and across individuals. A trend in WM research is to place individuals in groups of low vs. high working memory capacity (WMC) and have them complete a task that measures modes of control. A recurring finding in the literature is that low and high WMC individuals bias towards different modes of control (e.g., reactive vs. proactive control) (Redick, 2014; Richmond et al., 2015). However, it is unclear how the parameters of the task itself affect the use of strategy methods during the use of complex cognitive tasks. The purpose of the present study is to examine how different strategies are utilized by low vs. high WMC individuals under different task situations. Specifically, whether a shift in cognitive control will occur when the task favors one strategy method over another.

Context Processing

During a goal-oriented task, context becomes essential to for knowing what information to focus attention on in that task. Context can be described as task-relevant information that is internally represented in a way that can bias performance (Norman & Shallice, 1986). Information that becomes internally represented as “context” is encoded, maintained, and later retrieved from working and long-term memory. These context representations greatly influence how attention is allocated by directing it towards goal relevant information while also inhibiting task-irrelevant information. This can influence behavior to adopt strategy methods in order to complete the task efficiently (Badre, 2008; Kouneiher, Charron, & Koechlin, 2009; Miller, 1956; Posner & Snyder, 1975; Solomon et al., 2009). Cognitive control is the overarching process that directs attention towards goal-driven decisions (Posner & Snyder, 1975). Attention towards task-relevant context is required to activate the cognitive processes needed to implement cognitive control (Norman & Shallice, 1986).

Neurobiology of Cognitive Control

By examining lesion and neuroimaging studies in humans it can be seen that the prefrontal cortex (PFC) becomes active during tasks that require cognitive control (Stuss & Knight, 2013). Braver and Cohen (1999) also proposed a dopamine (DA) neurotransmitter gating system that modulates goal-oriented behavior in the PFC. The interaction between the PFC and the DA system is responsible for the selection, updating, and maintenance of context during goal-orientated tasks. During the delay period of tasks that require active maintenance of context the PFC exhibits sustained, stimulus-specific activation. Neurophysiological evidence also suggests that DA alters how certain excitatory and inhibitory neurons react in the PFC (Chiodo & Berger, 1986; Penit-Soria, Audinat, & Crepel, 1987). The DA system plays an important role in learning by implementing a system of rewards and punishments; where reward outcomes are either greater or lesser than anticipated, allowing for the system to bias behavior towards task-relevant information (context). This DA gating system can be tested using a delayed-response task such as the AX Continuous Performance Task (AX-CPT) (Cohen & Servan-Schreiber, 1992). The AX-CPT requires participants to respond to a specific cue-prob paring (AX trials) and requires a non-target response for all other trial types. During this task, DA can be seen as a gating mechanism to keep information in active memory in the PFC in response to reward prediction errors. With DA activity acting as a gating mechanism for task-relevant information in the PFC it provides a means for behavior to bias towards context.

Cognitive and biological changes that occur during healthy aging has been hypothesized to lead to declines in context processing (Braver et al., 2001). Older adults display deficits in multiple cognitive domains such as episodic memory, working memory, inhibition, and attentional control. These deficits emerge from disturbances in the PFC and the DA system during healthy aging. Older adults typically show deficits on neuropsychological test that are sensitive to PFC damage (Moscovitch & Winocur, 1995; Perfect, 1997; West, 1996). Brain imaging studies show that gray matter declines earliest in the PFC during healthy aging (Haug & Eggers, 1991; Salat, Kaye, & Janowsky, 1999). Age related declines in neurotransmitter functions also show a pronounced reduction of DA in the PFC (Goldman-Rakic & Brown, 1981). This reduction in DA is associated with a decrease in cognitive performance. For example, increasing DA system functions in monkeys with a pharmacological agent has been found to improve working memory (Arnsten, 1993; Arnsten, Cai, Murphy, & Goldman-Rakic, 1994; Arnsten, Cai, Steere, & Goldman-Rakic, 1995). In humans, it is believed that the specific role of DA is to control thought and behavior. Patients with PFC lesions show impairments on tasks such as the Stoop Task, Wisconsin Card Sorting Task (WCST), and the Self-Order Pointing Test (SOPT) (Hecaen & Albert, 1978; Struss & Benson, 1986).

CHAPTER TWO:

DUAL MECHANISMS OF CONTROL

AX Continuous Performance Task

The AX-CPT has been frequently used to measure attention and inhibition in cognitive control. It is a delayed response task that requires the maintenance and updating of task-relevant information. On each trial of the AX-CPT, participants are shown two letters, one at a time, and asked to look for a specific cue-probe pairing that indicates the target response. A target response is provided anytime the letter ‘A’ is followed by the letter ‘X’ (e.g., AX trial types). All other combinations require a non-target response. When an ‘X’ probe is proceeded by a non- ‘A’ cue it warrants a non-target response (e.g., BX trial types indicating a non-A-X stimulus sequence). Similarly, when an ‘A’ cue is followed by a non- ‘X’ probe this also warrants a non-target response (AY trial types indicating an A-non-X stimulus sequence). Lastly, there are also trials where neither ‘A’ nor ‘X’ stimuli are presented and these trials warrant a non-target response (BY trial types indicating a non-A, non-X stimulus sequence). The key feature of this task design is that context is only provided by the cue to determine whether or not a target response is appropriate for a probe. Thus, the AX-CPT is able to capture an individual’s ability to process contextual cues and utilize those cues to bias behavior to upcoming stimuli (Braver et al., 2001).

The traditional AX-CPT, termed AX-CPT 70, presents target trials (AX trials) at a high frequency rate (e.g., 70%). This is done to create an association between the target cue (letter A) and the target response, as well as, an association between the target probe (letter X) and a target response. This association leads to interference during AY trials since contextual cues create a bias for the target response that needs to be overcome. Participants begin to develop an increased target expectancy to any probe that follows an ‘A’ cue. This creates a situation where more attention is required during the presentation of the probe to inhibit the increased target expectancy bias during AY trial types. During BX trials, participants can also develop a prepotent target response tendency when presented with an X probe. Attention needs to be allocated to keeping the identity of the cue in memory in order to inhibit target response tendencies. BY trials simply serve as a control condition for the task.
Important information about the integrity of cognitive control in healthy young adults can be determined by comparing the performance on AY and BX trials (Braver et al., 2001). Proactive control is identified by an individual’s increased ability to efficiently use cue information to bias behavior. This is characterized by a behavioral signature in which performance is slower and less accurate on AY than BX trails. A pattern like this emerges when focus is allocated more to representing and maintaining cue related information. During AY trials, recall that contextual cues create a bias for the target response that needs to be overcome. Therefore, an increased ability to efficiently use a valid cue (A) leads to an

expectancy bias towards the target response with greater false alarms and slower response times in AY trails relative to BX trails. During BX trails, the ability to identify and maintain the cue as invalid inhibits the prepotent target response tendency when presented with an X probe. This leads to better performance on BX trails with fewer false alarms and faster response times relative to AY trails. In order to capture these individual differences in behavior the following formula: PBI = (AY-BX)/(AY+BX) is used to create a Proactive Behavioral Index (PBI) score based on RTs/ERs. An individual's use of proactive control is indicated by a higher PBI score.

Reactive Versus Proactive Control

A central hypothesis of cognitive control is that goal maintenance operates via two distinct modes: proactive control and reactive control (Braver, Gray, & Burgess, 2007). This theoretical framework for understanding the sources of variation in cognitive control is termed the dual mechanisms of control (DMC). The DMC represents and maintains context relevant information in order to bias attention, memory, and behavior towards specific strategy methods (Norman & Shallice, 1986). A real-world example of each type of control can be observed anytime a goal is set to be completed at a later point in time, such as stopping by the store after work. A proactive mode of control would require goal relevant information to be actively sustained from the moment the intention is formed until it is completed (e.g., periodically reminding oneself of what to pick up at the store). The benefit of this strategy method is that behavior can be adjusted at any time to optimally complete the goal (e.g., leaving work early before the store closes, or taking a shorter route). This mode of control relies on anticipating and preventing potential interference before it occurs. In contrast, goal relevant information in a reactive mode of control would only be transiently activated at the moment the intention is created. After that initial intention, goal relevant information needs to be reactivated by an appropriate contextual cue (e.g., passing the store on the way home from work). Since there is a need for repeated reactivation, there is greater dependence on the trigger event. This mode reflects a “late correction mechanisms” where information is only activated after the occurrence of a high interference event. It relies upon detecting interference but only seeks to resolve the issue after its onset.

In the AX-CPT, a proactive mode of control leads to a higher focus and maintenance of the cue rather than the probe. Individuals that use this mode of control will prepare their response prior to the presentation of the probe by keeping the cue active in conscious awareness. This strategy leads to faster response times and fewer errors in “AX” and “BX” trials; but slower response times and greater errors in “AY” trials. This pattern of behavior emerges because when presented with a B cue, individuals are able to prepare a non-target response and increase their likelihood of making a correct non-target response. When presented with an A cue they develop an increased target expectancy that the following probe will be an X. When the probe is an X, they are already prepared and increase the likelihood of making a correct target response. However, since there is a strong expectancy bias that the probe following an A cue will be an X, there is also an increased likelihood for an incorrect target response in AY trial types. AY trial types are the only trials that are able measure one's ability to successfully inhibit the increased target expectancy bias towards AX trials.

A reactive approach leads to the exact opposite pattern of performance. This strategy leads to slower response times and greater errors in "AX" and "BX" trials; but faster response times and fewer errors in "AY" trials. This mode of control utilizes a wait-and-see approach where the cue is stored in memory but not actively maintained. The cue is reactivated in memory based on information received from the probe. Under this mode of control, there is no expectancy bias for AX trial types. A response can be made for AY trials without the need of reactivating the cue back into working memory. However, when presented with a X probe there is a need to reactive the cue in order to make an appropriate response. As the task progresses, multiple probe trials types are stored in memory and create interference when reactivating the cue. Thus, AX and BX trials are susceptible to greater errors because more attention is required to reactivating the correct cue.

