AGE-RELATED DIFFERENCES IN COGNITIVE CONTROL: AN ERP STUDY OF INTERNALLY DIRECTED ATTENTION

by

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ABSTRACT

MONICA NELSON. Age-Related Differences in Cognitive Control: An ERP Study of Internally Directed Attention. (Under the direction of DR. MARK FAUST)

Attention and working memory are two cognitive abilities that have been the target of research to determine whether they are independent (Baddeley, 2003) or related constructs (Kiyonaga & Egner, 2013). Modifying traditional attention tasks to incorporate a working memory component allows direct investigation of this question. The first aim of the present study was to provide further evidence of the relatedness of attention and working memory by measuring behavioral and electrophysiological markers in a modified Stroop task (internal task originally developed by Kiyonaga & Egner, 2014). A second, related goal was to determine the extent to which the Dual Mechanisms of Control (DMC) theory (Braver, 2012) adequately explains patterns found in response to this modified Stroop task. Cognitive control is the process through which an individual maintains goal-directed behavior in the presence of ambiguous or conflicting information (i.e., staying on task; Abrahamse, Braem, Notebaert, & Verguts, 2016). The DMC theory states that there are two types of cognitive control—proactive and reactive—which have been dissociated in traditional distractor-interference attention tasks (Braver, 2012). Finally, the current study aimed to determine the extent to which young and older adults utilize similar control mechanisms in response to the modified Stroop task. The DMC proposes that aging results in diminished proactive but relatively preserved reactive control (Braver, Paxton, Locke, & Barch, 2009). The task used a list-wide proportion congruency manipulation in order to elicit conditions of proactive control (Gonthier, Braver, & Bugg, 2016). Results indicated a reduced Stroop interference effect in the mostly incongruent block compared to the mostly congruent block, evidence of Stroop interference disrupting response times to later memory retrieval, and confirmation of Flanker-like N2 effects in the ERP results of the internal task (Faust et al., 2017; 2018). Limited behavioral evidence for proactive control was found, as neither transfer effects nor congruency costs were found. Age-related results include a reduced Stroop interference effect in mean response times for older adults compared to young adults, a greater disruption in word retrieval time for older adults than for young adults, and differential ERP patterns found for young and older adults.

Keywords: Dual Mechanisms of Control Theory, Proactive Control, Reactive Control, Internal Stroop Task, Older Adults, ERPs

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LIST OF ABBREVIATIONS

ACC	Anterior Cingulate Cortex
ANOVA	Analysis of Variance
AX-CPT	AX Continuous Performance Test
dlPFC	Dorsolateral Prefrontal Cortex
DMC	Dual Mechanisms of Control
EEG	Electroencephalogram
ERP	Event Related Potential
LPC	Late Positive Component
LWMC	List-wide Mostly Congruent
LWMI	List-wide Mostly Incongruent
MC	Mostly Congruent
MFN	Medial Frontal Negativity
MI	Mostly Incongruent
MPN	Medial Posterior Negativity
ms	Milliseconds
PC	Proportion Congruency
PFC	Prefrontal Cortex
SOA	Stimulus Onset Asynchrony
SP	Conflict Slow Wave Potential or Parietal Sustained Potential

CHAPTER 1: INTRODUCTION

A hallmark of attention is the ability to focus on relevant information while ignoring distracting information (Aschenbrenner & Balota, 2015; Prakash et al., 2009). However, the presence of distracting information in the form of conflict (e.g., incongruency between the ink color [red] and the word [blue] in a Stroop task where the task is to respond to the color of the ink and ignore the semantic meaning of the word; Stroop, 1935) requires the brain to adjust its resources in order to respond correctly (Prakash et al., 2009).

Working memory is perceived as a place to manipulate internal information and to maintain goals (Kiyonaga & Egner, 2014). One traditional model of working memory proposes that working memory is composed of four interrelated components, the phonological loop, the visuospatial sketchpad, the central executive, and the episodic buffer (Baddeley, 2003). The phonological loop is used for verbal information, which has components that allow for short-term storage and rehearsal of this verbal information (Baddeley, 2003). The visuo-spatial sketchpad incorporates visual and spatial information that is to be remembered (Baddeley, 2003). A later added component is the episodic buffer which is conceptualized as the component that links long-term memory knowledge to current working memory goals (Baddeley, 2003). Finally, the central executive is conceptualized as the controller of working memory that allocates cognitive resources to either the phonological loop or the visuo-spatial sketchpad (Baddeley, 2003).

Whether the separate controller originally proposed by Baddeley actually exists has been challenged by researchers who have conceptualized working memory as utilizing the same processing resources as external attention (Engle, 2018; Kiyonaga &

Egner, 2013; Meier & Kane, 2017). The distinction between working memory and attention is less than clear, as these concepts seem to rely on the same cognitive resources and can influence one another in either a facilitative or inhibitive manner (see Kiyonaga & Egner, 2013 for theoretical review). Kiyonaga and Egner (2013) suggest that working memory can be conceptualized as internally directed attention that has a bidirectional relationship with externally directed attention, which are both governed by a limited cognitive capacity. The ability to modulate the interaction between internally and externally directed attention then seems to be executed by cognitive control, which allocates limited cognitive resources to respond most efficiently to current goals by facilitating task-relevant information and inhibiting task-irrelevant information (Bugg, 2014a).

Cognitive control is defined as a mechanism through which goal-directed behavior is accomplished in the midst of ambiguous or conflicting information (Abrahamse et al., 2016). The level of cognitive control needed to respond to tasks is influenced by the level of intentional or automatic goals in situations (Sahinoglu & Dogan, 2016). Intentional goals result in behaviors that are task relevant, voluntary responses. Automatic goals result in behaviors that can be task relevant, but are overlearned resulting in quick, involuntary responses. In most situations, both intentional and automatic goals overlap (e.g., a congruent trial [red word written in red ink] in a Stroop task), leading to the facilitation of a response (Sahinoglu & Dogan, 2016). However, when intentional and automatic goals compete (e.g., an incongruent trial [red word written in blue ink] in a Stroop task), there is a need for additional processing resources in order to respond correctly and override the automatic response (Sahinoglu & Dogan, 2016).

Abrahamse and colleagues (2016) review the four main experimental manipulations of cognitive control, namely conflict adaptation, task switching, response inhibition, and attentional control. They note that although these four types of cognitive control tasks have often been studied in isolation that they share specific components, including being influenced by context and reward and the lack of awareness needed for performance. Abrahamse and colleagues (2016) propose that these four control domains are all rooted in associative learning, meaning the extent to which task-relevant information or goals are learned throughout the course of the task influences patterns found within these tasks. Other researchers use the term executive function for cognitive control (Banich, 2009). Although using different terminology, executive function is also described as the ability to motivate goal-directed behavior in the presence of conflicting, unknown, or novel information. Deficits in executive functioning have been found in both developmental (children, adolescents, older adults) and psychiatric (e.g., depression, schizophrenia) conditions.

There are different theoretical constructs that aim to describe the role of cognitive control in behavior, notably the three-process model (Miyake et al., 2000), the conflict-monitoring theory (Botvinick, Braver, Barch, Carter, & Cohen, 2001), and the two-process model (Braver, Gray, & Burgess, 2007). Miyake and colleagues (2000) provided evidence for three main types of executive functions (shifting, updating, and inhibition) that are distinct but share some underlying cognitive resources. They found that these functions are the driving components to patterns found in tests of high-level executive functioning. In situations when conflict is present, cognitive control is especially needed to modulate resources to achieve goals through these limited and individual capacities (Botvinick et al., 2001). Botvinick et al. (2001) proposed that there is a cognitive system that monitors for the presence of conflict between information in the environment that then signals for modulations in the allocation of control when conflict is detected. This work is supported by the fact that the anterior cingulate cortex (ACC) has been found to become activated in the presence of conflict (Botvinick et al., 2001). Researchers have identified that the dorsolateral and ventrolateral prefrontal cortex (PFC) and the anterior cingulate cortex (ACC) are especially important for cognitive control and conflict, respectively (Larson, Clayson, & Clawson, 2014). Braver and colleagues (2007) have proposed the *Dual Mechanisms of Control Theory* (DMC) which refined the focus of the conflict monitoring theory (Botvinick et al., 2001) shifting the focus from specifically how conflict monitoring modulates the allocation of cognitive control to a dual-process model that includes both an early and late control mechanism to modulate cognitive resources.

1.1. Dual Mechanisms of Control Theory

The Dual Mechanisms of Control Theory hypothesizes differential patterns with cognitive control in response to conflicting information (Braver et al., 2007). The Dual Mechanisms of Control Theory states that there are two types of cognitive control, proactive and reactive (Braver, 2012). Based on the goals of the task and individual differences, participants will use either proactive or reactive control (Braver, 2012). Proactive control is a more global control mechanism that individuals use to actively maintain task goals (Braver, 2012). Although it requires more cognitive capacity to be allocated to goal maintenance, proactive control is also more efficient at processing stimuli (Braver, 2012). Proactive control has been described as an “early selection” mechanism, since task goals are biasing performance before the presentation of cognitively demanding tasks (Braver, 2012, p. 106). Additionally, proactive control has a forward-acting nature that prepares individuals for upcoming events often due to the learned knowledge of biased probabilities from recent experiences. Contrastingly, reactive control reactivates task goals on an as-needed basis—that is, when task goals are needed to process stimuli, as in the case of conflict—requiring lower overall cognitive capacity and potentially less efficient processing of stimuli (Braver, 2012). Reactive control is described as a “late correction mechanism,” since utilization of this control mechanism occurs after the presentation of cognitively demanding tasks (Braver, 2012, p. 106). Additionally, reactive control is a stimulus-driven reaction that is used when pre-learned patterns are consistent with current goals.

Not only are behavioral differences predicted to arise from utilizing these control mechanisms, but also differential brain activity is thought to be associated with these control mechanisms (Braver, 2012). Specifically, proactive control is predicted to be associated with sustained activation in the lateral PFC, while reactive control is predicted to be associated with transient activation in the lateral PFC in response to a stimulus event (Braver, 2012). Differentiation between proactive and reactive control has also been demonstrated through task manipulations, individual differences in working memory capacity and personality traits, and age-related or clinical contributions (Braver, 2012).

1.1.1. Testing the DMC Theory

In many tests of cognitive control, participants must ignore the presence of distracting information while attending to task-relevant information (i.e., a distractor-interference task; Larson, Clayson, Kirwan, & Weissman, 2016). Examples of distractor-interference tasks include attending to the color of the word while ignoring the semantic meaning of the word in the Stroop task and attending to the central target identity while ignoring the flankers' identity in the Flanker task (Larson et al., 2016). The classic Stroop effect is a slowing of response times when presented with an incongruent trial compared to a congruent trial (Bugg, DeLosh, Davalos, & Davis, 2007; Kiyonaga & Egner, 2014; Larson et al., 2016). One common type of manipulation that changes the Stroop effect is the proportion of conflict trials (i.e., having a higher proportion of incongruent trials [the word "RED" written in blue ink] reduces the Stroop interference effect; Gonthier, Braver, & Bugg, 2016). Participants are able to learn the rules for a specific block of trials, which then modulates how they respond to the task (i.e., facilitation on incongruent trials in a mostly incongruent block compared to a mostly congruent block; Gonthier et al., 2016). According to the DMC, aspects of the blocks can contribute to either a biasing of goals that occurs before a trial occurs or in reaction to the trial when it occurs (Gonthier et al., 2016).