These behaviors become more apparent when using a modified version of the AX-CPT, where "AX" trials are decreased by 30% and "BY" trials are increased by 30% in order to amplify the pattern of performance for each mode of control (Richmond, Redick, & Braver, 2015). This manipulation addresses two issues with the traditional AX-CPT 70. The first being that “B” cues occur less frequently than “A” cues, and so subjects can begin to differentially process cues based on frequency rate and not as the expected response to the subsequent probe (Chiew & Braver, 2013). With this manipulation, not only are the frequency rates of “A” and “B” cues presented equally throughout the entirety of the task (50/50 vs the traditional 80/20), but it also equates the cue validity of a specific probe. That is, “A” cues predict an “X” probe on 80% of the trials that have an “A” cue, and “B” cues predict a “Y” probe on 80% of the trials that have a “B” cue. The second issue that this manipulation addresses in the traditional AX-CPT 70 is that since AX trials are given so much more than BX trials there is a strong likelihood that an X probe was a target response. Individuals could make a target response to every X probe and still display a high level of overall accuracy. This manipulation equates the chances of seeing each type of probe throughout the entirety of the task so that X and Y probes are both shown 50% of the time. This places a greater emphasis on using cue information to make a response. Just like the traditional AX-CPT 70, this version does not favor either proactive or reactive control strategies. It only seeks to reduce potential sources of variation. Any biases towards one strategy method over another is due to individual preferences and not the nature of task.

Successful cognition is dependent upon some mixture of both proactive and reactive strategies. However, some factors influence an individuals’ bias towards one type of control over another. Healthy young adults generally exhibit a proactive control strategy method in the AX-CPT (Braver, Cohen & Barch, 2002; Paxton, Barch, Storandt & Braver, 2006). Individuals with reduced executive functions, like children (Chatham, Frank & Munakata, 2009; Lorsbach & Reimer, 2008), older adults (Braver et al., 2001; Paxton et al., 2006), or people with schizophrenia (Barch, Carter, MacDonald, Braver & Cohen, 2003; Dias, Butler, Hoptman & Javitt, 2011) exhibit a reactive control strategy. WMC has been found to be the strongest predictor of performance on attention capturing tasks (Richmond, Redick, & Braver, 2015). Even within healthy young adults, differences in WMC can lead to differences in the use of proactive and reactive control strategies. When compared to high WMC individuals, low WMC individuals tend to forget more items during a directed forgetting task (Delaney & Sahakyan, 2007), are more likely to miss hearing their name in a dichotic listing task (Conway, Cowan, & Bunting, 2001), exhibit smaller facilitation effects in the Stroop task (Kane & Engle, 2003), and perform worse on a surprise memory tests of neutral words from a previously completed Stoop task (Shipstead & Broadway, 2013). This suggests that the mechanisms used for proactive control are better developed in high WMC individuals. In contrast, low WMC individuals with memory impairments, like individuals with schizophrenia, perform in a manner that is consistent with the costs and benefits of reactive control. This may be due to the increased demand that proactive control puts on cognitive resources. Low WMC individuals may not have a system in place that is equipped to handle the cognitive load of proactive control.

CHAPTER THREE:

MEASURING WORKING MEMORY CAPACITY

Complex-Span Tasks

Complex-span tasks are the most reliable method of measuring WMC since they draw on both primary and secondary memory (Wilhelm, Hildebrandt, & Oberauer 2013). These tasks require individuals to recall a list of items in their serial position but presents them with a distractor task before the recall window. In complex-span tasks, a focus on controlled search in secondary memory is crucial for performance as soon as primary memory reaches its capacity limit. Primary memory can only store 3-5 units of information before reaching its capacity limit, but part of that capacity is being used for the distractor task. Over the course of each trial, more and more information will have to be displaced to secondary memory as the list lengths get longer. Retrieval from secondary memory is cue-dependent and is largely affected by proactive interference, encoding deficits, and output interference.

WMC is among the most important executive functions that cognitive control depends on during cognitive tasks. Working memory is made up of two storage systems, primary memory and secondary memory. These two systems work together simultaneously and make up the total working memory capacity (Shipstead, Lindsey, Marshall, & Engle, 2014). During an average task, both systems are constantly taking in context-relevant information, storing that information, and retrieving it when necessary. Primary memory, commonly known as short-term memory (STM), is a type of limited mental storage that maintains context-relevant information in the mind (Conwan, 2001; Luck & Vogel, 2013). Information stored in primary memory is easily accessible and aids WMC by holding that information active for immediate use during complex cognitive tasks. Some information is displaced to secondary memory as “to-be-remembered” items when the limited space of primary memory is reached. Information will eventually require retrieval from secondary memory storage based on context relevant cues (Unsworth & Engle, 2007). Cognitive control relies on the information stored in WMC, as well as, other important executive functions like attentional control, inhibition, task shifting, and working memory updating (Miyake et al., 2000).

Comparing groups with low and high complex-span scores in tasks like the Stroop task (Kane & Engle, 2003), dichotic-listening tasks (Conway, Cowan, & Bunting, 2001), and go/no-go task (Redick et al., 2011) show that low-span participants are slower and less accurate than high-span participants. Low-span participants show impaired performance in tasks that require a high degree of cognitive control. Older adults show similar impairments in tasks where information must to be maintained within working memory and attention is needed to inhibit interference and inappropriate response tendencies (Craik, Morris, Morris, & Loewen, 1990; Salthoure 1990; Duigheualt & Braun, 1993). These age-related declines have been attributed to delayed reaction time

(Cerella 1985; Myerson, Hale Wagstaff, Poon, & Smith, 1990; Salthouse 1996), reduced processing resources (Craik & Byrd 1982), reduced working memory capacity (Salthouse 1996; Park 2000), inhibitory deficits (Hasher & Zacks, 1988), and disturbed attentional control (Balota, Dolan, & Duchek, 2000). These goal maintenance deficits have been hypothesized to be the underlying issue for age-related declines in cognitive control tasks.

CHAPTER FOUR:

INDUCING REACTIVE AND PROACTIVE CONTROL

Several studies have successfully induced proactive control in participants using directed strategy training or extended practice (Braver, Paxton, Locke, & Barch, 2009). During the AX-CPT, if participants are instructed to prepare a target response for an ‘A’ cue, and to prepare a non-target response if the ‘X’ probe does not follow the ‘A’ cue, participants are able to demonstrate increased proactive control (Paxton, Barch, Storandt, & Braver, 2006). An increase in proactive control can also be observed when participants receive extended practice with the AX-CPT (Braver, Paxton, Locke, & Barch, 2009; Edwards, Barch, & Braver, 2010).

Another factor that produces a change in cognitive control strategy is the expected WM load. Speer, Jacoby, and Braver (2003) designed a task that induces reactive control strategies under high load conditions. The task required participants to maintain a list of words and respond to a probe word by indicating whether or not it matched one of the words from the list. A proactive pattern appears when the word list is short (1-5 words) and a reactive pattern appears when the word list is long (7-11 words). However, it is important to note that despite the actual difficulty of the task this pattern of responses only occurred when the expected difficulty of the task was high. This suggests that simple conscious awareness of task difficulty is enough to influence cognitive control to switch strategy methods over to something it would be perceived as being more optimal for the current situation.

Braver, Paxton, Locke, and Barch (2009) also found that when a cue becomes less predictable of the probe, and if incorrect responses are penalized, then participants are less likely to use proactive control strategies. This can be demonstrated by adding no-go trials to the typical AX-CPT (Braver, Paxton, Locke, & Barch, 2009). During a no-go trial, a number is presented in place of the probe and participants are instructed to not respond in any way. A second manipulation to this version of the AX-CPT is that a penalty is given for any incorrect responses during this task. Healthy young adults, that typically bias towards proactive control, will shift to reactive control during this version of the AX-CPT. Gonthier, Macnamara, Chow, Conway, and Braver (2016) expanded on this by combining strategy training and no-go trials in the same experiment. Participants completed the AX-CPT, including the no-go trials. Then underwent strategy training, and then completed the same version of the AX-CPT a second time. This experiment successfully demonstrated that modes of cognitive control can be altered by manipulating the task. The non-go trials demonstrated that the pattern of performance can be shifted from proactive control to reactive control, and strategy training was successful in showing that performance can be shifted back to proactive control.

CHAPTER FIVE:

SUMMARY AND HYPOTHESIS

When it come to the DMC, reactive and proactive modes of control lead to both costs and benefits among different situational tasks. The traditional version of the AX-CPT purposely does not favor one mode of control over another so that individuals can utilize either reactive or proactive control and still complete the task to a high degree of accuracy. Individuals will naturally bias towards one mode of control and receive the cost and benefits of that control strategy. It has been consistently established that WMC is a strong indicator of which mode of control an individual will bias towards. Typically, high WMC individuals will bias towards proactive control and low WMC towards reactive control (e.g., Richmond et al., 2015). Proactive control creates a consistent strain on cognitive resources and it is usually only adopted by individuals with high WMC (Kane & Engle, 2002). Nevertheless, recall that proactive control can still be invoked in individuals by simply suggesting to them to use proactive control strategies (Braver, Paxton, Locke, & Barch, 2009). This indicates that the cognitive mechanisms required for proactive control are present in individuals that might otherwise bias towards reactive control. However, it is unclear why these individuals bias towards reactive control when they are capable of utilizing proactive control strategies.

Although it has never been directly tested, as seen by previous research, it is possible to influence individuals to switch their mode of control by implementing simple task manipulations. However, since WMC has never been explicitly measured, it remains unclear whether low WMC individuals are capable of engaging proactive control. The primary purpose of the present study is to demonstrate that a proactive mode of control can be successfully utilized by *both* high and low WMC individuals without explicitly directing them to do so. The present study will manipulate task parameters in order to induce proactive control in low (and high) WMC people. Specifically, individuals that bias towards reactive control will exhibit a natural switch, and successfully use proactive control, when the task favors such strategies.

In order to observe a shift to proactive control a modified version of the AX-CPT will be created that favors proactive control strategies. In this modified version of the AX-CPT (this version will be referred to as the AX-CPT -color version), cues and probes will be presented in varying colors. That is, letter stimuli will be presented in either the color red or green. Each cue-probe condition of the AX-CPT will consist of four trial types, two with matching cue-probe color identities (i.e., AX gg and AX rr) and two with mismatching cue-probe color identities (i.e., AX gr and AX rg). Participants must respond to the probe based on the rule that target responses are anytime the “A” cue is followed by the “X” probe *and* the cue-probe letters have the same color identity. As with Richmond et al.’s (2015) version, ‘AX’ trials are presented 40% of the time (10%

for each ‘AX’ condition). Of the four ‘AX’ trial conditions, only two of them are considered target responses. The critical difference with the present version of the AX-CPT and previous versions is that a target response is to be given only on AX trials where the cue and probe are presented with the same color identity (i.e., a green ‘A’ cue is followed by a green ‘X’ probe or when a red ‘A’ cue is followed by a red ‘X’ probe). When the cue and probe in ‘AX’ trials have mismatched colors, a non-target response is required to be given. All ‘BX’ trials are considered non-target responses, regardless of the color, and are presented 10% of the time (2.5% for each ‘BX’ condition). Similarly, ‘AY’ conditions are also non-target responses, regardless of the color, and are presented 10% of the time (2.5% for each ‘AY condition). Lastly, ‘BY’ trial conditions are presented 40% of the time (10% for each ‘BY’ condition) and serve as a control condition.

Due to the versatility of the AX-CPT -color, the task will first be administered with the traditional AX-CPT ruleset. That is, instructions will not include the requirement for cue-probe color matches for target responses. This ruleset only requires that the “A” cue is followed by the “X” probe for a target response, regardless of the color of the cue and probe. The purpose of including this ruleset is to both replicate previous findings with the AX-CPT and to create a baseline for cognitive control. The color of the cue and probe (red vs. green) are not predicted to have a significant impact on cognitive control. Thus, it is predicted that performance will be similar to what is found in traditional AX-CPT findings. In other words, high WMC individuals will perform in a pattern indicative of proactive control while low WMC will have a pattern indicating reactive control. Color of the stimuli will still be examined post-hoc in the event that color has an influence on cognitive control.

The color of the stimuli only becomes essential when the cue-probe color match requirement is included in the ruleset for target responses. This manipulation is likely to increase proactive control because two contextual cues are now required to make an appropriate target response. Both the letter and color identity of the cue will provide vital information that must be correctly recalled or maintained to make an appropriate response. If the cue is recalled later, only after the presentation of the probe, as it is with reactive control, there is greater risk of interference when attempting to recall either the letter or color correctly. With the addition of more stimuli, reactive control becomes a less effective strategy to utilize cognitive control to a high degree of accuracy. With proactive control, the addition of more stimuli should not have a significant impact on how the cue is maintained. Working memory can typically store anywhere from 3-5 units of information before reaching its mental capacity limit (Cowan, 2000). As long as WM isn't overloaded then the letter and color of the cue can be actively maintained without the risk of decay when utilizing proactive control. A switch to proactive control is predicted to occur when individuals realize that the costs associated with reactive control become too great to accurately complete the AX-CPT -color to a high degree of accuracy. This switch is expected to occur with both high and low WMC individuals in a mixed design study. A switch will be characterized by an increased PBI score when compared to the non-color ruleset condition of the AX-CPT -color. Specifically, when compared to the non-color condition there will be faster RTs and fewer errors on all BX trials, but slower RTs and greater errors on all AY trials.

CHAPTER SIX:

METHODS

Subjects

Seventy-one undergraduate students (82.4% females and 17.6% males; M_{age} = 27.71 years, *SD* = 8.80) attending a collage campus with the following ethnicity breakdown: 75% Hispanic, 10.3% White, 5.9% African American, 2.9% Asian, and 5.9% Other participated in the study. In return for their participation, students received extra credit points applicable to any CSUSB psychology course that offers extra credit. All participants were treated according to the Ethical Principles of Psychologists and Code of Conduct (American Psychological Association, 2017).

Design

The study used a 4 (Trial type: AX vs AY vs BX vs BY) x 2 (Instruction type: color rule vs. no color rule) x 2 (WMC: low vs. high) mixed design. Trial type and instruction type will vary within participants, while WMC varied between participants. Response time (RT) and error rate (ER) on the AX-CPT served as dependent variables. A Proactive Behavioral Index (PBI) was calculated based on mean RTs/ERs for each participant in order to measure which control strategy was being used by the participant (Gonthier, Macnamara, Chow, Conway, & Braver, 2016). PBI scores were calculated using the following formula: PBI =

(AY-BX)/(AY+BX). Positive scores indicated that participants were utilizing proactive control, while a negative score indicated reactive control. PBI scores for mean RTs and ERs were calculated separately for each individual participant.

Apparatus

Due to complications brought on from the “novel” coronavirus (nCoV-19) pandemic all tasks were acquired from the Millisecond Test Library and administered through Zoom with an online data collection software called Inquisit. WMC was intended to be measured using three established complex span tasks: operation span, symmetry span, and rotation span (Wilhelm, Hildebrandt, & Oberauer, 2013). However, a version of rotation span was not present in the test library and we were required to substitute it with reading span. Each complex span task followed the same procedures as Unsworth, Redick, Heitz, Broadway, and Engle (2009) consisting of a single block of three trials with varying set-sizes. The set-sizes ranged from three to seven to-be-remembered items making a total of 75 letters and 75 math problems. To-be-remembered stimulus were presented at the center of the screen for 1000 ms. The length of time that participants had to respond to the distractor task was on the following screen was based on the average response time for completing the series of distractor task trials in the second practice section. If participants took longer than 2.5 SD of their average response time during the distractor task section then the screen would automatically proceed to the next trial and count their response as an error. A percentage score of their correct responses was displayed on the top right corner of the screen to deter careless responses. Typically, participants complete three blocks of each complex span task but by administrating a shortened version of the complex span tasks, it greatly reduces the time required to complete the task while not sacrificing the reliability of the task (Foster et al, 2015). Most of the variance explained by complex tasks in WMC (R^2 = .87) and Gf (R^2 = .47) can by accounted for in the first block of each task. Removing the second and third block are considered reasonable since those blocks don't account for significant statistical variance.

Before beginning each task, participants were given instructions and required to complete three types of practice. In the first practice section, to-be-remembered stimulus appeared one at a time, and participants must recall each stimulus in the serial order they were presented. This is done by selecting them from a list of 16 possible stimulus shown at the end of each trial. In the second practice section, participants preformed a series of distractor task trials. This distractor task required participants to solve simple math problems or make judgments about another visual stimulus. Participants must respond as quickly, and as, accurately as possible by clicking on either the "True" or "False" buttons located under the solution; or on the following screen. In the third practice section, participants performed both the to-be-remembered stimulus recall and the distractor task together. This final practice section was identical to the trials that participants would be doing in the task. Complete trials showed participants a sequence of to-be-remembered stimulus one at a time. Participants were then required to complete a distractor task directly after the presentation of each stimulus in order to reduce the use of memory strategies. At the end of each trial, participants must recall each to-be-remembered stimulus in the serial order they were presented by selecting them from a list of 16 possible stimulus shown at the end of each trial.

Operation Span

Participants were shown a series of to-be-remembered letters, one at a time, while also solving simple math problems. Each to-be-remembered letter was presented in black font at the center of the screen for 1000 ms. The distractor task directly followed each letter stimulus and required participants to solve a simple math equation as quickly and as accurately as possible before clicking to the following screen (i.e., 20 - 2(10) =?). A possible solution to the problem was shown on the following screen and a response was required by clicking on either the “True” or “False” buttons to indicate a valid or invalid solution. An average response time for the distractor task was calculated for each participant during the practice section. If participants took longer than 2.5 SD of their average response time during the distractor task section then the screen would automatically proceed to the next trial and count their response as an error. A percentage score of their total correct responses in the distractor task was displayed on the top right corner of the screen to deter careless responses. At the end of each trial, participants must recall each to-be-remembered letter in the serial order they were presented by selecting them from a list of 16 possible letters shown.

Reading Span

Participants were shown a series of to-be-remembered letters, one at a time, while also making judgments on whether a sentence made sense. Each to-be-remembered letter was presented in black font at the center of the screen for 1000 ms. The distractor task directly followed each letter stimulus and required participants to quickly read a sentence and respond on whether the sentence made sense or not (i.e., I can study in the wall during summer). On the following screen and a response was required by clicking on either the “True” or “False” buttons to indicate if the sentence was valid or invalid. An average response time for the distractor task was calculated for each participant during the practice section. If participants took longer than 2.5 SD of their average response time during the distractor task section then the screen would automatically proceed to the next trial and count their response as an error. A percentage score of their total correct responses in the distractor task was displayed on the top right corner of the screen to deter careless responses. At the end of each trial, participants must recall each to-be-remembered letter in the serial order they were presented by selecting them from a list of 16 possible letters shown.

Symmetry Span

Participants were shown a series of red boxes, one at a time, located in a 4x4 matrix and were required to remember the location of the red box while also judging whether a picture was symmetrical when folded vertical. Boxes appeared in an 4x4 matrix of 16 possible boxes. Each to-be-remembered box was presented in red on the 4x4 matrix for a 1000 ms and the location of the box must be recalled. The distractor task directly followed the box stimulus and required a judgment be made on whether a picture is symmetrical when folded vertical. Participants must respond as quickly and as accurately as possible by clicking on either the “True” or “False” buttons to indicate their response. An average response time for the distractor task is calculated for each participant during the practice section. If participants took longer than 2.5 SD of their average response time during the distractor task section then the screen will automatically proceed to the next trial and count their response as an error. A percentage score of their total correct responses in the distractor task was displayed on the top right corner of the screen to deter careless responses. At the end of each trial, participants must recall location of each to- be-remembered box in the serial order they were presented by selecting them from a 4x4 matrix with 16 possible boxes shown.

Participants were classified as low vs. high WMC based on a composite score using the three complex span tasks. A score was calculated for each trial based on the number of items correctly recalled in their serial position. A weighted average score was taken across all trials for each block and served as a measure of WMC for each participant. A median split determined placement of either low or high WMC.

AX Continuous Performance Task with Color

Cognitive control and modes of control (proactive vs. reactive) were measured using a modified versions of the AX Continuous Performance Task (AX-CPT) (Braver, 2012). The standard version of the AX-CPT measures cognitive control with a series of trials consisting of two letters appearing, one at a time, in a cue-probe format. Both letters in the cue-probe pairing are presented with the same color (e.g., black). The first letter shown is the cue and is represented by either the letter “A” or “B” (where “B” represents any non-A cue). The second letter is the probe is represented by either the letter “X” or “Y” (where “Y” represents any non-X probe). After each trial, a “yes” or “no” response is required to identify target trials. Target trials are identified based on a rule given during the instructions phase. The traditional goal in the AX-CPT is to respond “yes” anytime the letter “X” is proceeded by the letter “A”. The current study used a modified version of the AX-CPT referred to as the AX-CPT- color. The key difference in this task is that the cue-probe letters were be shown in either the color red or green. This creates situations where the cue and probe letters match (or mismatch) in color. Two different rule sets were given for target trials. One that doesn’t include color and another that depended on color matches.

Session one, participants completed the AX-CPT- color with the traditional AX-CPT rule for valid target trials (“A” cue is followed by the “X” probe). The frequency of each trial type followed the same breakdown as the AX-CPT 40 (Gonthier et al., 2016; Richmond et al., 2015). “AX” and “BY” trial types were shown 40% of the time. While, “AY” and “BX” were shown 10% of the time. This particular proportion was designed present each letter an equal number of times throughout the task to eliminate the expectation bias of seeing the “A” cue followed by the “X” probe. It was also to create a baseline for cognitive control and to replicate past findings found among low vs. high WMC individuals. Low WMC individuals follow a pattern that is indicative of reactive control and the exact opposite pattern of proactive control is found among high WMC individuals.