Cognitive tests motivated by the DMC aim to dissociate the influence of proactive and reactive control though different experimental manipulations. For example, Gonthier and colleagues (2016) used list-wide and item-specific proportion congruency manipulations in a picture-word interference task (a modified Stroop task) in order to

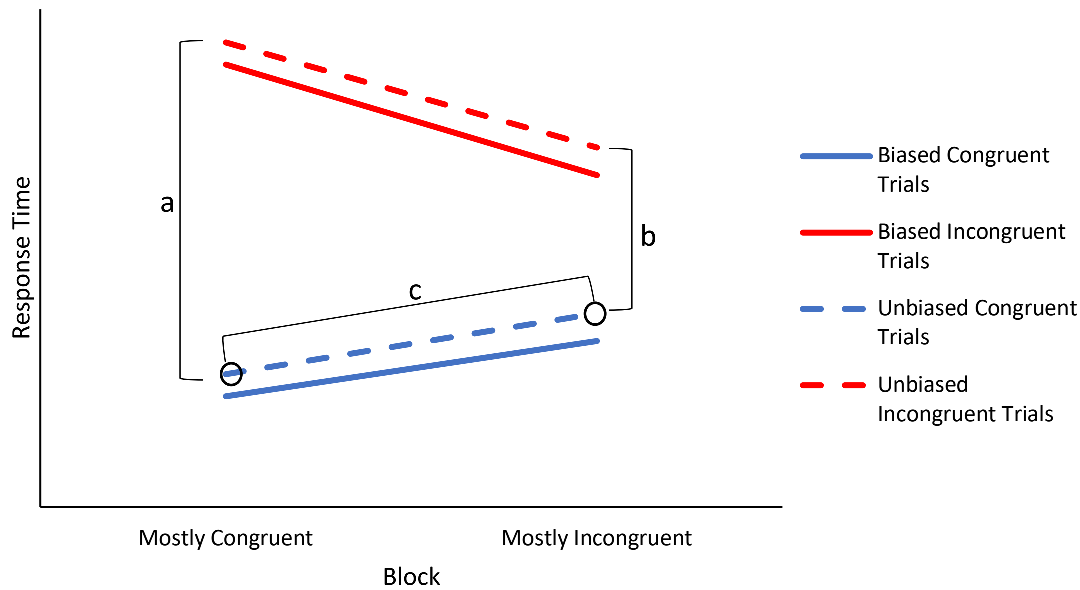

Figure 1. Example of effects that result from block proportionality manipulations. Biased trials evidence a reduced Stroop interference effect (smaller difference between incongruent and congruent trials) in the mostly incongruent block compared to the mostly congruent block. Unbiased trials (50% congruency) also evidence a reduced Stroop interference effect in the mostly incongruent block compared to the mostly congruent block (difference between a and b) since task goals are transferring to the unbiased items. Unbiased (50% congruency) congruent trials in the presence of the mostly incongruent block evidence a slowing of congruent trials compared to unbiased congruent trials in the mostly congruent block (congruency cost illustrated by c). Both the transfer and congruency cost provide evidence for proactive control. Adapted from “Dissociating proactive and reactive control in the Stroop task,” by C. Gonthier, T. S. Braver, and J. M. Bugg, *Memory and Cognition*, p. 781. Copyright 2016 by Psychonomic Society, Inc.

disentangle the control effects demonstrated by proactive and reactive control (see Figure 1 for example of list-wide congruency predictions). In this task, participants received pictures (the relevant dimension) with words (the irrelevant dimension) superimposed on them. Participants had to name the picture while ignoring the word (i.e., participants could see a picture of a bird with the word “BIRD” written on it [congruent trial] or the word “CAT” written on it [incongruent trial]). Thus, this task represents a distractor-interference task, as the word reading interferes with the naming of the picture. Gonthier and colleagues (2016) manipulated congruency over the entire list to be 75% or 25% congruent in the list-wide blocks and manipulated congruency for specific items to be either 75% or 25% congruent in the item-specific block (with the overall congruency in this block set at 50%). The congruency manipulations were based on the relevant (picture) dimension instead of the irrelevant (word) dimension. According to the DMC theory, the list-wide manipulations should result in proactive control, since more cognitive resources would be allocated to prepare for a conflict trial before it occurs (Gonthier et al., 2016). Due to the globally biased nature of the list-wide block, individuals would benefit from biasing their cognitive resources in a block manner and would thus use proactive control. Contrarily, an item-specific manipulation (as overall congruency for the block is maintained at 50%) should result in reactive control, since a predictive biasing of a response would not be possible; rather, the item-specific nature of the trials would signal the need for control after the pictures have been experienced by the participant (Gonthier et al., 2016). Critically, it is only after the presentation of the picture that goal-related information could be utilized by participants since the overall block proportionality would not bias responses meaningfully. Importantly, Gonthier and colleagues (2016) also included equal congruency trials that allowed examination of transfer effects. A transfer effect is defined as the reduction in Stroop interference in an unbiased (50% congruent) list of items in the presence of a biased block (Gonthier et al., 2016). Transfer effects occur when an individual is using proactive control; specifically, the task goals from the list-wide congruency manipulation are transferred to the equally congruent items in the block thereby reducing the Stroop interference effect (Gonthier et al., 2016). They found that in the list-wide blocks, the Stroop interference effect was reduced in the mostly incongruent compared to the mostly congruent block (a finding that has replicated across a number of studies—see Gonthier et al., 2016 for examples), and that this effect transferred to the unbiased list. This pattern illustrates proactive control as task goals utilized in the mostly incongruent block modulated the Stroop interference effect in items that have an equal likelihood of appearing in a congruent or incongruent form (i.e., pictures that are presented with the same word ["COW" written on a picture cow] or a different word ["FROG" written on a picture of a cow] in equal probability).

Gonthier et al., (2016) also found that there was an item-specific effect as the Stroop interference effect was reduced for the mostly incongruent items compared to the mostly congruent items. The item-specific effect reflects reactive control, because instead of manipulating the overall block congruency (it is maintained at 50% congruency), the manipulation is in an item-specific manner (Gonthier et al., 2016). The item-specific effect allows researchers to compare items that have been assigned high incongruency with high congruency—any modulation of the Stroop interference effect could then only be attributed to the congruency manipulation of the item since the overall block congruency is maintained at 50% (Gonthier et al., 2016). The item-specific effect should also specifically result in reactive control since it is only after the presentation of the item that control settings can be implemented (i.e., participants cannot predict ahead of time whether a trial will be congruent or incongruent since their overall congruency state is 50%; Gonthier et al., 2016). Notably, this effect did not transfer to the unbiased items, indicating that reactive control is being used to respond to the specific nature of the items instead of in a sustained method for the block (Gonthier et al., 2016). This lack of transfer represents the use of reactive control since the participant does not have cognitive resources that are biasing their response towards the picture dimension; rather, in the presence of unpredictable conflict, any modulation could only be made in response to goals associated with specific items on an as-needed basis.

Gonthier and colleagues (2016) also demonstrated that proactive and reactive control mechanisms can result in specific costs, providing further evidence for their dissociation. Specifically, only the list-wide blocks were affected by a congruency cost, in that individuals were slower to respond to congruent items that were 50% congruent in the incongruent block compared to the congruent block, indicating that participants were using task goals instead of the facilitative word information. The congruency cost is an effect representative of proactive control, since individuals are using cognitive resources that are biasing their response to the relevant picture dimension instead of the irrelevant (although facilitative) word dimension (Gonthier et al., 2016). Additionally, the item-specific block was affected to a greater extent by a transfer cost, meaning that there was greater interference moving from the 25% congruent items to the 50% congruent items. This effect is representative of reactive control, since cognitive resources that are utilized after the presentation of the trial were specific to the items' congruency manipulations, rather than an overall biasing towards task goals (Gonthier et al., 2016). Thus, task goals were not maintained in this block; rather, participants were more likely to utilize reactive control and respond on a trial-by-trial basis instead of globally. Illustrating both the benefits and costs that are unique to each of these control mechanisms garners further support for the separation of these mechanisms.

Bugg and Hutchison (2013) also provide evidence for the dissociation of proactive and reactive control by utilizing list-wide and item-specific congruency manipulations. Their task utilized a traditional color-word Stroop interference task, in which participants must respond to the color of a word while ignoring the meaning of the word. An example of a congruent display is the word “RED” written in red, whereas an incongruent display is the word “RED” written in blue. They also suggest that list-wide congruency manipulations are consistent with proactive control while item-specific congruency manipulations are consistent with reactive control. Bugg and Hutchison (2013) find evidence for transfer of item-specific effects, in that mostly incongruent colors are responded to faster than mostly congruent colors when paired with a novel incongruent word. This transfer effect seems to be due to the item-specific nature of the colors, rather than maintained task goals.

Not only is there behavioral evidence for the dissociation of proactive and reactive control, but also there is electrophysiological evidence for the separation of these components. Irlbacher, Kraft, Kehrer, and Brandt (2014) reviewed fMRI and ERP studies, finding evidence of different brain networks utilized by proactive and reactive control. They propose that reactive control is comprised of a network including the bilateral inferior frontal gyrus, the left dorsolateral prefrontal cortex, the lateral parietal lobe, and the right pre-supplementary motor area. They propose that proactive control is comprised of a network including the pre-supplementary motor area, the left dorsolateral prefrontal cortex, the left inferior frontal gyrus, and inferior parietal regions. Irlbacher and colleagues (2014) note that the temporal dynamics of proactive and reactive control differ, providing evidence for the DMC theory. Further, West and Bailey (2012) conducted an ERP study using a counting Stroop task to identify whether electrophysiologically proactive and reactive control are unique. Specifically, they proposed that the hallmark component of the Stroop task, the N450, can be divided into the medial frontal negativity (MFN) and the medial posterior negativity (MPN) which represent proactive and reactive control, respectively. Also included in their analyses were the frontal positivity and the parietal sustained potential (SP). They modulated the proportionality of the counting Stroop task, predicting that the mostly congruent block would be associated with reactive control while the mostly incongruent block would be associated with proactive control. West and Bailey (2012) found that the MFN was significantly associated with the mostly incongruent block and the MPN was significantly associated with the mostly congruent block. They also found evidence to suggest that the frontal positivity is associated with reactive control while the sustained potential is associated with proactive control. Behaviorally, they found a larger Stroop effect in the congruent block compared to the incongruent block and lower accuracy of the incongruent trials in the congruent block compared to the incongruent block. Thus, by illustrating behavioral and electrophysiological differences in congruency manipulations of the counting Stroop task, West and Bailey (2012) provide further evidence for the DMC theory. However, whether the differentiation of the N450 is replicable across variations of the Stroop task remains to be investigated.

1.1.2. DMC and Aging

Young and older adults have been found to utilize different control strategies, but training, and modulation of penalty and reward can also change the control mechanism utilized (Braver, Paxton, Locke, & Barch, 2009). In some types of cognitive tasks, older adults show deficits, while other tasks are preserved. The DMC theory predicts preservation of reactive control in older adults whereas proactive control should show declines (Braver et al., 2009). Braver and colleagues (2009) illustrate this effect through their use of the AX Continuous Performance Test (or AX-CPT). In this task, the goal is to respond to a probe (X) but only when it is preceded by a certain cue (A). Other task types include AY trials, in which the correct cue is presented, but it is followed by a non-target probe; BX trials, in which the probe is presented after an incorrect cue; and BY trials, in which neither the cue nor the probe are correct (Braver, Cohen, & Barch, 2002). Braver and colleagues (2009) note that greater neural activation of the lateral PFC during the cue-phase is associated with proactive control whereas greater activation during the probe-phase is associated with reactive control. Braver et al. (2009) provide evidence for the fact that young adults seem to utilize proactive control whereas older adults utilize reactive control; however, inducing penalty or implementing training can alter the control strategy used by these respective groups. Braver and colleagues (2009) suggest that the initial patterns of control processes utilized by older adults likely represent a compensatory mechanism that results from the diminishment of goal maintenance.

The DMC has become important for testing age-related differences in cognitive control (Braver et al., 2009; Bugg, 2014a, 2014b). Some researchers have used distractor-interference tasks (such as the Stroop) to illustrate age-related differences in cognitive control strategies (Bugg, 2014a, 2014b). In support of the DMC theory, researchers have found that reactive control is preserved in aging (Bugg, 2014b), while proactive control shows detriment in aging (Bugg, 2014a). In her study, Bugg (2014a) conducted several experiments to test the list-wide congruency manipulation effects in young and older adults. She included a mostly congruent block and a mostly incongruent block that had a list of 50% congruent items intermixed between these blocks. Evidence for proactive control would be provided if there was a significant reduction in the Stroop interference effect for the 50% congruent items in the mostly incongruent block compared to the mostly congruent block. This reduced Stroop interference effect would indicate that task goals (i.e., attending to the color of the word instead of the meaning of the word) were transferred to items that were equally congruent or incongruent. Specifically, Bugg (2014a) found that proactive control was utilized by young adults, showing that task goals transferred to the 50% congruent items in the mostly incongruent block (i.e., participants were faster to respond to incongruent items in this block compared to incongruent items in the mostly congruent block). An inability to engage proactive control would result in similar response times for the 50% congruent items in the mostly congruent and mostly incongruent blocks because the task goals would not be transferred in this condition (Bugg, 2014a). Whereas Bugg (2014a) found that older adults exhibited a modulated Stroop interference effect for mostly incongruent items compared to mostly congruent items, they exhibited similar Stroop effects for 50% congruent items in the mostly incongruent and mostly congruent blocks. The difference in Stroop interference between the unequally congruent and equally congruent items suggests that older adults are not engaging the same control mechanism as young adults are (i.e., proactive control), since the patterns of response times converge for this group in the 50% congruent items. Bugg (2014a) provided evidence that the sustained control mechanism of proactive control declines with age. Thus, it is likely that the item-specific information learned in mostly incongruent situations contributed to the reduced Stroop effect for the mostly incongruent items compared to the mostly congruent items, instead of a global task goal modulation.