In Session two, the AX-CPT- color was given with a different rule (valid target responses are when the “A” cue is followed by the “X” probe and the cue-prob letters are the same color). This manipulation was intended to increase the cognitive load required for completing the task by including the element color matches. With this rule, AX trials were only valid when the cue and the probe share the same color (AX gg and AX rr). For example, a green “A” cue and a green “X” probe is considered a target trial (AX gg) with this rule. The addition of color matches was intended to promote proactive control since both the color and letter identity of the cue must be recalled in order to properly respond to each trial. A reactive control response patterns suggests stronger encoding of the probe, but not the cue. Therefore, it was expected that reactive control would lead to greater interference and more errors.

Procedure

Participants were recruited through SONA, an online management system, in order to earn extra credit points in exchange for their participation in the study. Through SONA, they were given a link for a personal Zoom meeting where they were required to attend during their session time. Once in the Zoom meeting, participants were instructed to share their screen and were messaged a link for the informed consent through the Zoom chat. After signing the informed consent, participants were instructed to download a web add-on that allowed Inquisit to run locally within their web browser. After installing the software, all participants completed a single block of operation span (OSPAN), reading span (RSPAN), and symmetry span (SSPAN) complex span tasks. All instructions were automated and participants were required to complete three practice sections before beginning each task. After completing all complex span tasks, participants then completed the AX-CPT- color without the requirement of color matches. Two letters were shown, one at a time, at the center of the screen in a cue-probe format in either the color green or red. The first letter shown is the cue and is represented by the letter “A” or “B”. The second letter is the probe and is represented by the letter “X” or “Y”. Each letter is shown for 500ms and separated by a delay screen with a single cross fixation point located at the center of the screen for 1000ms. Instructions were given to the participant by the research assistant over a zoom video call while the participant shared their screen with the researcher. Participants were told that two letters will appear in each trial one at a time. Participants were required to indicate whether the trial was a "target" or "non-target" trial by responding as quickly and as accurately as possible directly after seeing the probe. Instructions in the first session gave the rule that valid target responses were when the "A" cue is followed by the "X" probe. With this rule, cue-probe letter colors were irrelevant and valid targets include all AX trial types (i.e., AX gg, AX rr, AX gr, and AX rg). For example, a green "Ag" cue and a red "Xr" probe is considered a target trial (AX gr) with this rule. An invalid target response is required for all other trial types (i.e., BX gg, BX rr, BX gr, BX rg, AY gg, AY rr, AY gr, AY rg, BY gg, BY rr, BY gr, and BY rg). "AY" trial types are anytime the cue is the letter "A" and the probe is the letter "Y". "BX" trials are anytime the cue is the letter "B" and the probe is the letter "X". These two trial types served as an indicator of modes of control. A shift towards proactive control was indicated by improved performance on "BX" trials and decreased performance on "AY" trials. After completing the AX-CPT- color a first time, participants returned no later than three days later for session two to complete the AX-CPT- color a second time. In session two, instructions were then given for the color ruleset condition. The rule for valid targets responses in this ruleset were when the "A" cue is followed by the "X" probe and the cue-prob letters are the same color. With this rule, AX trials were only valid when the cue and the probe share the same color (i.e., AX gg and AX rr). An invalid target response was required for all other trial types (i.e., AX gr, AX rg, BX gg, BX rr, BX gr, BX rg, AY gg, AY rr, AY gr, AY rg, BY gg, BY rr, BY gr, and BY rg). The frequency of each trial type followed the same breakdown as the AX-CPT 40. A ratio split of 40% “AX” trials, 40% “BY” trials, 10% “AY” trials, and 10% “BY” trials was used so that participants see each cue (A and B) and each probe (X and Y) presented an equal number of times. The purpose of this manipulation is so that participants don’t form expectancy biases towards certain trial types throughout the task. A total of 400 trials were used in order to increase the power of the effect in each individual trial type. The breakdown for each trial type was: 80 trials each of AX gg and AX rr (i.e., 40% AX trial types), 40 trials each of BY gg, BY rr, BY gr, and BY rg (i.e., 40% BY trials) and 8 trials each of AX gr, AX rg, AY gg, AY rr, AY gr, AY rg, BX gg, BX rr, BX gr, and BX rg (i.e., 10% AY and 10% BX trial types).

CHAPTER SEVEN:

RESULTS

The full data set contained responses from a total of seventy-one students. However, data from four participants were removed from all subsequent analyses due to low performance in either AY or BX trails (i.e., ER > 50%). These scores were identified as being extreme outliers (i.e., Z > 3.4), which suggests that these participants did not accurately understand the instructions of the task. Furthermore, only trials with response times greater than 200 ms and less than 2000 ms were analyzed to remove variance caused by computer error. The final analysis included mean RTs and ERs from 67 participants (see Table 1). The standards used for reporting effect size were Cohen's *d* (i.e., 0.2 is small, 0.5 is medium, and 0.8 is large) and η^2 (i.e., 0.01 is small, 0.09 is medium, and 0.25 is large).

Our first analysis was to examine whether we were able to replicate the relationship between WMC and PBI that was found with Richmond et al (2015). To test WMC a span composite score was calculated for each participant based on a partial span score for each WMC measure (i.e., OSPAN, RSPAN, & SSPAN). Partial span scores were calculated according to Conway et al. (2005), where, for each WMC measure, the total number of correct responses in the correct place was summed up and divided by the total length of the sequence for each individual trial (see Table 2). Partial span scores were then averaged across all three WMC measures to provide an accurate measure of WMC (Foster et al., 2015). A Proactive Behavioral Index (PBI) score was also calculated for each participant using a composite based on mean RTs and ERs for AY and BX trials. Only AY and BX trials with correct response were included in this calculation. Mean RTs were calculated for each participant and trial types using the standard PBI formula (AY-BX)/(AY+BX). For ERs, a corrected PBI formula was required to account for individuals with no errors. These scores were calculated according to previous research (e.g., Braver et al., 2009; Gonthier et al., 2016; Mäki-Marttunen et al., 2018), where scores of "0" were corrected using the following formula (0.5)/(number of trials + 1). The corrected scores were then used with the standard PBI formula to calculate PBI for ERs. The final composite PBI score was computed by converting RT and ER PBI scores to z-scores and averaging them across both scores (see Table 2). Data from the No Color Rule condition was examined first by conducting a regression analysis using WMC and PBI as variables. PBI was found to be related to WMC, such that higher WMC span scores were associated with higher PBI scores, however this relationship was only marginally significant, $\beta = .219$, $t(66) = -1.808$, $p = .075$; $R^2 = .048$, $F(1, 66) = 3.27$, $p = .075$ (see Figure 1). The relationship between WMC and PBI that was found in the present study somewhat replicates the findings of Richmond et al. (2015). Next, we examined whether a relationship between PBI and WMC was present when the Color Rule condition was in effect. Thus, a regression was run between WMC and PBI for when color mattered. This relationship showed no significant correlation, $\beta = .133$, $t(66) = 1.078$, $p = .285$. Also, the amount of variance in PBI that was once explained by WMC in the No Color Rule condition was reduced when color mattered, $R^2 = .018$, $F(1, 66) = 1.162$, $p = .285$.

To further examine the relationship between WMC, Color Rule condition, and PBI a 2 (WMC: low vs. high) x 2 (Rule Condition: no color vs. color rule) repeated measures ANOVA was conducted, with PBI scores as the dependent variable. There was no interaction found between WMC and PBI ($F < 1$) (see Figure 2). However, there was a significant main effect of rule condition, $F(1, 65) = 4.11$, $p < .05$, $\eta^2 = .06$. Thus, regardless of WMC, participants yielded higher PBI scores in the Color Rule ($M = -.10$, $SD = .54$) condition than in the No Color Rule condition ($M = -.25$, $SD = .51$).

Effect of Working Memory Capacity, Rule Condition, and Color

Due to the nature of the color manipulation within the AX-CPT-color there were mismatch and matching conditions for each trial type. The mis-match condition was any trial type where the cue and probe had different colors (i.e., AX gr). On the contrary, the matching condition was when the cue and probe had the same color (i.e., AX gg). All trials within the AX-CPT-color were counter balanced and presented randomly to participants in a within subject design. RT and ER for each trial type (i.e., AX, AY, BX, & BY) were looked at separately to determine if

WMC, Rule Condition, and Color Match had an effect on performance in each trial type.

AX Trials

AX trials were unique in that No Color Rule and Color Rule data could not be directly compared like other trial types. This is due to the fact that AX mismatch trials mean different things from the No Color Rule to the Color Rule condition. In the No Color Rule condition, a mismatch AX trial is considered a valid target. However, when there is a Color Rule in effect the mismatch AX trials become non-valid targets. Therefore, the decision was made to exclude AX mismatch trials from the analysis and only focused on matching AX trials since they remained as valid targets across both conditions. Thus, a 2 (WMC: low vs. high) x 2 (Rule Condition: no color rule vs. color rule) repeated measures ANOVA for AX matching trials was conducted with RT and ER data. With RT data, there was no interaction found between WMC and rule condition for matching AX trials, ($F < 1$; see Figure 3). However, there was a main effect of rule condition, $F(1, 65) = 6.228$, $p < .05$, $\eta^2 = .09$. Low and high WMC individuals were slower in the No Color Rule condition (M = 690 ms, SD = 170.2) than in the Color Rule condition (M = 655 ms, SD = 206.2). With ER data, there was also no interaction found between WMC and Rule Condition for matching AX trials, ($F < 1$; see Figure 4). The main effect of Rule Condition was only marginally significant, $F(1, 66) = 3.744$, $p = .06$, $\eta^2 = .05$. This trend revealed that low and high WMC individuals made fewer errors in the No Color Rule condition (M = .07, *SD* = .09) than in the Color Rule condition (*M* = .102, *SD* = .12). Although the effect of Color Rule was only marginally significant in the error rate data, taken together, these patterns suggest that participants may have been trading speed for accuracy on AX trials when the cue and probes matched making the effect of Color Rule difficult to interpret.

In order to investigate the effect of Color Match in AX trials, we also conducted a 2 (WMC: low vs. high) x 2 (Color Match: mismatch vs. match) ANOVA in the No Color Rule condition. No significant findings were present with RT data. In the ER data, there was a significant interaction between WMC and Color Match, $F(1, 65) = 8.15$, $p < .01$, $\eta^2 = .11$ (see Figure 5). This interaction was further broken down by examining the effect of Color Match separately for low and high WMC groups. For the high WMC group, a simple main effects test revealed that ERs were greater when cues and probes matched (*M* = .06, *SD* = .11) than when they mismatched (*M* = .03, *SD* = .09), $t(33) = 5.46$, $p < .01$. This was opposite for the low WMC group who made more errors when the cues and probes mismatched. However, this effect was not significant ($|t| < 1$). No other effects were significant with AX trials.

<u>AY Trials</u>

AY trials were analyzed using a 2 (WMC: low vs. high) x 2 (Color Match: mismatch vs. match) x 2 (Rule Condition: no color rule vs. color rule) ANOVA with both RT and ER. With the RT data, there was a significant main effect of Rule condition, $F(1, 65) = 20.814$, $p < .001$, $\eta^2 = .24$) . Participants responded significantly faster in the Color Rule condition (*M* = 661 ms, *SD* = 170.0) than in the No Color Rule condition (*M* = 716 ms, *SD* = 160.0). However, this main effect was qualified by a marginally significant WMC x Color Match x Rule Condition interaction, $F(1, 65) = 3.28$, $p = .075$, $\eta^2 = .05$ (see Figure 6). This interaction was further explored by examining the WMC x Color Match interaction separately for the No Color and Color Rule conditions. For the Color Rule condition, an interaction was not found ($F < 1$). However, for the No Color Rule condition, a significant interaction was found, $F(1, 65) = 5.55$, $p < .05$, $\eta^2 = .08$ (see Figure 6). For low WMC participants, simple main effects test revealed that RTs were faster when cues and probes matched (*M* = 688 ms, *SD* = 130.2) than when they mismatched (*M* = 706 ms, *SD* = 143.2), $t(32) = -2.74$, $p < .05$. However, for high WMC participants RTs did not differ between the matched and mismatched trials. For the error rate data, no significant main effects or interactions were found.

BX Trials

BX trials were analyzed using a 2 (WMC: low vs. high) x 2 (Color Match: mismatch vs. match) x 2 (Rule Condition: no color rule vs. color rule) ANOVA with both RT and ER. With RT data, there was a significant three way interaction between WMC, color match, and rule condition, $F(1, 65) = 5.46$, $p < .05$, $\eta^2 = .08$ (see Figure 7). This three-way interaction was further explored by examining the WMC x Color match interaction separately for the color and no color rule conditions. However, the WMC x Color Match interaction was not significant for either the no color rule, $F(1, 65) = 1.673$, $p > .20$, or the color rule condition, *F*(1,

65) = 2.072, $p > .15$. For the ER data, the WMC x Color Match x Rule Condition interaction was not significant ($F < 1$), but significant main effects of matching condition, $F(1, 65) = 7.318$, $p < .01$, $\eta^2 = .10$) and rule condition, $F(1, 65) = 6.742$, $p < .05$, $\eta^2 = .09$) were found. Participants tended to make more errors on matching trials (*M* = .13, *SD* = .18) than on mismatching trials (*M* = .09, *SD* = .13). Furthermore, participants also would have more errors on color match trials in the no color rule condition (*M* = .133, *SD* = .177) than in the color rule condition (*M* = .079, *SD* = .135).

Table 1. Response Times and Error Rates

	Session One															
	Low WMC								High WMC							
	Mismatch				Match				Mismatch				Match			
Trial:	**RT**	**SD**	**ER**	**SD**	**RT**	**SD**	**ER**	**SD**	**RT**	**SD**	**ER**	**SD**	**RT**	**SD**	**ER**	**SD**
AX	669	140.4	0.09	0.13	673	135.8	0.08	0.08	707	220.94	0.03	0.09	706	198.8	0.06	0.1
AY	706	143.2	0.03	0.06	688	130.2	0.03	0.05	734	183.55	0.03	0.09	134	182.9	0.04	0.1
BX	667	209.1	0.09	0.12	640	199.6	0.13	0.17	657	217.43	0.09	0.13	668	232.1	0.13	0.2
BY	606	155.6	0.03	0.07	595	146.1	0.05	0.1	634	203.87	0.04	0.1	652	216.9	0.04	0.1
	Session Two															
	Low WMC								High WMC							
	Mismatch				Match				Mismatch				Match			
Trial:	**RT**	**SD**	**ER**	**SD**	**RT**	**SD**	**ER**	**SD**	**RT**	**SD**	**ER**	**SD**	**RT**	**SD**	**ER**	**SD**
AX	639	148.8	0.2	0.22	641	168.9	0.1	0.1	712	229.61	0.18	0.2	668	238.8	0.11	0.1
AY	639	139.1	0.02	0.03	640	136.5	0.02	0.03	682	203.69	0.04	0.09	682	204.7	0.04	0.1
BX	573	174.6	0.04	0.09	580	181.3	0.08	0.16	604	260.76	0.06	0.1	576	219.8	0.08	0.1
BY	534	154.1	0.03	0.08	544	147.7	0.02	0.06	583	222.11	0.04	0.09	581	228.6	0.04	0.1

Table 2. Composite Scores

	Session One			
Task Name:	**Low WMC**		**High WMC**	
	M	**SD**	**M**	**SD**
SPAN Composite:	0.55	0.14	0.83	0.07
AX-CPT - No Color Rule PBI:	-0.285	0.58	-0.21	0.45
	Session Two			
	Low WMC		**High WMC**	
	M	**SD**	**M**	**SD**
AX-CPT - Color Rule PBI:	-0.21	0.52	-0.001	0.56

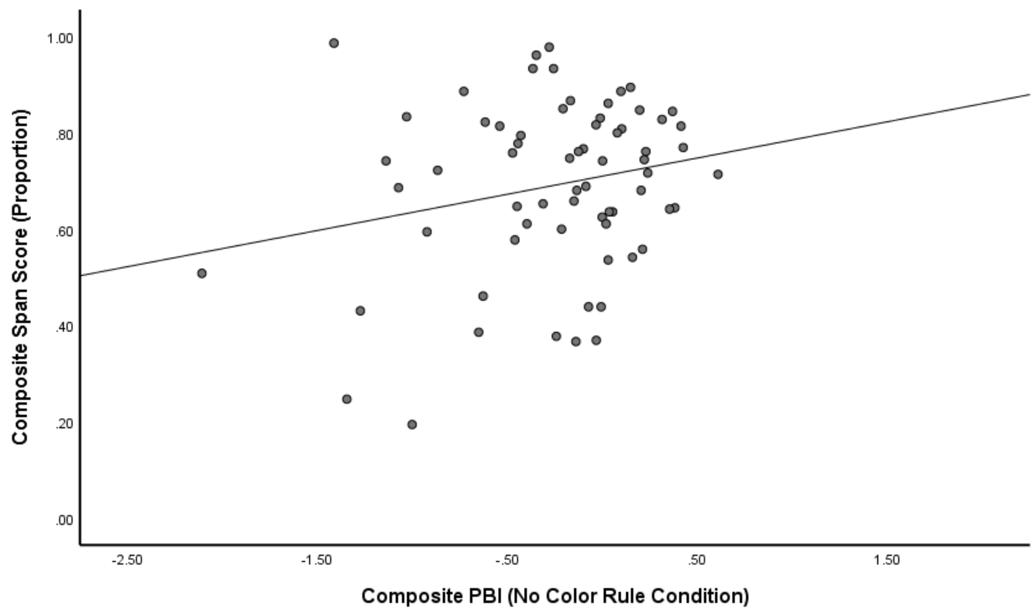

Figure 1. Session One No Color Rule
Relationship between working memory capacity scores and proactive behavioral index for no color rule condition.

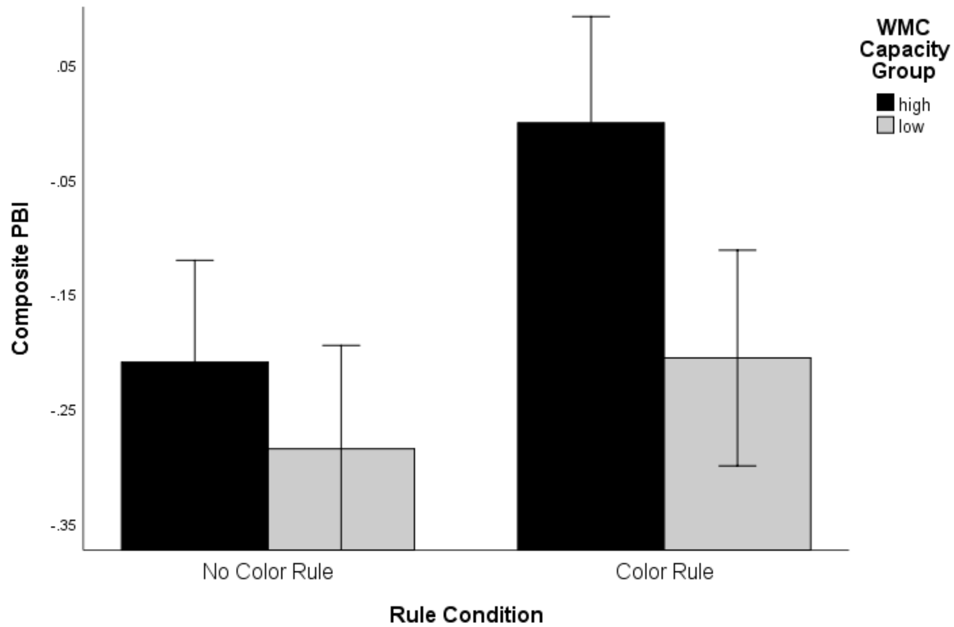

Figure 2. Session Two Proactive Behavioral Index
Comparison of proactive behavioral index mean scores for low and high working memory capacity individuals in the no color rule and color rule condition.

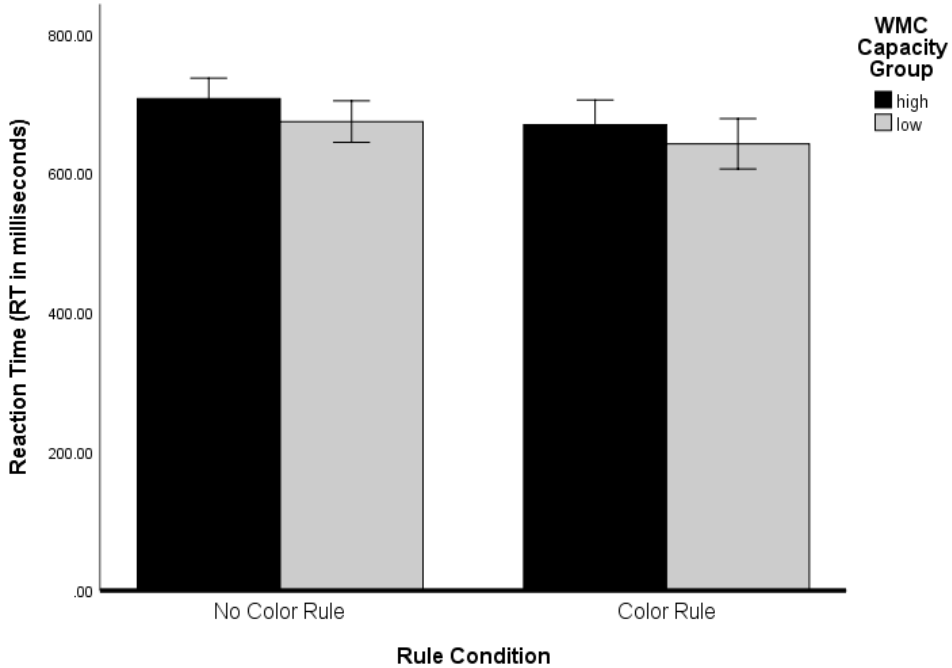

Figure 3. Reaction Times for AX Matching Trials
Comparison of mean reaction time scores for AX matching trials for low and high working memory capacity individuals in the no color rule and color rule condition.