Bugg (2014b) utilized a picture-word Stroop task, modulating congruency via items, to yield mostly incongruent and mostly congruent items. She also included transfer trials which had equal congruency but were new exemplars from the same categories which had biased congruency. She found that both young and older adults exhibited less interference for the mostly incongruent items compared to the mostly congruent items, and that this effect transferred to the 50% congruent items, which were new items from the same categories. It appears that the context of the items from the mostly incongruent list transferred to these new exemplars with 50% congruency. Critically, instead of being identified as a new item, the new exemplars maintained the control settings associated with the biased items and were responded to in a trial-specific manner (Bugg, 2014b). Thus, although item-specific context information can be used by older adults to facilitate performance (evidence of preserved reactive control), transferring task goals on a global level to facilitate performance is not utilized by older adults (evidence for diminished reactive control). Therefore, tests of aging differences should include experimental manipulations to highlight the differential control mechanisms used by young and older adults.

1.2. Measuring Cognitive Control with the Stroop Task

Researchers have provided evidence that the Stroop effect reflects an individual's ability to maintain goal-directed behavior in spite of cognitive conflict that results from the presentation of distractor interference (the semantic meaning of the word) that can match or conflict with the target information (the color of the word; Abrahamse et al., 2016). Proponents of the control account of the Stroop effect propose that cognitive control is needed to accurately respond to incongruent trials (Gonthier et al., 2016), since cognitive resources are needed to bias attention away from providing the automatic response (reading the word) to providing the intentional response (saying the color; Sahinoglu & Dogan, 2016). The level of control needed can be modulated based on manipulations of congruency (e.g., in a mostly congruent block, word reading is frequently facilitative, so little control is needed for correct responses, whereas in a mostly incongruent block, frequent conflict signals a greater need for cognitive control resources; Gonthier et al., 2016).

Critics of a control account of the Stroop effect have argued that contingency (or associative) learning is responsible for the patterns found in the Stroop task (Bugg, 2014a). To examine whether contingency learning was the only contributor to the Stroop effect, Bugg (2014a) conducted several experiments to determine the nature of control present in various manipulations. Her work illustrated that although contingency learning effects can contribute to the Stroop effect, this seemed to occur when there are only two items that can be paired together, whereas the presence of additional items prevents predictability in incongruent items, subsequently preventing associative learning. Thus, while associative learning is present in two-color blocks in which top-down control was not needed, more demanding tasks (e.g., a four-color block) with unpredictable incongruent responses need to utilize top-down control to facilitate responses. By examining the Stroop effect in both two- and four-response sets, Bugg and Hutchison (2013) also illustrate that item-specific effects do not seem to be due to contingency learning effects when the incongruent item cannot be predicted (i.e., in four-response sets), but do contribute to the Stroop effect when the incongruent item can be predicted (i.e., in two-response sets).

1.3. Event-Related Potentials

Luck (2014) provides an overview of the event-related potential (ERP) technique. Electroencephalograms (EEGs) measure dynamic voltage changes across the scalp continuously (Luck, 2014). The electrical activity that is detected through the scalp can only be detected if several neurons are firing at approximately the same time and are oriented in approximately the same direction (so that the activity does not cancel out; Luck, 2014). The most prevalent location of neurons that are able to have their electrical activity measured via the scalp is close to the surface of the brain (specifically cortical pyramidal cells; Luck 2014). Since these cells are aligned mainly perpendicular to the scalp, the electrical field that is created can be measured on the scalp through the dipole (positive and negative voltages) created through the firing of the neurons (Luck, 2014). However, due to the folding of the cortex, the dipoles can then project their electrical fields in different directions (Luck, 2014). The ERP technique is used to create an averaged waveform of the electrical activity measured through the EEG (Luck, 2014). ERPs are stimulus-locked and reflect cognitive processes from underlying components (Luck, 2014). Although ERPs have excellent temporal resolution (detecting changes on the order of ms), the localization of ERPs is difficult due to the distributed nature of the electrical activity along the scalp and the potential contribution of multiple components to the ERP waveform (Luck, 2014). ERP waveforms are traditionally named according to the direction of the activity (P for positive or N for negative) paired with a number that either represents the location of the peak (i.e., P1 is the first positive-going peak) or the timing of the peak (i.e., N450 is a negative-going wave that peaks around 450 ms; Luck, 2014). ERPs can be described according to their amplitude or latency (the shape and onset time of the waveform, respectively; Luck, 2014).

1.3.1. ERPs and the Stroop Task

In addition to behavioral measures of the Stroop task, researchers have investigated ERP markers that are standard in the Stroop task (Liotti, Woldorff, Perez, & Mayberg, 2000; Larson et al., 2014; Larson et al., 2016). Liotti and colleagues (2000) found that electrophysiologically, there are two main timepoints that the brain seems to process interference in the Stroop task. Liotti et al. (2000) found an early component that showed divergence between congruent and incongruent trials that onsets between 350-500 ms and is more negative for incongruent compared to congruent trials (now often called the N450). Liotti and colleagues (2000) also found a later component (the late positive complex) that exhibited divergence between the congruent and incongruent trials that onsets between 500 and 800 ms post-stimulus onset and was more positive for incongruent trials than congruent trials.

More recently, Larson and colleagues (2014) reviewed ERP components characteristic of conflict tasks. Specifically, they identified the N450 and conflict slow wave potential (SP) as ERP markers typically found in the Stroop task, whereas the N2 effect is typically found in a Flanker task. Larson and colleagues (2016) described ERP components that were characteristic of the Stroop task. They found a significant N450 in the Stroop task that was more negative in incongruent trials compared to congruent trials. Larson et al. (2016) also found a significant SP in the Stroop task that was more positive in incongruent trials compared to congruent trials. The presence of these early and late components is thought to reflect conflict detection and resolution (N450) and increased cognitive control/compensatory mechanisms (SP; Larson et al., 2016). However, Liotti et al. (2000) suggested that the late positive complex could reflect the semantic processing of the word information.

1.4. Internal Stroop Task

Kiyonaga and Egner (2014) developed the Internal (Working Memory) Stroop analog task to test whether working memory is more accurately conceptualized as internally directed attention. Internally directed attention (or working memory) is attention that must be maintained endogenously since the environmental input has been removed, while externally directed attention is attention that can be maintained exogenously as the environmental input is present (Kiyonaga & Egner, 2014). The Internal Stroop task is a modification of the traditional color-word Stroop task in which participants are first presented with a distractor word, which they must maintain internally (or in memory), followed by the target patch (a colored rectangle), to which the participant must respond. Although conflict is still present in the internal Stroop task, the location of the conflict has moved (i.e., in a traditional Stroop task, both elements are presented externally, whereas in this modification, the distractor is being maintained internally while the target is presented externally). Kiyonaga and Egner (2014) compared the internal Stroop task to a traditional color-word Stroop task to determine whether behaviorally the two tasks exhibited similar results. They found evidence to suggest that the traditional Stroop and the internal Stroop task seem to utilize the same resources, as both tasks exhibited a Stroop effect in a situation of equal congruency, both tasks were similarly affected by stimulus and response conflict, and both tasks exhibited a modulated Stroop interference effect depending on the proportion of congruent and incongruent trials in a block of trials (i.e., mostly congruent, mostly incongruent, and equally congruent). Stimulus conflict is the conflict that is represented by the presence of the stimuli (i.e., the word and color dimensions that can either match or conflict; Kiyonaga & Egner, 2014). Response conflict is present when the two stimuli dimensions cue different manual responses (i.e., the participant may be presented with the word "RED" which maps to the right-hand pointer finger, written in the color blue which maps to the right-hand middle finger). Since the conflict is now at the level of the response (i.e., pressing the correct button), there is an additional dimension of conflict that must be addressed. Additionally, learning and manipulating stimulus-response mappings is a basic component of cognitive control (e.g., through a two- versus four-response option; Donahue, Appelbaum, McKay, & Woldorff, 2016), so by responding to these manipulations similarly in the tasks, Kiyonaga and Egner (2014) provide evidence that cognitive control is operating similarly between the internal (working memory) and external (attention) task. Thus, Kiyonaga and Egner (2014) concluded that working memory operates like attention behaviorally, since similar behavioral effects were found in both tasks.

1.5. Cognition and Aging Differences

Many researchers have discovered age-related differences in behavioral and neurological patterns between young and older adults. Older adults exhibit deficits in cognitive domains including memory, attention, and executive functioning (Braver & Barch, 2002). Some explanations include general slowing (Salthouse, 1996), deficient frontal lobe functioning (Pinal, Zurron, & Diaz, 2015), brain changes in the PFC and dopamine systems (Braver & Barch, 2002), and neural compensation (Grady, 2012; Park & Reuter-Lorenz, 2009; Prakash et al., 2009).

Park and Reuter-Lorenz (2009) provide a review that presents evidence of neurological changes that impact older adults that seem to be related to changes in cognition. These include shrinkage of brain volume, white matter hyperintensities, reduction of dopaminergic receptors, and dedifferentiation (Park & Reuter-Lorenz, 2009). The authors note that behaviorally, older adults exhibit declines in speed of processing, working memory, executive control processes, and long-term memory (Park & Reuter-Lorenz, 2009). Park and Reuter-Lorenz (2009) note that deficits in executive control processes are often due to dysfunctional inhibitory control mechanisms that can contribute to both the inability to ignore goal-irrelevant information and the inability to update working memory content by clearing irrelevant information. The authors also note that cognitive control is affected in aging by older adults being more impacted by automatic or prepotent responses that interfere with their ability to respond in an intentional manner. In this review, the authors propose the Scaffolding Theory of Aging and Cognition (STAC) which presents explanations of the neurological and behavioral patterns found in older adults (Park & Reuter-Lorenz, 2009). This theory states that when these various neurological changes occur, the brain often compensates by utilizing other brain regions via scaffolding (that are not damaged but are less efficient than the primary pathway) that were initially used during learning of a specific task (Park & Reuter-Lorenz, 2009). This compensation can only protect against behavioral deficits to a certain point—thus, when demanding tasks arise, deficient behavioral patterns would result (Park & Reuter-Lorenz, 2009).

Braver and Barch (2002) illustrate their view of declines that occur in cognitive aging that are critically linked to the role of cognitive control. Specifically, declines that occur neurobiologically (in the dopamine and dlPFC systems) are linked to the inability to represent, maintain, and update context information which is particularly important for a range of cognitive tasks (Braver & Barch, 2002). Thus, declines in cognitive control can be seen as a pathway to detriments in other cognitive domains which warrant further investigation.

1.6. The Current Study

The current study was developed to replicate and extend past work examining the DMC theory in the context of the internal Stroop task (distractor interference from the word held internally or in working memory) originally developed by Kiyonaga and Egner (2014), rather than in the context of a traditional Stroop task. Specifically, the aim of the study was to adapt measures of proactive control developed for an external distractor-interference task (Gonthier et al., 2016) to be used in a modified version of the internal Stroop task. Like past work, the current study utilized a list-wide congruency manipulation with transfer trials to determine how the Stroop effect is modulated (Gonthier et al., 2016). The focus of the current study was on proportionality manipulations used in a list-wide manner to emphasize proactive control, as the inclusion of purely item-specific manipulations (to measure reactive control) was dropped due to testing time constraints. The current study utilized a color-word Stroop task instead of the picture-word Stroop task used in Gonthier and colleagues (2016), which has been found to elicit the Stroop effect in many studies (Bugg, 2014a; Bugg & Hutchison, 2013; Donahue et al., 2016; Kiyonaga & Egner, 2014). Focusing on a congruency manipulation in a list-wide manner sought to delineate whether a completely item-specific manipulation is needed to elicit reactive control, or if the level of conflict experienced across a trial can modulate the control mechanism used (as found in West & Bailey, 2012). The current study was used as another attempt to characterize the nature of attention and working memory, specifically if working memory is characteristic of internally directed attention. Finally, the current study also incorporated age and neuroimaging as other factors to consider in the DMC theory.