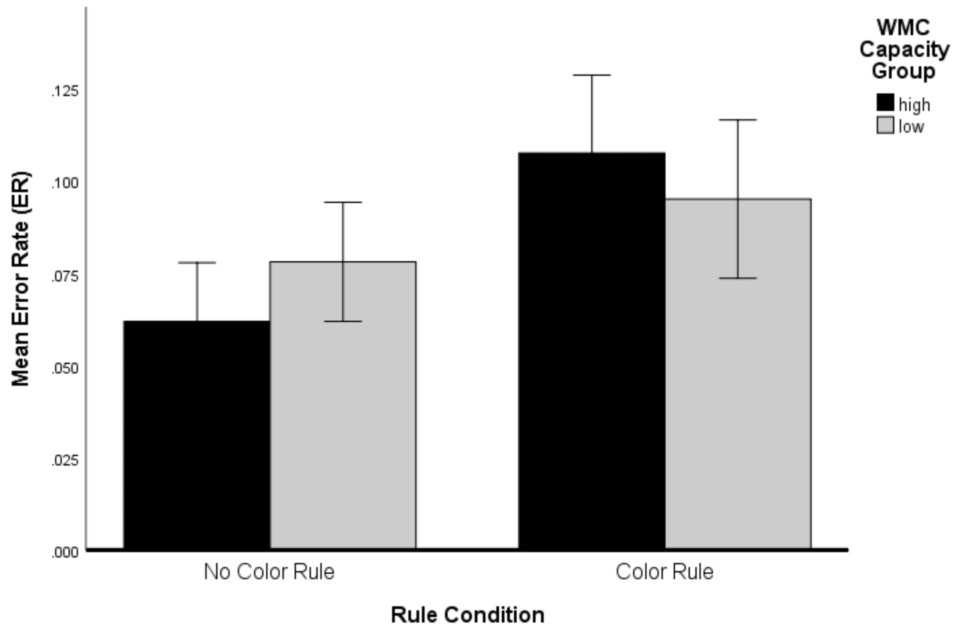

Figure 4. Error Rates for AX Matching Trials
Comparison of mean error rate scores for AX matching trials for low and high working memory capacity individuals in the no color rule and color rule condition.

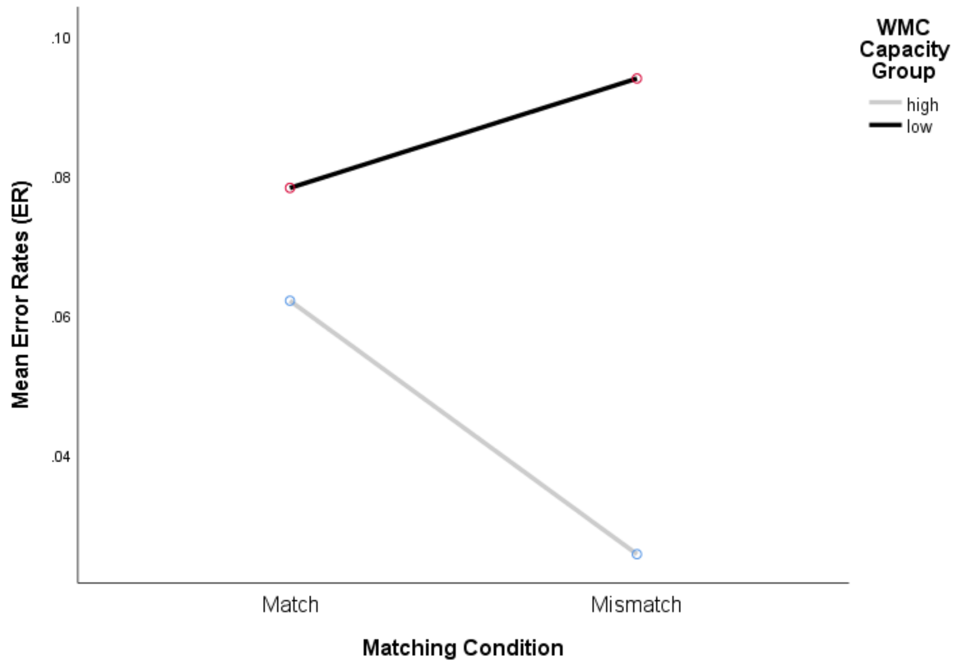

Figure 5. Error Rates for AX Mismatch Trials
Comparison of mean error rate scores for AX match versus mismatch trials for low and high working memory capacity individuals.

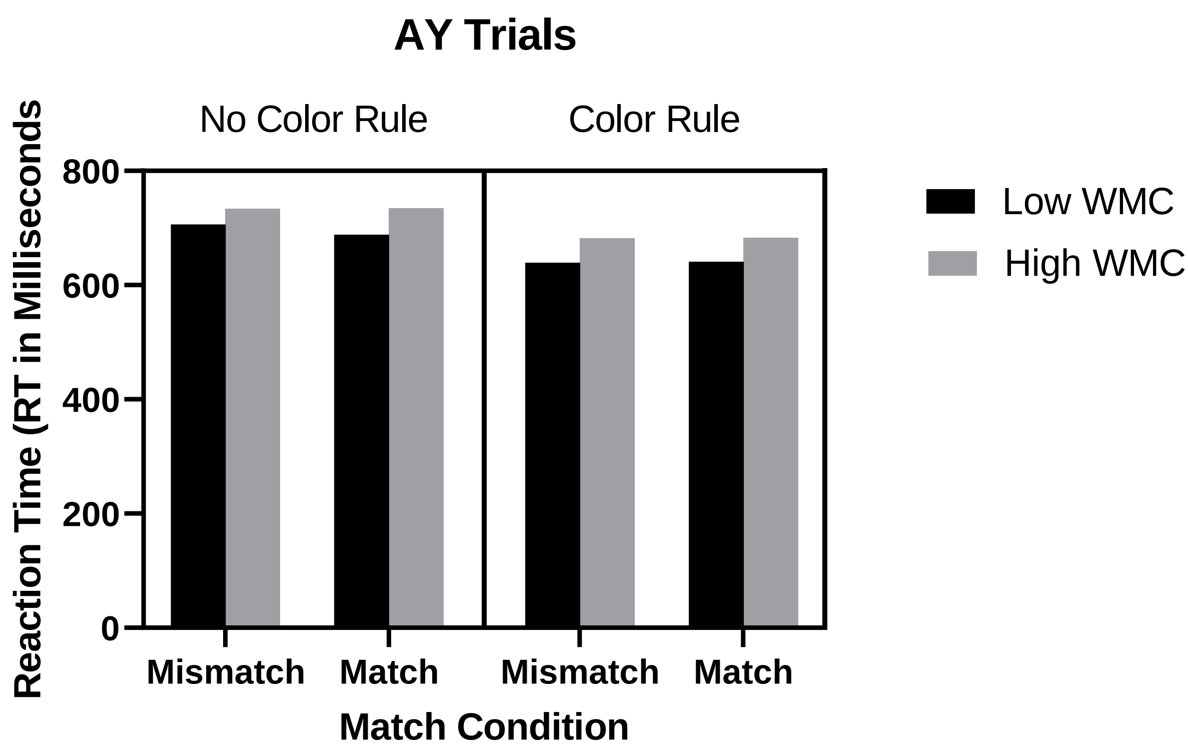

Figure 6. AY Mismatch versus Matching Trials
Three-way interaction between working memory capacity, Rule condition, and Match condition for reaction time in AY trail types.

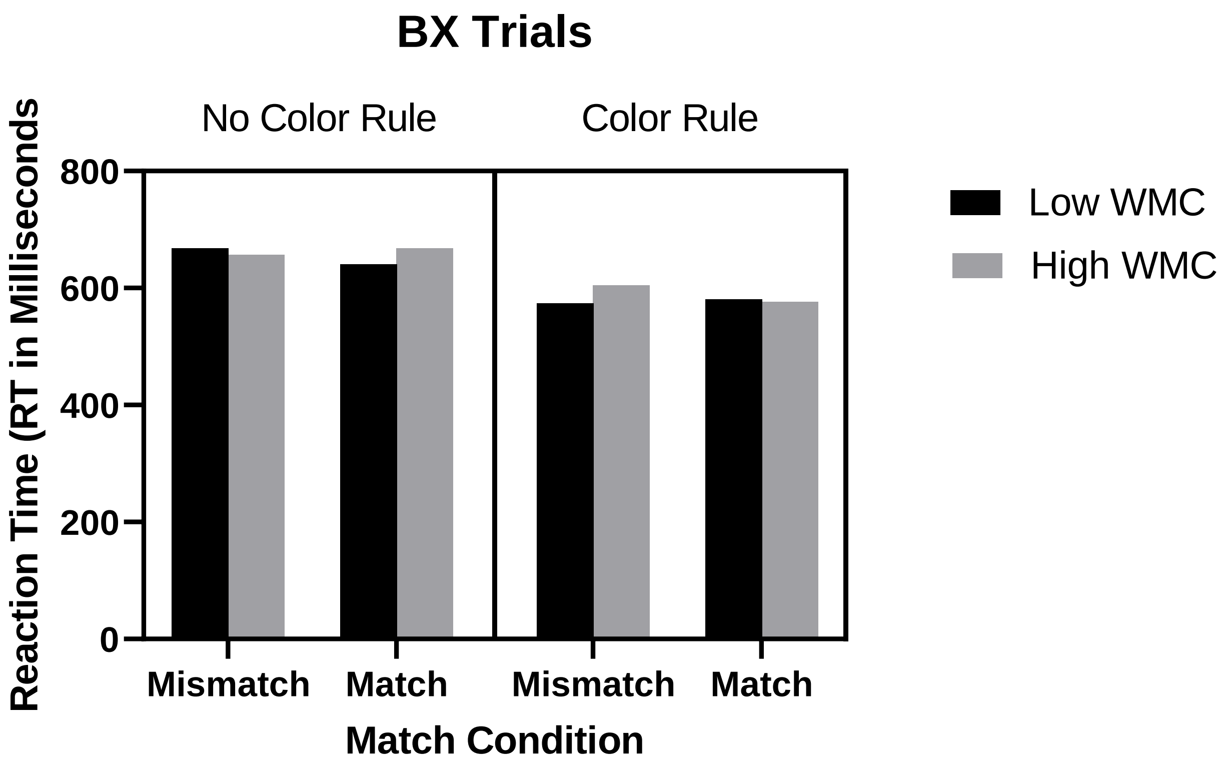

Figure 7. BX Mismatch versus Matching Trials
Three-way interaction between working memory capacity, Rule condition, and Match condition for reaction time in BX trail types.

CHAPTER EIGHT:

DISCUSSION

The present study was designed to investigate how PBI is affected in the AX-CPT when individuals, with varying levels of WMC, are faced with a task that specifically favors a proactive strategy method. Our aim was to increase proactivity by adding a color manipulation to the AX-CPT. The traditional AX-CPT requires participants to correctly identify valid "AX" cue-probe pairings. In the AX-CPT-color, a color stimuli manipulation was added to the cue-probe pairings that adds a second level to the task where "AX" pairings must also match in color to be considered valid targets. This manipulation was expected to increase the cognitive load when storing cue information because both letter and color information needed to be stored for the cue in order to properly respond to the following probe. As a result, the AX-CPT-color version was expected to be more difficult for individuals using a reactive control strategy. Consequently, we predicted that participants would shift towards proactivity during the AX-CPT-color since reactive control would become less optimal for completing the task. A 4 (Trial type: AX vs AY vs BX vs BY) x 2 (Instruction type: color rule vs. no color rule) x 2 (WMC: low vs. high) mixed design was conducted to determine if an increased load, through the addition of color, had a positive shift on proactivity for low and high WMC individuals.

The literature has multiple accounts that report that low and high WMC individuals bias towards different modes of control (Redick, 2014; Richmond et al., 2015). In healthy young adults, those with low WMC tend to bias towards reactive control, while those with high WMC bias towards proactive control. Our first goal was to attempt to replicate these findings using the modified AX-CPT-color task. This was done by using the AX-CPT-color, but excluding the “color match” requirement from the task instructions. This way, the AX-CPT-color was comparable to the standard version of the AX-CPT and could be used for replication testing. In addition, by doing so, we were able to eliminate the presence of color as a possible confound variable for increased proactivity by keeping the task consistent between the “No Color Rule” and “Color Rule” conditions. Although the correlation was not statistically significant due to low power, we did find some evidence for a relationship between WMC and PBI that was consistent with Richmond et al. (2015). When there was no requirement for a color match included with the instructions, high WMC individuals tended to employ greater proactivity than low WMC participants (see Figure 1). These findings provide further evidence that healthy young adults with intact executive functioning generally tend to bias towards a proactive control strategy when presented with a somewhat traditional AX-CPT (Braver, Cohen & Barch, 2007; Paxton, Barch, Storandt & Braver, 2006). The current theory states that when individuals use proactive control during the AX-CPT they are proactively preparing a target response based on the cue prior to the presentation of the probe (Redick, 2014; Richmond et al., 2015). Since proactively preparing a response requires greater cognitive resources, we believe that individuals with higher WMC are able to activate and maintain goal information more readily than lower WMC individuals. Lower WMC individuals may possess an underdeveloped proactive control system preventing them from successfully utilizing proactive control. Furthermore, perhaps these individuals also have less well-developed abilities to maintain attention or concentration for extended periods of time.

Previous research has demonstrated that individuals shift toward greater proactivity when they are specifically directed to use a proactive control strategy (Speer, Jacoby, & Braver, 2003; Paxton, Barch, Storandt, & Braver, 2006; Braver, Paxton, Locke, & Barch, 2009; Edwards, Barch, & Braver, 2010). Thus, the primary purpose of the present study was to investigate whether a shift in the mode of control, that participants used during the task, could be brought about through the use of the modified AX-CPT-color when the inclusion of a "color match" requirement is presented with the task instructions. As predicted, a significant main effect of rule condition was found such that both low and high WMC individuals exhibited a shift towards proactivity when the color rule match requirement was in effect. It appears that not only can individuals be explicitly told to use a more proactive strategy, but an increase can be induced by task parameters themselves, without blatantly directing participants to use proactive control. Prior to the present study, a shift from reactive to proactive control that was not a direct result of strategy training has not yet been reported in the literature. We found that the low WMC group improved to a level of PBI in the color rule condition that was comparable to the high group in the no color rule condition (see Figure 2). Even more interesting, although not significant, the low WMC group made fewer errors across all trial types in the color rule condition when compared to the high WMC group. We can conclude that this shift towards proactivity was a direct result of the need to utilize color information while completing the AX-CPT-color. This brings up an important question regarding how different modes of control are activated.

The present study indicates that WM load is capable of inducing shifts in modes of control. The addition of a color rule in the AX-CPT-color required participants to store both a letter and color identity. The shift from reactive to proactive control, that was observed in the present study, is likely a direct result of participants realizing that reactive control became less effective when the color rule was in effect. This is in accordance with similar studies that have reported shifts in modes of control when completing a task that requires the memorization of word lists with varying lengths (Speer, Jacoby, & Braver, 2003). When participants were presented with a short list, they would automatically memorize the entire list and utilize a proactive control strategy method. When presented with a long list, participants would use a reactive control strategy method and recall words they recognized from the list. It is important to note that in this experiment a shift was only observed if participants were expecting a long list condition. If participants weren’t aware of the long list condition prior to the beginning of the trial they would attempt to use proactive control and memorize the entire list until reaching their WMC limit. It is possible that a shift in modes of control is dependent on an individual realizing the effectiveness of a specific strategy method for a specific task.

The current explanation for modes of control is that low WMC individuals bias towards reactive control due to a limit of cognitive resources. However, it is important to note that high WMC do not consistently out preform lower WMC individuals in all cognitive tasks. For example, when compared to low-WMC individuals, in a directed forgetting task participants with high WMC will often show more forgetting of items from a 'forget' list (Delaney & Sahakyan, 2007); are more likely to incorrectly hear their own name in an unattended dichotic listening task (Conway, Cowan, & Bunting, 2001); will exhibit a smaller facilitation effect when completing the Stroop task (Kane & Engle, 2003); and perform worse on surprise memory tests of neutral words from a Stroop task that they previously completed (Shipstead & Broadway, 2013). These findings might suggest that when higher WMC individuals are engaging in higher cognitive functions they exhibit some sort of costs in performance. In order to utilize higher cognitive strategies, like proactive control, individuals are required to dedicate great deal of cognitive resources to activity maintain that strategy method. Furthermore, although these types of strategy methods could be beneficial in one situation it can actually be detrimental in another as valuable cognitive resources are wasted on a strategy that will lead to no real advantages.

The present study suggests that both modes of control are readily available to both low and high WMC induvial. Low WMC individuals were capable of utilizing a more proactive mode of control without it overloading their cognitive resources. It is possible that low WMC individuals bias towards reactive as an effort to save cognitive resources. This can be described as a “path of least resistance” approach to a task. It may be the case that low WMC individuals automatically begin with the simplest and least cognitive intensive strategy and first determine the successfulness and effectiveness of that strategy method before moving onto more robust methods. Some relationship may exist between how efficient and accurate an individual is in a task and how much cognitive resources they allow for that given task. This can somewhat be seen in the present study. The number of cognitive resources required to effectively complete the AX-CPT-color increased from the no color rule to the color rule condition. In response, all participants increased in PBI and began to respond in a more proactive behavior. However, while all participants shifted towards proactivity, high WMC still had greater PBI scores than low WMC in both the no color and color rule condition (see Figure 2). Even though proactivity can be induced in a low WMC individuals, there may still be a limit to how much proactivity can be induced in these individuals. With the current manipulation, low WMC individuals were required to hold two stimuli in memory (i.e., letter and color). However, with the addition of two or three more stimuli to the task it could reveal a limit to how much proactivity could be induced in lower WMC individuals. There are two possible outcomes that could occur. We could continue to see both low and high WMC individuals increase in proactivity until both groups reach the same PBI level. Alternatively, the gap between the low and high could continue to grow as the task becomes so difficult it could only be completed by individuals with high WMC. In this situation, both low and high WMC groups put in the same amount of effort and motivation into completing the task. However, even though both groups put in the same effort the high WMC group has access to greater resources and are able to operate at a comfortable level of proactivity that would be straining for the low WMC group. That is, the difference in cognitive resources is a physical restraint in lower WMC individuals and will prevent them from ever reaching a level of proactivity comparable to higher WMC individuals. This would need to be tested in a follow up experiment as this would reveal how modes of control are evoked in individuals with varying levels of WMC. Specifically, it may help reveal which specific factors lead an individual to adopt one mode over another. For example, how “perceived effectiveness” of a specific strategy method impacts an individual’s decision to bias towards that strategy method.

By only varying the rule condition we were able to keep the AX-CPT-color task consistent between each session and remove color as a possible explanation for the increased proactivity that was observed in the color rule condition. We did not expected color to have an effect in the no color rule condition. At most, we expected that color might be encoded but that information would ultimately be ignored as it wasn't useful for completing the task. However, during data analysis, we discovered that color had an effect on behavior in not only the color rule condition but in the no color rule condition as well. With a 2 (Color match: mismatch vs. match) x 2 (Instruction type: color rule vs. no color rule) x 2 (WMC: low vs. high) mixed design for each AX, AY, and BX trial types we were able to determine that a significant relationship exists between color match and WMC. For the no color rule condition, where color match requirements were not included in the instructions, we discovered that the low and high WMC groups responded differently depending on if the trial was a color mismatch or match. The most drastic difference was found with AX trials where the low WMC group made more errors than the high WMC group on mismatching trials but the exact opposite was found for matching trials (see Figure 5). For AY trial types, we found similar findings in that when compared to high WMC individuals, participants with low WMC were slower on mismatching trials than matching trials. Interestingly, for BX trials all participants performed better on mismatching trails than matching trials but this could have been an effect of low power. It is unclear why a cue-probe color mismatch or match had an effect on behavior when there was no color rule in effect. One possible explanation for this occurrence is that the color aided in segmenting the cue and probe from one another creating an "event boundary" in a similar way that you might see with a locational cue-probe shift (Reimer et al., 2015). When measuring the effects of locational shifts in modes of control a manipulation similar to color match is applied to the traditional AX-CPT. Rather than cues and probes mismatching or matching in color they are presented on either the same or different side of a computer screen. A location shift manipulation yields the same results as what was found in the present study with a color manipulation. Providing an event boundary between that cue and the probe enhances participants cognition relative to when there is no event boundary. Furthermore, Reimer et al., (2015) also tested the effects of color in order to determine if a general change to the cue and probe, that was not a locational shift, was capable of producing a change in cognition. They determined that color had no effect but they did not account for WMC as a variable and were unable to capture the differences found between low and high WMC individuals. Had they accounted for color they could have possible seen variation in behavior depending on trial type and WMC. The effect of color in the AX-CPT is still a relatively new concept and requires further research. Specifically, the effects of color on individuals with varying levels of WMC.