Donahue et al., (2016) examined behavioral and ERP responses to Stroop and Flanker tasks using two- and four-response items. In their design, the authors separated the word and color dimension in the Stroop task (i.e., using words on colored rectangles). Donahue and colleagues (2016) found a Stroop effect behaviorally (response times and accuracy) and electrophysiologically (N450) in response to 50% congruent trials in both the two- and four-response trials. Thus, although the color and word dimensions appeared together in this task, the separation of these components into words and rectangles did not appear to interfere with the presence of the Stroop effect.

In our lab (Faust et al., 2018; Faust, Gowan, Nelson, Anderson, & Multhaup, 2017) we have investigated the similarities between the internal Stroop task and an external color-word Stroop task on a measure of conflict adaptation (behaviorally and electrophysiologically). Conflict adaptation is the adjustment of cognitive control that facilitates responses on a current trial when the prior trial had conflict (incongruency) compared to non-conflict (congruency; Larson et al., 2016). Specifically, the presence of conflict on the previous trial results in reduced Stroop interference on the current trial, whereas a larger Stroop interference effect would result on the current trial if the previous trial did not exhibit conflict (Larson et al., 2016). We found evidence that behaviorally (response times) the internal and external Stroop tasks operate similarly, as they both exhibited reduced interference in the current trial when the previous trial was incongruent compared to when the previous trial was congruent (i.e., the Stroop effect [incongruent trial minus congruent trial response times] was smaller in the latter compared to former condition, exhibiting evidence of conflict adaptation and the adjustment of cognitive control resources on the current trial due to the prior experience of conflict). However, these tasks seem to diverge in similarity when reviewing their electrophysiological correlates. The internal task exhibited evidence of a marginally significant N2 (which is often found in a Flanker task; Larson et al., 2014) and a significant P3. Contrarily, the external task exhibited evidence of a significant N450 and SP (characteristic components of a traditional Stroop task; Larson et al., 2014) as well as a P3. Thus, whereas behaviorally these tasks seem to result in similar patterns of data, electrophysiologically they seem to diverge. The lack of the SP in the internal task could represent the fact that the word information had already been processed since it was presented before the relevant color dimension. Conversely, the word may not have been maintained well over the target presentations, leading to the reduced need for extended cognitive processing that is thought to reflect what is occurring during the SP.

A similar experimental manipulation to the internal Stroop task is the paradigm used by Appelbaum, Boehler, Davis, Won, and Woldorff (2014), who modified the stimulus onset asynchrony (SOA) of the target and distractor in a color-word Stroop task. Presentations of the irrelevant (word) dimension could precede (i.e., -200 ms, -100 ms), occur simultaneously (0 ms), or follow (100 ms, 200 ms) the relevant color patch dimension. The conditions in which the word preceded the color are similar to the presentation of the word dimension before the color dimension in the internal Stroop task (although in this paradigm, the word remained available externally instead of only being available internally). Additionally, these researchers used a color patch and word design which aligns with the presentation of targets and distractors in the current study but differs from the traditional color-word Stroop paradigm in which the color word is written in a color. Appelbaum et al., (2014) found that the greatest incongruency effects were present when the distractor item preceded the target item, and this effect declined as the SOA became later. Earlier SOAs also generated greater amplitudes and earlier latencies for the N450 and the late positive component (LPC) compared to later SOAs. Thus, the greatest behavioral and neural interference effects seemed to appear when the irrelevant dimension preceded the target. In the current study, since the irrelevant word dimension is preceding the relevant color dimension, it is possible that the behavioral and electrophysiological effects could be earlier and amplified, which could explain why our previous examinations of the ERP markers of the internal Stroop task appeared more like a flanker (N2) instead of a Stroop (N450).

Tillman and Wiens (2011) investigated the Stroop and Flanker tasks behaviorally and electrophysiologically with a congruency manipulation. In the Stroop task, behavioral interference effects were greater in the mostly congruent block compared to mostly incongruent block. Additionally, they found a significant N450 effect in the mostly congruent block, but not the mostly incongruent block. This pattern indicates that more sustained cognitive control (proactive control) was likely present in the mostly incongruent block since the level of interference was reduced in this block compared to the mostly congruent block. Additionally, more transient cognitive control (reactive control) was likely present in the mostly congruent block, as the greater levels of interference indicated that task goals were reactivated on an as-needed basis instead of having heightened levels of cognitive control throughout the task which would have reduced the level of interference.

1.6.1. The Effect of Aging

Researchers have illustrated that aging is associated with preserved reactive control and impaired proactive control (Bugg, 2014a, 2014b). However, whether older adults are solely utilizing reactive control, indicative of differential behavioral and brain activity, in the internal Stroop task has not been investigated. By including transfer trials of 50% congruency within mostly congruent and mostly incongruent blocks, the utilization of proactive or reactive control will garner further evidence.

Bugg et al. (2007) found evidence for an increase in response times across all Stroop measures for older adults compared to young adults, with a marked increase for the incongruent condition compared to the neutral-color-naming and word-naming conditions of the Stroop task. Notably, they found this effect even when controlling for the slowing of processing that occurs in aging (Bugg et al., 2007). Additionally, West (2004) investigated the effect of aging in behavioral and electrophysiological measures of the Stroop task. He found a greater Stroop effect in response times for older adults compared to young adults in the color-naming version of the task. Electrophysiologically, West (2004) found that the N450 was attenuated for older adults compared to young adults in both the color and word naming versions of the Stroop task; the amplitude of the SP was greater for young adults than older adults in the color naming version of the

Stroop task in the parietal region; and the SP was attenuated for older adults compared to young adults in the color naming version of the Stroop task for the lateral frontal region.

1.6.2. Aims and Hypotheses

The aims of the current study included: (a) determining behavioral and electrophysiological signatures of an internal Stroop task with different congruency manipulations, (b) determining the extent to which the DMC theory explains patterns found, and (c) determining to what extent aging shows differences in these patterns of data. The use of the internal task (rather than a traditional external Stroop task) built on existing knowledge of internal and external attention (Kiyonaga & Egner, 2013, 2014) to further our understanding of the relationship between cognitive control and working memory (Meier & Kane, 2017). By examining the influence of aging on patterns found in response to these tasks, I extended knowledge of the nature of declines in cognitive control with age which expands our understanding of age-related cognitive decline. Further, if internal and external attention are operating similarly, then age-related declines in proactive control that are traditionally found in external attention tasks (Bugg 2014a) should have translated to the current study of the internal attention task.

Hypothesis 1: Behaviorally (i.e., response times) I predicted that there would be a reduced Stroop effect in the mostly incongruent block compared to the mostly congruent block in both young and older adults (Bugg, 2014a). This reduction would be evidenced by the presence of reduced response times for the incongruent trials in the mostly incongruent block compared to the mostly congruent block. This pattern of response times would provide further evidence for working memory operating as internally directed attention, by exhibiting similar effects found in a traditional Stroop task.

However, the reason that young and older adults have a reduced Stroop interference effect in the mostly incongruent block compared to mostly congruent block would likely be due to different control strategies utilized (Bugg, 2014a). Young adults would utilize proactive control to bias their responses throughout the block, whereas older adults, who experience age-related declines in proactive control, would rely more on their preserved reactive control to respond to the incongruent items in an item-specific manner (Bugg, 2014a).

Hypothesis 2: I predicted that age differences would manifest in behavioral effects associated with the transfer of task goals and congruency costs. Transfer effects would indicate that proportionality manipulations learned in a biased block governed by proactive control processes were then applied to an unbiased set of items that did not vary in proportionality across blocks (Gonthier et al., 2016). Based on the fact that young adults have preserved proactive control, I predicted that young adults would show evidence of a modulated Stroop interference effect in the mostly incongruent block for the unbiased trials (Hypothesis 2a; Bugg, 2014a). Specifically, the young adults would have a faster response time to the incongruent trials that are 50% congruent in the mostly incongruent block compared to the mostly congruent block (Gonthier et al., 2016). This modulation would signify that the young adults were able to transfer their task goals in the mostly incongruent block to the unbiased trials. Young adults would further exhibit evidence for proactive control through the presence of congruency costs found in the mostly incongruent block (Gonthier et al., 2016). Unbiased congruent trials in the mostly incongruent block should have been responded to slower than unbiased congruent trials in the mostly congruent block (Hypothesis 2b; Gonthier et al., 2016). This pattern would indicate that young adults were using proactive control and their responses were biased according to task goals in the mostly incongruent block compared to the mostly congruent block (Gonthier et al., 2016). Since older adults have not shown evidence for the use of proactive control in response to traditional Stroop tasks (Bugg, 2014a), I predicted that they would not show evidence of transfer effects or congruency costs like the young adults would.

The current study was designed to elicit modulations in the electrophysiological patterns found in response to the task based on experimental manipulations including biased and unbiased items and block proportionality. Finding modulated ERP effects based on the experimental manipulations would allow for further investigation of early and late cognitive processing mechanisms used by young and older adults. An early ERP component related to conflict detection generated by the ACC should have been sensitive to congruency (Larson et al., 2014). Hypothesis 3: Electrophysiologically, young adults would show evidence of an early ERP component that differentiated congruent and incongruent trials in the internal distractor interference task that I used (an N2 effect would replicate past work with the internal Stroop task; Faust et al., 2017, 2018; an N450 effect would replicate past external Stroop research; Larson et al., 2014). Whether the early ERP effect can be deconstructed into the MFN and MPN according to control mechanism used as presented by West and Bailey (2012) remains to be investigated. Hypothesis 4: Young adults would also show evidence of a later ERP component that was more positive for incongruent trials than for congruent trials (SP; Larson et al., 2014; Liotti et al., 2000). Hypothesis 5: ERP amplitudes for older adults would be attenuated for both the early and late ERP components (Ramos-Goicoa, Galdo-Alvarez, Diaz, & Zurron, 2016; West, 2004).

CHAPTER 2: MATERIALS AND METHODS

2.1. Participants

We collected data from 30 young adults and 20 older adults. Young and older adults were retained if they adequately completed both the color identification and word memory recognition task at greater than 80% accuracy (note that 92.9% of participants completed the color identification at 90% accuracy or greater and 95.2% of participants completed the word memory recognition test at 90% accuracy or greater). No participant was dropped due to poor color recognition performance. Four young adults were dropped from analyses due to excessive electrophysiological artifacts detected during the trial (i.e., greater than an average of 25% of their total trials rejected across both blocks and greater than 30% of trials rejected in a single block; see ERP Processing subsection for criteria), resulting in 26 young adult participants (M_{age} = 19.08, *SD* = 1.83; 10 men; 69.2% Caucasian). Four older adults were dropped from analyses due to low memory retrieval (i.e., word recognition was less than 70%; two participants) and excessive electrophysiological artifacts (same criteria as young adults; two participants), resulting in 16 older adult participants (M_{age} = 67.34, *SD* = 6.12; 6 men; 62.5% Caucasian). Table 1 includes full demographic data on the participants. College students at a large, public university in the southeast United States participated for partial course credit and were recruited via an online experiment management system. Inclusion criteria for young adults included: being at least 18 years old at the time of testing, being right handed, and having normal or corrected-to-normal vision. Exclusion criteria included having a history of epilepsy or seizures and being color-blind. Older adults were recruited through the community—specifically, emails were sent to all faculty and staff from the same

Table 1

Demographic Information About Participants

Demographic Variables	Young Adults	Older Adults
	M (SD) or Count (%)	*M (SD) or Count (%)*
Age	19.08 (1.83)	67.34 (6.12)
Years of Education[a]	12.56 (0.78)	16.5 (2.45)
Race		
African American	2 (7.7%)	0 (0%)
Asian	3 (11.5%)	0 (0%)
Caucasian	18 (69.2%)	10 (62.5)
Hispanic	2 (7.7%)	0 (0%)
Mixed Race	1 (3.8%)	2 (12.5%)
Unreported	0 (0%)	4 (25%)
Gender		
Men	10 (38.5%)	6 (37.5%)
Women	16 (61.5%)	10 (62.5%)

Note. $N = 42$ (Young: $n = 26$, Older: $n = 16$).

[a]Due to a change in forms, young adult data for years of education was not available for the first participants. Thus, for the young adults, this variable was calculated with $n = 18$.

university as the undergraduates (see Appendix A for email script, Appendix B for study flyer) and a calling list of older adults who had participated in prior research was utilized (list was developed by the Memory & Aging Lab, Davidson College, Dr. Kristi Multhaup, lab director; see Appendix C for calling script). Inclusion criteria for older adults include: being at least 60 years of age or older, being right handed, and having normal or corrected-to-normal vision. Exclusion criteria include a history of epilepsy or seizures and being color-blind. Older adults were compensated parking for the day and received a $25 Target gift card for their participation.

2.2. Design

A 2 (age: young adult, older adult) x 2 (block order: AB, BA) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (bias: biased, unbiased) x 2 (congruency: congruent, incongruent) mixed design was used, with the between-subjects factors of age and block order. Block order (receiving the mostly congruent block then the mostly incongruent block and vice versa) was counterbalanced between participants stratified by age to ensure equal presentation of blocks in both age groups. Dependent variables include mean response times and ERPs. Accuracy was used as a screening measure to ensure participants were on task.

2.3. Materials and Apparatus

Both tasks were presented on a computer screen utilizing EPrime software. All stimuli were presented on a white background. Words were written in black. The color-words and color rectangles used were red, green, and blue. The color-box responses for red, green, and blue mapped onto the pointer, middle, and ring fingers of the right hand, respectively, of a dedicated button response box that was on the table in front of the computer. The word recognition memory test (yes, no) mapped onto the middle and pointer finger of the left hand, respectively. Participants responded to the word recognition memory test using a computer mouse that was on the table in front of the computer. A 64-channel electroencephalogram (EEG) cap was used, with electrodes placed along the cap according to the expanded International 10-20 system. EEG recordings were collected using a 64-channel Synamps amplifier system from Neuroscan. Standard filtering and analysis software routines were applied to the EEG continuous recordings using ERPLAB (Lopez-Calderon & Luck, 2014) and EEGLAB (Delorme & Makeig, 2004) software toolboxes for the MATLAB scientific analysis software program with Neuroscan Software.

2.4. Procedure

Originally, we attempted to test young and older adults during their peak performance time (afternoon for young adults, morning for older adults; Zacks, Hasher, & Li, 2000); however, due to scheduling conflicts, participants were scheduled when available. However, time of testing was recorded in order to determine whether time of testing influenced results. Once participants arrived at the lab, they first completed informed consent, followed by a general health and handedness questionnaire (Appendix D), in order to determine eligibility. The questionnaire was a screen to ensure participants met inclusion criteria (specifically, no history of epilepsy or seizures and being right handed). After the questionnaire had been completed, participants had an EEG cap placed on their head. This process was completed by two to three trained research assistants. The cap placement procedure includes preparation of the cap to measure neural activity. Research assistants filled the electrodes on the cap with an electrically conducive gel with blunt-tipped syringes. All electrodes on the cap except for OZ, O1, O2, CB1, and CB2 were filled. Additionally, the four facial electrodes were filled to track eye blinks and eye movements and the two mastoid electrodes were filled for future re-referencing. Once adequate impedances were achieved with the EEG cap, the participant proceeded with the testing process. All participants completed both of the tasks in a counterbalanced order, with a practice session preceding each task. The total testing time was approximately 1 ½ to 2 hours (5 – 10 minutes of consent and questionnaire; 20 – 45 minutes of cap placement; 30 – 40 minutes of cognitive testing; 10 – 20 minutes of clean up).

2.4.1. Internal Stroop task. This task is a variation of the traditional color-word Stroop task (Stroop, 1935), originally utilized by Kiyonaga and Egner (2014). In this task, participants were first presented with a color-word (e.g., "RED"). The participant was then asked to remember this word for a later memory test. Then a colored rectangle appeared that was either congruent (i.e., red) or incongruent (e.g., blue) with the word. Participants responded to the color of the rectangle by pressing the corresponding color on a color box as quickly and accurately as possible. Participants then saw another word (e.g., "RED") as a forced-choice memory comparison in which they were instructed to reply with a button press on a mouse of whether this word matched the word that was first presented with either "Y" or "N" taped to the left and right mouse buttons, respectively (see Figure 2 for an example trial sequence with timing).

2.4.2. Congruency manipulations. The Internal Stroop Task was composed of two separate blocks that have congruency manipulated on a list-wide basis. One block

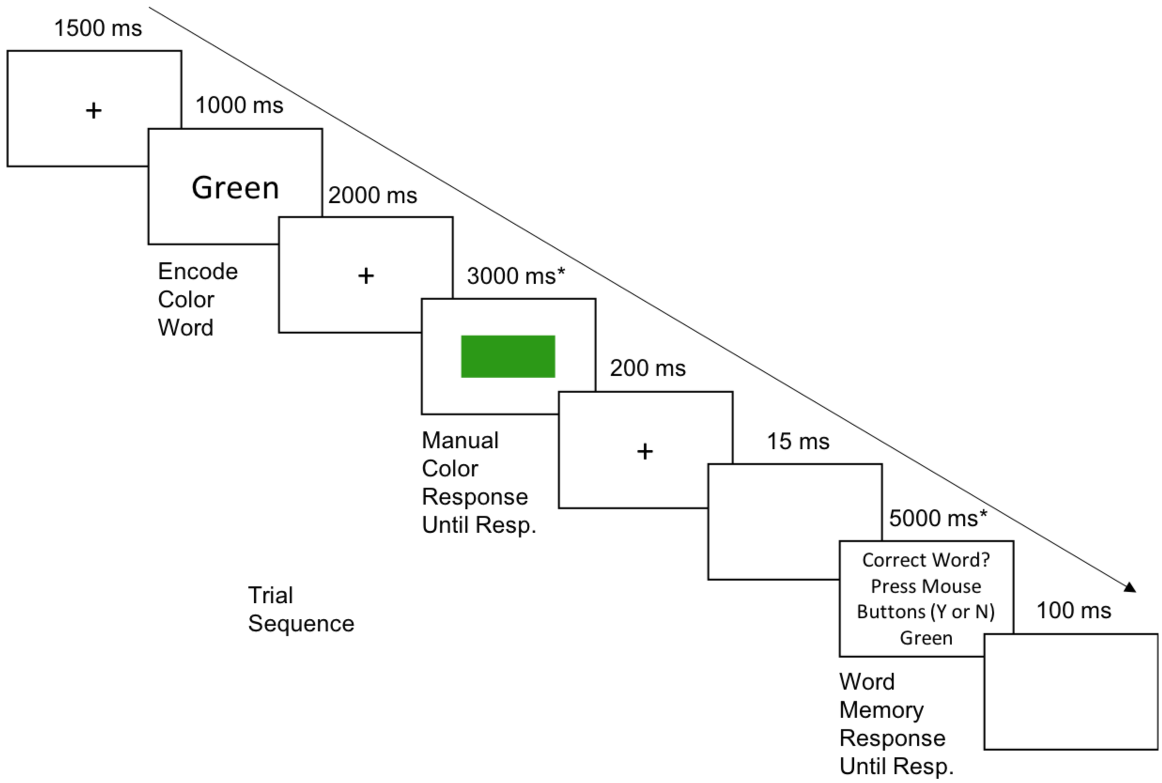

Figure 2. Example of a congruent task sequence in the internal Stroop task that could be presented to a participant. *Participants responded to these trial types, but the task would continue without a response if the participant did not respond within the 3,000 ms and 5,000 ms timeouts, respectively.

was mostly congruent, in which the colors red and blue were modulated to appear congruently on 67% of the trials. The other block was mostly incongruent, in which the colors red and blue were modulated to appear congruently on 33% of the trials. These congruency manipulations were chosen based on a design constraint that used a three-color button box (this design matches our previous work; Faust et al., 2017, 2018). The tradition in Stroop tasks is to repeat all possible stimuli an equal number of times—in order to ensure the presentation of the items were balanced, the proportionality must be divisible by three (thus, our congruency manipulations diverged from past researchers who allocated congruency based on four or eight stimuli [75% and 25% proportion congruency]; Gonthier et al., 2016). Within each of these blocks, the color green was presented as an equally congruent color (i.e., it is presented 50% congruent in both the mostly congruent and mostly incongruent blocks). The green item manipulation allowed for the examination of transfer of task goals to an unbiased item (see Table 2 for congruency manipulations). Both blocks were composed of 16 practice trials and 144 experimental trials for a total of 32 practice trials and 288 experimental trials.

2.5. Planned Analyses

Descriptive statistics were calculated. Separate Analyses of Variance (ANOVAs) were calculated for biased and unbiased trials. Analyses were planned based on measures of proactive control found in Gonthier and colleagues (2016) who exhibited a modulated Stroop interference effect in addition to transfer effects and congruency costs. I first sought to provide evidence of a modulated Stroop effect by examining the biased trials from the mostly congruent and mostly incongruent blocks. I calculated a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean response times. I expected a reduced Stroop interference effect from the mostly incongruent block compared to the mostly congruent block for both young and older adults (Bugg, 2014a). Next, I examined the evidence for the differentiation of control strategies used by young and older adults by explicitly examining the unbiased (equal congruency) trials. For this analysis, I calculated a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean response times. I expected age to moderate the relationship between the Stroop interference effect and level of congruency such that young adults would exhibit a reduced Stroop interference effect for the mostly incongruent block compared to the

Table 2

Congruency Proportion Manipulations for Experimental Design

Task block	Item type[c]	Color	Word		
			Red	Green	Blue
LWMC[a]	PC-67	Red	8	2	2
	PC-50	Green	3	6	3
	PC-67	Blue	2	2	8
LWMI[b]	PC-33	Red	4	4	4
	PC-50	Green	3	6	3
	PC-33	Blue	4	4	4

Note. Participants received a total of 288 trials with 144 trials occurring in each block. Each set of trials was randomly ordered for each of four successive repetitions of the set, thus four repetitions of the set made up a block of 144 trials. Blocks were counterbalanced among participants stratified by age.

[a]LWMC stands for list wide mostly congruent

[b]LWMI stands for list wide mostly incongruent

[c]Item types are represented by their proportion congruency (PC), which can be mostly congruent (67), equally congruent (50), or mostly incongruent (33)

mostly congruent block for the unbiased trials, while older adults would not exhibit this same pattern. This age difference in the Stroop interference effect would provide evidence for the presence of transfer in young adults (proactive control) while older adults would not exhibit signs of transfer (reactive control). Regarding congruency costs, I predicted that young adults would exhibit behavioral evidence for a congruency cost in the mostly incongruent block compared to the mostly congruent block (proactive control), whereas older adults would not exhibit evidence of a congruency cost (reactive control). I examined evidence for a congruency cost by reviewing mean response times for the unbiased congruent trials which would result in a significant slowing of congruent trials in the mostly incongruent block compared to the mostly congruent block. I measured electrophysiological differences in response to congruent and incongruent trials in an early and late time window to determine whether the internal Stroop task mirrored external Stroop ERP markers (Larson et al., 2014; West, 2004) or continued to exhibit a Flanker-like N2 effect and an absence of the SP effect (Faust et al., 2018).