Limitations

Unfortunately, keeping the task consistent throughout each session also left the design vulnerable to test-retest effects. This was unavoidable due to the nature of our manipulation. In the present study, counterbalancing the AX-CPT-color between sessions was not a possibility due to the fact that participants had to compete the “no color condition” first. Had participants first completed the color rule condition it would have eliminated the option of using the no color rule condition as a baseline for PBI. A possible work around to this problem would be to pair the AX-CPT-color with a similar “high load” task that also measures modes of control. With the addition of a second task, it then becomes possible to counter balance each task with each version of the task. By doing this, it would eliminate test-retest effects from becoming a potential explanation for increased proactivity. This would further reveal how modes of control is affected by “high load” cognitive control tasks and should be a considered a natural progression of this study.

The present study was also conducted during the “novel” coronavirus (nCoV-19) pandemic. As a result, we faced some unique limitations during the data collection phase due to the nationwide pandemic and mandatory lockdowns. Participants were unable to physically appear in the research lab for testing during the campus lockdown. Therefore, data collection was shifted to an online format that utilized an online remote testing software called Inquisit Web. With the purchase of an Inquisit license researches were given access to the “Millisecond Test Library”, an open-source library of over 705 well-known cognitive tasks. A version of the AX-CPT was present in this library and was recoded to include a color manipulation. The task was changed to include double the trials to account for the mismatch vs. match trial types. However, this caused some issues during testing and data analysis. The task had to be extended to 30 mins in order to include all the necessary trial types for testing. In order to reduce participant exhaustion, the AX-CPT-color was split up into two identical parts that was taken back-to-back with a 2-3 min. break in-between tasks. While the break did help reduce some exhaustions there were common comments from participants after completing the task. These comments included remarks like, “It was long and difficult to focus towards the end” or “Towards the end I kept expecting it to end but it just kept going”. This suggests that the task may have been too long and should have possible been reduced in the number of trials. During data analysis, another issue arose while comparing AX mismatch trials in the no color rule vs. color rule condition. In the no color rule condition, AX mismatch trials were considered valid targets and could be used in all AX analysis. However, this no longer becomes true when there is a color rule in effect. A mismatching AX trial becomes a non-valid target and could no longer be compared to its “no color rule” counterpart. These trials could be considered either AY or BX trials depending on the mode of control. Due to this fact, mismatch AX trials were thrown out of analysis and as a result our power was greatly reduced for AX trials. A portion of AX mismatch trials should have been changed to matching trials in the color rule condition in order to increase power.

There was also an issue with obtaining the tasks for the WMC measure. The three recommended tasks for creating a composite measure for WMC are operation span (OSPAN), spatial span (SSPAN), and rotation span (RoSPAN)

(Foster et al., 2015). However, the Millisecond Test Library only had two of the required tasks, OSPAN and SSPAN. There was a version of reading span (RSPAN) present in the test library and this task was chosen as a replacement for RoSPAN. While this change is not expected to have a large effect on the overall composite span score, it is recommended to use RoSPAN when possible. Other issues that were faced arose from the online software itself. The Inquisit software required participants to download a web add-on onto their browsers that allowed for remote data collection. While most participants ran into no issue, there were some that had technical difficulties causing them to restart; or had logged into the session in a nosy environment. With remote testing, it becomes impossible to control for all the variables that are present in a participant testing environment. While remote testing does provide benefits for researchers it is still not comparable to the controlled environment that could be achieved within a research lab.

Conclusion

The present study provided further evidence to how modes of control are activated in individuals with varying levels of WMC. However, in order to be resolved, this issue requires additional research and should be researched in future studies. While it appears that perceived cognitive load is capable of altering modes of control there are still many competing variables that still need to be explored. This is an important field in psychological research as it provides insight into how cognition works and how it can be altered. It could potentially assist in early intervention programs and aid in identifying individuals with deficits in order to provide them adequate resources to help them improve in performance. As additional data provides insight into how different modes of control are activated researchers will be better able to recommend effective strategy methods to help improve cognition in lower WMC individuals.

APPENDIX A

INFORMED CONSENT

Informed Consent

You are invited to participate in a study designed to investigate the nature of cognitive control strategies in college students. This study is being conducted by Mina Selim, Graduate Student, and Dr. Jason Reimer, Professor of Psychology. The University asks that we obtain your consent before your participation in this study. This study has been reviewed and approved by the California State University San Bernardino Institutional Review Board.

PURPOSE: The purpose of this study is to assess the use of control strategies during a cognitive control task.

DESCRIPTION: In this study, you will be asked to complete two tasks: a working memory task and a cognitive control task. Both tasks will be administered online (remotely). In the working memory task, you will be required to remember items (e.g., letters, locations, and arrow orientations) while completing math problems, making symmetry decisions, or processing letter orientations. The cognitive control task involves the presentation of letters on a computer screen. The task requires you to remember each letter and make responses depending on the specific combination of letters and colors that you see. These tasks will be completed during across two test sessions. The first session will take approximately 1 hour each to complete, and the second session 30 min to complete. The sessions must be completed within one week. During the tasks, response times and accuracy will be recorded.

In order to complete the study, you must have a personal computer. All the tasks will be completed online (remotely) and will require you to download a small, free program onto your computer in order to run the tasks. You may delete the program after your participation ends. The program does not collect any personal information and does not log IP addresses. You will also be required to meet with a researcher on Zoom during your testing session in order to collect some demographic information and to provide you download and task instructions. The Zoom meetings will be private, and will not be recorded in any way.

PARTICIPATION: Your participation in this study is entirely voluntary. You are free to withdraw your participation at any time during the study, or refuse to answer any specific question, without penalty or withdrawal of benefit to which you are otherwise entitled.

CONFIDENTIALITY: While identifying information (i.e., names) will be collected during the study in order to provide you with your compensation (SONA research units), this information will be kept in a locked laboratory room that is accessible to only the researchers. Identifying information will be destroyed once data collection has been completed. The final data set will be stripped of this information to protect participant confidentiality. Data will be stored indefinitely on a password-protected hard drive and on a secure server (without any identifying information) on Millisecond (the software company) servers. The results of this study may be submitted for publication in a scientific journal. Analyses of the data will be conducted on group responses and not individual responses.

DURATION: Participation will require approximately 1.5 hours of your time (a 1-hour session and a 30-minute session).
RISKS: This study involves no risk beyond those routinely encountered in daily life. Participants will be informed of their right to discontinue at any time.
BENEFITS & COMPENSATION: There are no direct benefits to you as a result of participating in this study. However, if you complete both sessions of the study, you will receive 6 SONA research units that may be converted to course extra credit at your instructor's discretion. If you only complete the first session you will receive 4 SONA research units.
RESULTS AND CONTACT: All data will be reported in group form only. You may receive the group results of this study after September 2020 by contacting Jason Reimer at jreimer@csusb.edu. If you have any questions or concerns about this study, please feel free to contact Jason Reimer at jreimer@csusb.edu. You may also contact the Human Subjects office at California State University, San Bernardino (909) 537-7588 if you have any questions or concerns about this study.
I acknowledge that I have been informed of and understand the true nature and purpose of this study, and I freely consent to participate. I acknowledge that I am at least 18 years of age. Please indicate your desire to participate by placing and "X" on the line below.
Participant's X _______
Date: ___________

APPENDIX B

INSTITUTIONAL REVIEW BOARD APPROVAL

May 19, 2020

CSUSB INSTITUTIONAL REVIEW BOARD

Administrative/Exempt Review Determination Status: Determined Exempt
IRB-FY2020-261

Mina Selim and Jason Reimer
Department of CSBS - Psychology
California State University, San Bernardino
5500 University Parkway
San Bernardino, California 92407

Dear Jason Reimer:

Your application to use human subjects, titled “Inducing Proactive Control with High Load AX-CPT” has been reviewed and approved by the Chair of the Institutional Review Board (IRB) of California State University, San Bernardino has determined that your application meets the requirements for exemption from IRB review Federal requirements under 45 CFR 46. As the researcher under the exempt category, you do not have to follow the requirements under 45 CFR 46 which requires annual renewal and documentation of written informed consent which are not required for the exempt category. However, exempt status still requires you to attain consent from participants before conducting your research as needed. Please ensure your CITI Human Subjects Training is kept up-to-date and current throughout the study.

Your IRB proposal ([Protocol Name, Protocol Number]) is approved. You are permitted to collect information from [Enter Number of Participants] participants for [Compensation]from [Specify Sample Source]. This approval is valid from [Date] to [Date].

The CSUSB IRB has not evaluated your proposal for scientific merit, except to weigh the risk to the human participants and the aspects of the proposal related to potential risk and benefit. This approval notice does not replace any departmental or additional approvals which may be required.

Your responsibilities as the researcher/investigator include reporting to the IRB Committee the following three requirements highlighted below. Please note failure of the investigator to notify the IRB of the below requirements may result in disciplinary action.

- Submit a protocol modification (change) form if any changes (no matter how minor) are proposed in your study for review and approval by the IRB before implemented in your study to ensure the risk level to participants has not increased,

- If any unanticipated/adverse events are experienced by subjects during your research, and
- Submit a study closure through the Cayuse IRB submission system when your study has ended.

The protocol modification, adverse/unanticipated event, and closure forms are located in the Cayuse IRB System. If you have any questions regarding the IRB decision, please contact Michael Gillespie, the Research Compliance Officer. Mr. Michael Gillespie can be reached by phone at (909) 537-7588, by fax at (909) 537-7028, or by email at mgillesp@csusb.edu. Please include your application approval identification number (listed at the top) in all correspondence.

If you have any questions regarding the IRB decision, please contact Dr. Jacob Jones, Assistant Professor of Psychology. Dr. Jones can be reached by email at Jacob.Jones@csusb.edu. Please include your application approval identification number (listed at the top) in all correspondence.

Best of luck with your research.

Sincerely,

Donna Garcia

Donna Garcia, Ph.D., IRB Chair
CSUSB Institutional Review Board

DG/MG

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