2.6. ERP Processing

EEG data were processed using MATLAB and the EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) toolboxes (see Appendix E for scripts). Raw EEG Neuroscan files were first imported into MATLAB and saved as an EEG dataset. Missing electrodes (CB1, CB2, O1, OZ, O2) were then removed from the dataset. A bandpass filter of 0.1 Hz and 30 Hz was applied to the data. Data files were then resampled to 250 Hz to reduce the file size and increase processing speed for the analyses. Channel locations were then added to the datasets. All channels were then re-referenced to the average of the two mastoid electrodes. Epochs were then created with the time window of -200 ms to 800 ms around the presentation of events in the data. Epochs were categorized according to trial type in the experimental design. Artifact detection was completed using the moving window peak-to-peak technique that looks for artifacts of a certain voltage in a specific time window in the epoch (Luck, 2014). Artifact detection was run on 12 electrodes (P1, PZ, P2, CP1, CPZ, CP2, C1, CZ, C2, FC1, FCZ, and FC2) including the two target electrode sites chosen for investigation based on our previous research on ERPs in the internal Stroop task (FCZ and PZ; Faust et al., 2017, 2018). A 100-microvolt threshold was used as the peak amplitude that would result in an artifact being rejected. The time window during which artifact detection took place was the width of the epoch (i.e., -200 ms to 798 ms). The epoch was checked for artifacts within a 200 ms window that moved forward in 50 ms steps. When artifacts were detected, epochs containing artifacts were then rejected from further analyses. All participants who had no greater than an average of 25% of their total trials rejected across both blocks, with no greater than 30% of trials rejected in a single block, were retained. Four young adults and two older adults did not meet these criteria and were excluded from further analysis. For young adults, the average percentage of trials rejected in the mostly incongruent block was 2.80% and the average percentage of trials rejected in the mostly congruent block was 1.81%. For older adults, the average percentage of trials rejected in the mostly incongruent block was 3.47% and the average percentage of trials rejected in the mostly congruent block was 2.78%. Artifact detection and rejection resulted in removing four young adults and two older adults from further analyses due to their excessive artifacts. After artifact rejection, the average ERPs were calculated for each subject. Finally, grand average ERPs were calculated resulting in four averaged

ERP waveforms, young adults mostly incongruent, young adults mostly congruent, older adults mostly incongruent, and older adults mostly congruent. Mean amplitudes were then calculated to be used in analysis. Time windows of interest were identified by inspection of group ERP plots and based on our prior ERP study of the internal Stroop task (Faust et al., 2017, 2018). Our prior work indicates an N2-like effect beginning about 200 ms post-stimulus, an N450-like effect beginning about 450 ms post-stimulus, and an SP effect beginning about 500 ms post-stimulus. Based on the group ERP plots we identified the time windows of interest of 200-300 ms and 500-650 ms to examine ERP amplitudes. We confirmed the scalp distribution of these ERPs through visual inspection of the scalp maps (see Figures 3 and 4). Areas of the scalp with the greatest levels of negative (cold spot) and positive (hot spot) voltages were used to identify relevant electrodes for further investigation. Electrodes of interest were identified as FCZ for the early ERP component and PZ for the late ERP component.

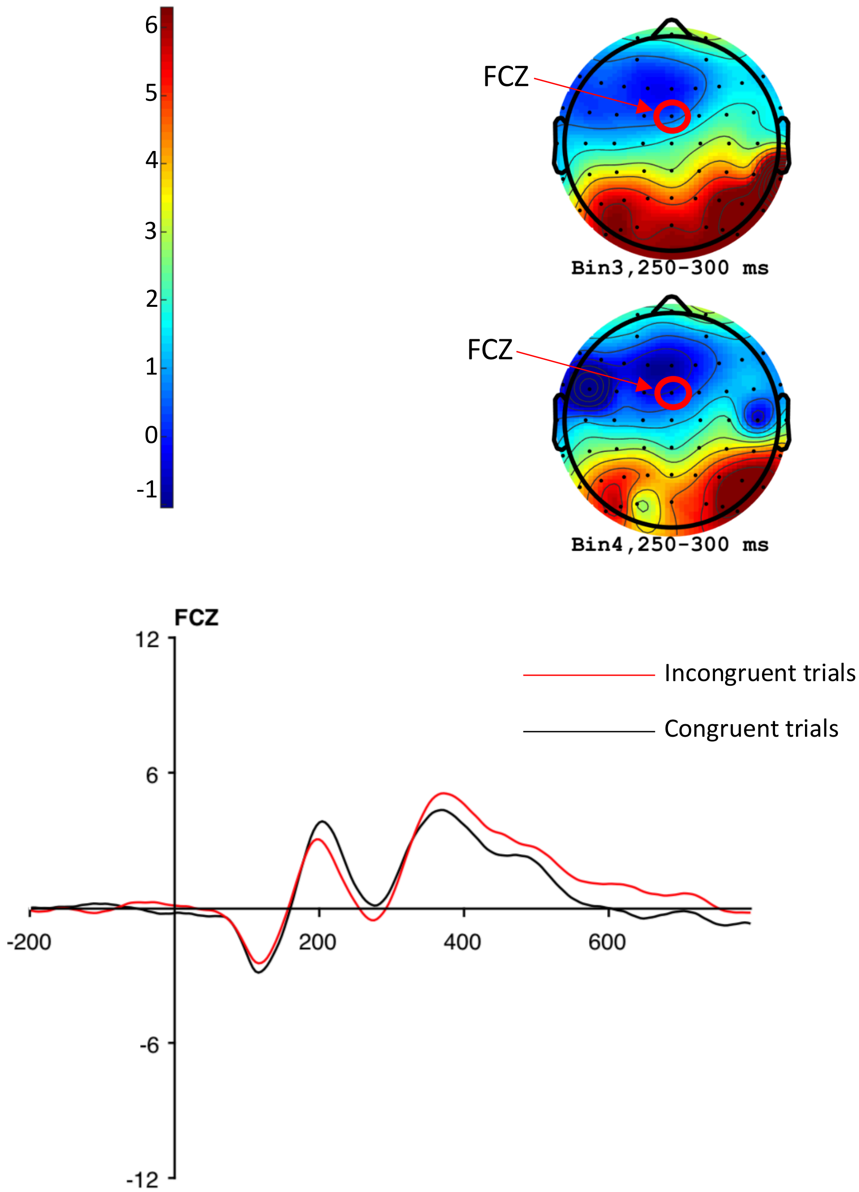

Figure 3. Top: Scalp map of the time window 250 – 300 ms for young adults. Examination of the maps indicates that the incongruent trials (Bin 4) are more negative than congruent trials (Bin 3) during this time window. The cold spot is present around electrode FCZ. The scale goes from -1 to 6 microvolts, with zero as the baseline at the start of the epoch. Bottom: ERP curve for young adults at electrode FCZ for congruent and incongruent trials. Examination of time window 200 – 300 ms for the negative effect.

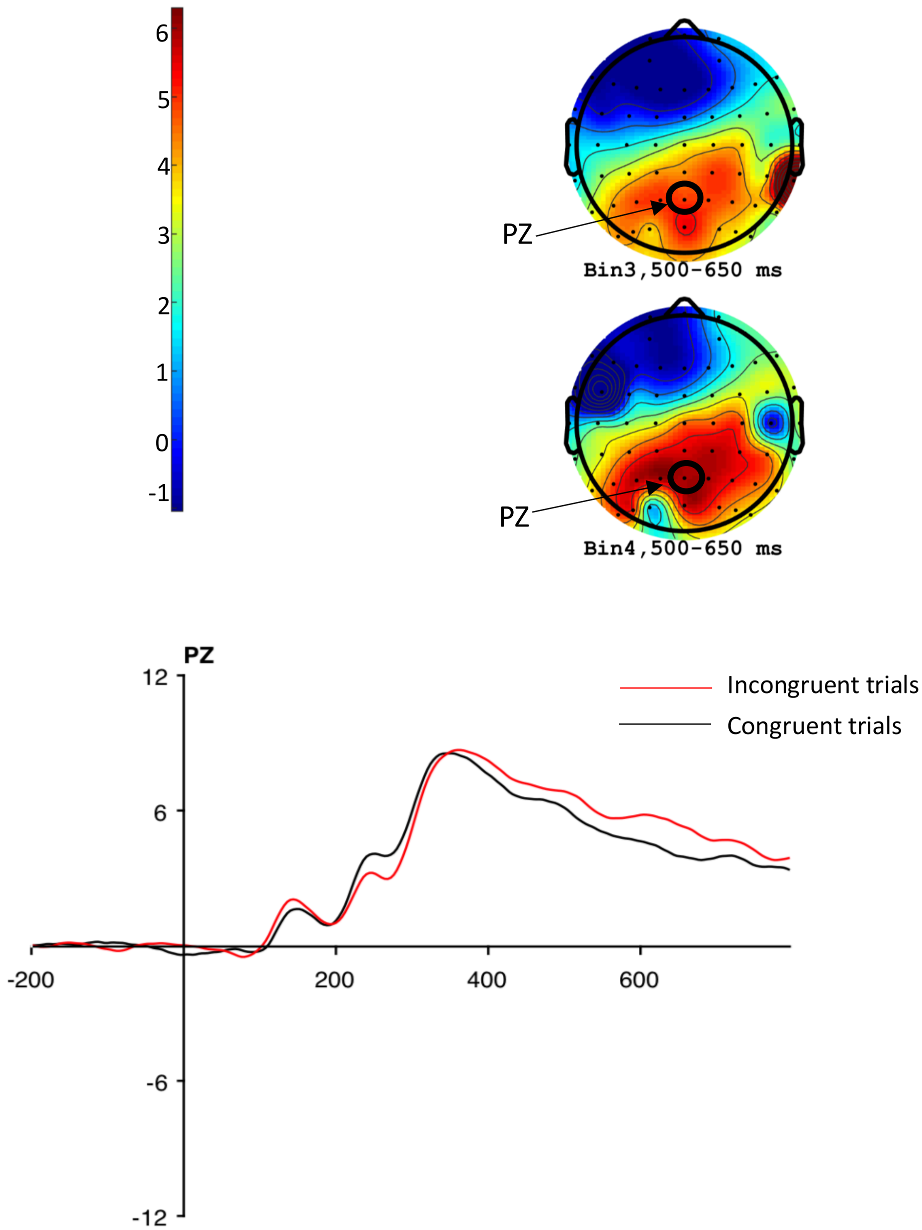

Figure 4. Top: Scalp map of the time window 500 – 650 ms for young adults. Examination of the maps indicates that the incongruent trials (Bin 4) are more positive than congruent trials (Bin 3) during this time window. The hot spot is present around electrode PZ. The scale goes from -1 to 6 microvolts, with zero as the baseline at the start of the epoch. Bottom: ERP curve for young adults at electrode PZ for congruent and incongruent trials. Examination of time window 500 – 650 ms for the positive effect.

CHAPTER 3: RESULTS

3.1. Pilot Results

Pilot behavioral data were collected with 12 undergraduate students to determine whether the congruency manipulation was adequately modulating the Stroop interference effect. Response times and accuracy rates were collected (no EEG). For the biased trials (mostly congruent and mostly incongruent) a 2 (proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on response times produced a significant main effect of congruency, $F(1,11) = 17.83$, $p < .001$, and a significant proportionality x congruency interaction, $F(1,11) = 7.01$, $p = .02$. Proportionality was not a significant main effect, $F(1,11) = .22$, $p = .65$. Examination of means indicates that the Stroop effect was reduced in the mostly incongruent block (M_C = 860.14, SD = 54.66; M_I = 961.26, SD = 50.11; M_{diff} = 101.12) compared to the mostly congruent block (M_C = 816.16, SD = 40.51; M_I = 983.18, SD = 57.94; M_{diff} = 167.02).

3.2. Main Study Behavioral Results

Response time data were first screened in Excel to ensure response times were only included for correct trials (i.e., participants hit the correct color button) and that no response times were shorter than 100 ms (response times shorter than this likely did not indicate a meaningful response) or longer than 2,000 ms (response times beyond this likely did not reflect on-task behavior and could skew results). Analyses were conducted in SPSS Version 26. First I conducted a 2 (age: young adult, older adult) x 2 (block order: AB, BA) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (bias: biased, unbiased) x 2 (congruency: congruent, incongruent) ANOVA on average response times to determine whether block order significantly affected the results. This

ANOVA revealed no significant main effect of block order, a significant block proportionality x block order interaction, $F(1, 38) = 28.54$, $p < .001$, and no other significant interactions with block order (p's ≥ .055). Investigation of the interaction revealed that the interaction seemed to be driven by learning effects, as the second block was responded to faster than the first block. Due to the lack of significant block order effects except for the block order by block proportionality interaction, especially any interactions with congruency (which would have indicated a differential Stroop effect due to the presentation of blocks), block order was removed from further analyses and the data were reanalyzed collapsing across block order.

I then conducted a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (bias: biased, unbiased) x 2 (congruency: congruent, incongruent) ANOVA on mean response times collapsed across block order. The ANOVA revealed a significant main effect of congruency, $F(1, 40) = 30.14$, $p < .001$, a significant congruency x age interaction, $F(1, 40) = 8.49$, $p = .006$, and a significant block proportionality x congruency interaction, $F(1, 40) = 4.34$, $p = .044$. No other main effects or interactions were significant (p's ≥ .053). Examination of the age x congruency interaction revealed that older adults ($M_{diff} = 36.20$ ms) had a significantly smaller Stroop effect (incongruent minus congruent response times) than young adults ($M_{diff} = 118.13$ ms; see Figure 5). Examination of the block proportionality x congruency interaction revealed that the mostly incongruent block ($M_{diff} = 65.25$ ms) resulted in a significantly smaller Stroop effect than the mostly congruent block ($M_{diff} = 89.08$ ms; providing partial support for Hypothesis 1; see Figure 6).

3.2.1. Biased trials. Next, I examined the biased trials (red and blue) separately to

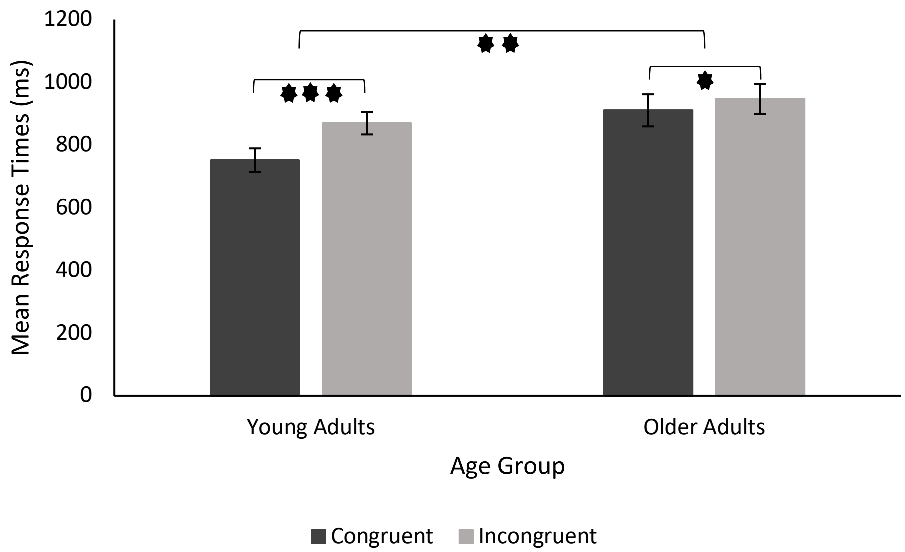

Figure 5. Mean response times for congruent and incongruent trials for young and older adults collapsing across block proportionality. A significant age x congruency interaction revealed that older adults had a significantly smaller Stroop effect (mean incongruent trials response times – mean congruent trials response times) than the young adults for all trial types. Young and older adults also had a significant main effect of congruency indicating that congruent trials were responded to faster than incongruent trials. * $p < .05$, ** $p < .01$, *** $p < .001$. Error bars represent standard error of the mean.

determine the influence of the biased congruency manipulation on response times. The list-wide proportionality manipulation (i.e., mostly congruent vs. mostly incongruent) should lead to an emphasis on proactive control, as participants will learn the globally biased task goals. I conducted a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean response times. The ANOVA revealed a main effect of congruency, $F(1, 40) = 28.34$, $p < .001$, and a significant congruency x age interaction, $F(1, 40) = 4.80$, $p = .034$. No other main effects or interactions were significant (p's $\geq$ .073). As expected, the main effect of congruency indicated that congruent trials were responded to faster than incongruent trials. Analysis of the congruency x age interaction

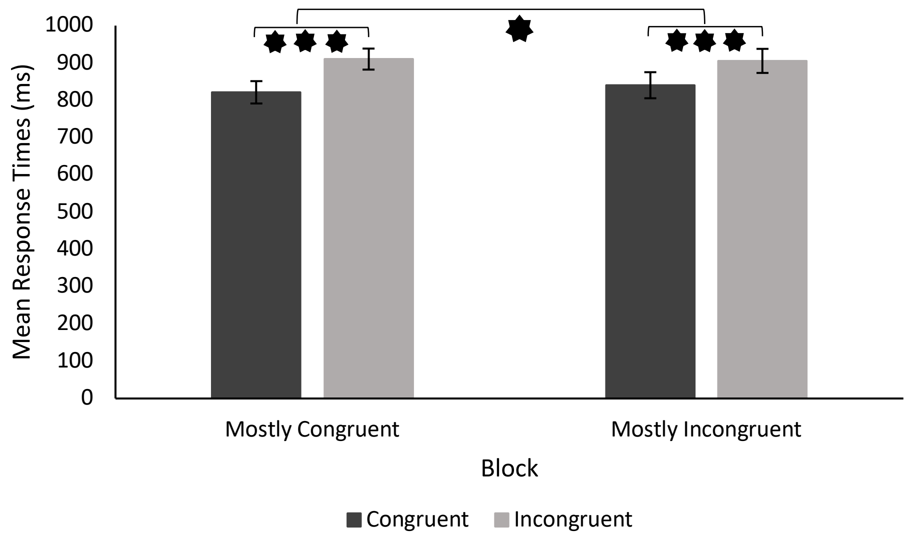

Figure 6. Mean response times for congruent and incongruent trials in the mostly congruent and mostly incongruent blocks for all trial types collapsing across age. A significant block proportionality x congruency interaction revealed that the Stroop effect (mean incongruent trials response times – mean congruent trials response times) was significantly smaller in the mostly incongruent block compared to the mostly congruent block. * $p < .05$, *** $p < .001$. Error bars represent standard error of the mean.

revealed that older adults (M_{diff} = 46.97 ms) had a significantly smaller Stroop effect than the young adults (M_{diff} = 112.62 ms), the same pattern found when examining biased and unbiased trials together (i.e., Figure 5). Post-hoc analyses of the congruency effects revealed a significant difference between congruent and incongruent trials for both the older adults, $t(15) = -2.28$, $p = .038$, and the young adults, $t(25) = -5.99$, $p < .001$.

Due to the unbalanced nature of the groups and the fact that group comparisons have lower statistical power, I also split the data to examine the effects of congruency and block proportionality separately for young and older adults to determine whether the pattern of significance was qualitatively different across groups. For the older adults, the 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean response times revealed a significant main effect of congruency, $F(1, 15) = 12.86$, $p = .003$. Neither the main effect of block proportionality nor the block proportionality x congruency interaction was significant (p's $\geq .866$). Older adults were significantly faster on congruent trials ($M = 889.39$, $SD = 47.93$) compared to incongruent trials ($M = 936.36$, $SD = 47.01$). For the young adults, the 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean response times revealed a significant main effect of congruency, $F(1, 25) = 26.18$, $p < .001$, and a block proportionality x congruency interaction, $F(1, 25) = 5.99$, $p = .022$. The main effect of block proportionality was not significant, $p = .311$. Examination of the interaction revealed that young adults had a significantly smaller Stroop interference effect in the mostly incongruent block ($M_{diff} = 95.88$ ms) compared to the mostly congruent block ($M_{diff} = 129.36$ ms) for the biased (red and blue) trials (providing partial support for Hypothesis 1; Figure 7).

3.2.2. Unbiased trials. According to Gonthier and colleagues (2016), the strongest measure of proactive control is the presence of list-wide task goals transferring to an unbiased set of items. This pattern indicates that the cognitive control mechanism is biasing attention on a global, block-wise scale in order to facilitate responses. In order to determine whether task goals are transferring to the unbiased items, I conducted a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean response times for the green (50% congruent) items (Figure 8). The ANOVA revealed a significant main effect of congruency $F(1, 40) = 22.00$, $p < .001$, a significant main effect of age, $F(1, 40) = 4.35$, $p = .043$, and a significant congruency x age interaction, $F(1, 40) = 9.55$,

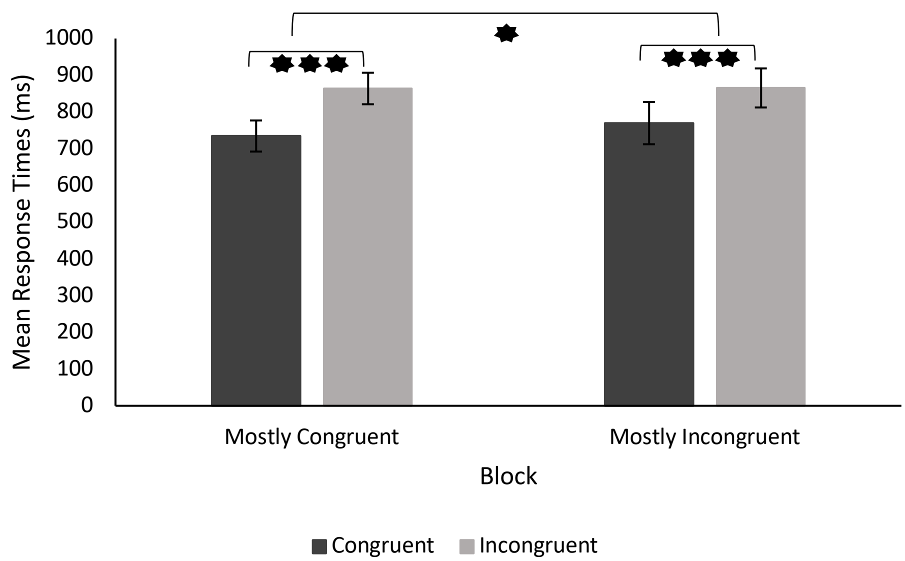

Figure 7. Behavioral results of the Stroop interference effect for young adults in the mostly congruent and mostly incongruent block for the biased trials. The block proportionality x congruency interaction was significant. Young adults showed evidence of a reduced Stroop interference effect in the mostly incongruent block compared to the mostly congruent block. Follow-up *t*-tests revealed significant differences between the congruent and incongruent trials for both the mostly congruent and mostly incongruent block. Stroop interference = mean incongruent trials response times – mean congruent trials response times. * $p < .05$, *** $p < .001$. Error bars represent standard error of the mean.

$p = .004$. No other main effects or interactions were significant (p's $\geq .098$). Examination of the interaction revealed that older adults ($M_{diff} = 25.44$ ms) had a significantly smaller Stroop effect than young adults ($M_{diff} = 123.64$ ms), the same pattern found previously examining all trials and biased trials. Due to the unbalanced nature of the groups and the fact that group comparisons have lower statistical power, I also split the data to examine the effects of congruency and block proportionality separately for young and older adults to determine whether the pattern of significance was qualitatively different across groups. For the older adults, the 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean response times for the green trials revealed no significant main effects or

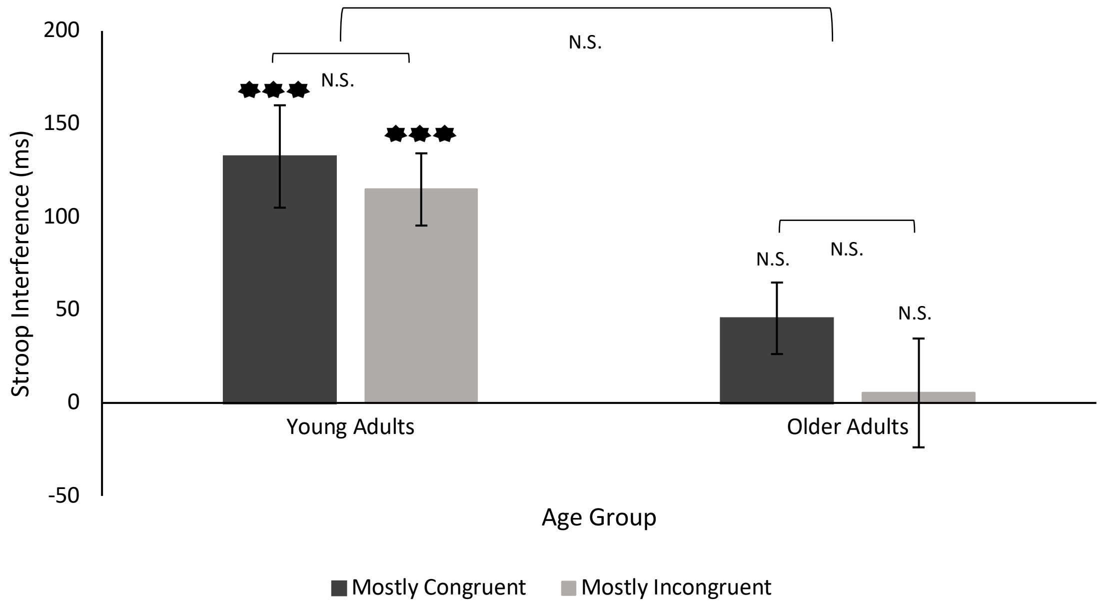

Figure 8. Behavioral results for the presence of transfer of congruency effects to the unbiased trials. The overall age x block proportionality x congruency interaction was not significant. For the unbiased trials, proportionality manipulations did not modulate the Stroop effect for young adults or older adults. The significant congruency x age interaction indicates that for the unbiased trials, older adults have a significantly smaller Stroop effect than the young adults in both the mostly congruent and mostly incongruent block. Follow-up Bonferroni-corrected *t*-tests indicated that young adults had significant Stroop effects in both the mostly congruent and mostly incongruent blocks whereas older adults did not have significant Stroop effects for either the mostly congruent or mostly incongruent block. Stroop interference = mean incongruent trials response times – mean congruent trials response times. N.S. = non-significant. *** $p < .001$. Error bars represent standard error of the mean.

interactions, p's $\geq .091$. For the young adults, the 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean response times for the green trials revealed a significant main effect of congruency, $F(1, 25) = 35.12$, $p < .001$. Neither the main effect of block proportionality nor the block proportionality x congruency interaction was significant, p's $\geq .449$. Young adults were significantly faster at responding to congruent trials ($M = 750.08$, $SD = 40.02$) than incongruent trials ($M = 873.71$, $SD = 39.75$). In the absence of the block proportionality x congruency interaction for young and older adults there was no evidence that mean response times to the unbiased (green) items were modulated by the block congruency manipulation. Lack of this pattern indicates that participants did not show evidence of using proactive control to bias their attention on a list-wide manner since task goals did not transfer to the unbiased items, thus Hypothesis 2a was not supported.

3.2.3. Congruency cost. Gonthier and colleagues (2016) also note that the presence of a congruency cost is another measure of proactive control which results in a slowing of congruent unbiased trials that are in the presence of a mostly incongruent block compared to a mostly congruent block. This pattern would indicate that participants are using the relevant color dimension information more prevalently than the irrelevant (but facilitative) word information for the unbiased congruent items in the mostly incongruent block compared to the mostly congruent block which would slow their responses to these congruent trials. Thus, I conducted a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) ANOVA on only the unbiased (green) congruent trials mean response times to examine for a congruency cost. The ANOVA revealed a significant main effect of age, $F(1, 40) = 7.34$, $p = .01$. The main effect of block proportionality and the block proportionality x age interaction were not significant, p's $\geq .402$. I also conducted a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) ANOVA on the biased (red and blue) congruent trials in order to determine whether congruency was manipulated for the biased trials (a weaker congruency cost that would provide evidence for proactive control). This ANOVA also revealed only a significant main effect of age, $F(1, 40) = 5.06$, $p = .03$, but neither a main effect of block proportionality nor a block proportionality x age interaction, p's $\geq .281$. Thus, for both the biased and unbiased congruent trials, older adults were significantly slower to respond than young adults. Post-hoc *t*-tests of the congruent trials in the mostly congruent and mostly incongruent blocks for the biased and unbiased trials revealed no significant congruency cost in any condition for young adults or older adults (Hypothesis 2b was not supported; Figure 9).

3.2.4. Word response time results. Examination of mean response times to the word recognition memory test was included as a post-hoc analysis to further investigate age differences in cognitive control. To evaluate the effect of interference on the retrieval time of the memory word, I conducted a 2 (block order: AB, BA) x 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (match: same, different) x 2 (congruency: congruent, incongruent) ANOVA on mean response times. The ANOVA revealed a significant main effect of match, $F(1, 38) = 35.29$, $p < .001$, a main effect of age, $F(1, 38) = 24.74$, $p < .001$, a main effect of congruency, $F(1, 38) = 43.55$, $p < .001$, a block proportionality x block order interaction, $F(1, 38) = 55.81$, $p < .001$, a block proportionality x age x block order interaction, $F(1, 38) = 5.61$, $p = .023$, and a match x congruency x age interaction, $F(1, 38) = 5.64$, $p = .023$. No other main effects or interactions were significant (p's $\geq .113$). Examination of the block proportionality x age x block order interaction indicates that learning occurred, as the second block was faster than the first block for both young and older adults. As block order only interacted with results through learning, this variable was dropped for further analyses.

I then conducted a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (match: same, different) x 2 (congruency: congruent, incongruent) ANOVA on mean response times. The ANOVA revealed a

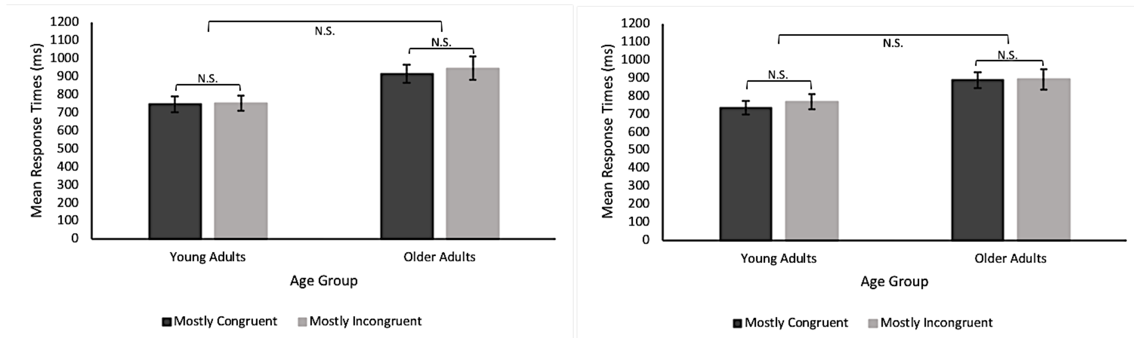

Figure 9. Behavioral results for the presence of a congruency cost. Neither the young adults nor the older adults exhibited a congruency cost in the mostly incongruent block compared to the mostly congruent block for either the biased (right) or unbiased (left) trials. The ANOVA revealed a significant main effect of age for both the biased and unbiased trials, indicating that older adults responded to the congruent trials more slowly than the young adults. Lack of a main effect of block proportionality or a block proportionality x age interaction indicates that evidence for proactive control was not shown in this condition. N.S. = non-significant. Error bars represent standard error of the mean.

significant main effect of match, $F(1, 40) = 36.83$, $p < .001$, a main effect of age, $F(1, 40) = 26.77$, $p < .001$, a main effect of congruency, $F(1, 40) = 43.90$, $p < .001$, and a significant match x congruency x age interaction, $F(1, 40) = 6.41$, $p = .015$ (Figure 10). No other main effect or interactions were significant (p's $\geq .109$). To examine the nature of the match x congruency x age interaction, I then split the data to investigate the match x congruency interaction separately by age groups. The 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (match: same, different) x 2 (congruency: congruent, incongruent) ANOVA on mean response times for the older adults revealed a significant main effect of match, $F(1, 15) = 13.64$, $p = .002$, a significant main effect of congruency, $F(1, 15) = 22.45$, $p < .001$, and a significant match x congruency interaction, $F(1, 15) = 7.40$, $p = .016$. No other main effects or interactions were significant (p's $\geq .357$). Examination of the match x congruency interaction revealed that although older adults were slower to respond to the words following an incongruent trial, they were even

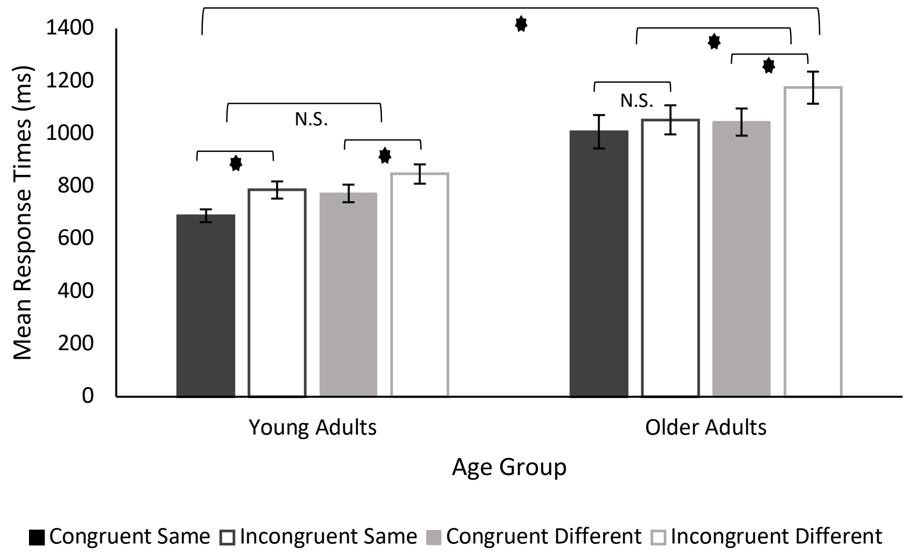

Figure 10. Behavioral results for the mean response times to the word recognition memory test for young and older adults collapsed across block proportionality. A significant age x match x congruency interaction was present in the data. Examining the congruency x match interactions separately for young and older adults revealed a significant interaction for older adults but not for young adults. Paired samples *t*-tests of congruent versus incongruent trials that had the word matching or not revealed significant differences between the same and different trials for young adults, but only a significant difference between the different trials for older adults. Thus, whereas young adults exhibited Stroop interference effects in trials in which the word matched and did not match, older adults only exhibited a Stroop interference effect in trials which the words did not match. N.S. = non-significant. * $p < .05$. Error bars represent standard error of the mean.

slower to respond to words that did not match the original word when preceded by an incongruent trial (M_C = 1044.30, SD_C = 206.56; M_I = 1175.06, SD_I = 244.01; M_{diff} = 130.76) than to words that did match the original word (M_C = 1007.44, SD_C = 253.86; M_I = 1052.74, SD_I = 221.26; M_{diff} = 45.29). The 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (match: same, different) x 2 (congruency: congruent, incongruent) ANOVA on mean response times for the young adults revealed a significant main effect of match, $F(1, 25) = 24.90$, $p < .001$, and a significant main effect of congruency, $F(1, 25) = 25.22$, $p < .001$. No other main effects or interactions were significant (p's $\geq .171$). Young adults were significantly faster to respond to words when they followed a congruent trial ($M = 730.32$, $SD = 147.37$) compared to when they followed an incongruent trial ($M = 816.37$, $SD = 176.54$). Young adults were also significantly faster at responding to words that matched the original word ($M = 737.04$, $SD = 145.24$) than to words that did not match the original word ($M = 809.86$, $SD = 178.67$).

3.3. ERP Results

To examine the electrophysiological markers prevalent in the study, we identified two time windows of interest and two electrodes of interest based on our previous work with the internal Stroop task (Faust et al., 2017; 2018), previous literature examining Stroop and Flanker ERP effects (Larson et al., 2014), and examination of group ERP curves and scalp distributions. The early ERP effect was maximal in the frontal regions (electrode FCZ of interest) in the time window 200 – 300 ms (see Figure 3). Our previous work identified this as an N2-like effect (Faust et al., 2017; 2018). The late ERP effect was maximal in the posterior regions (electrode PZ of interest) in the time window 500 – 650 ms (see Figure 4). Our previous work identified this as late positivity effect (Faust et al., 2018).

3.3.1. Early ERP effect. In order to investigate the early frontal electrophysiological component, I first conducted a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (bias: biased, unbiased) x 2 (congruency: congruent, incongruent) ANOVA on mean amplitude at electrode FCZ in the time window of 200 ms to 300 ms. This ANOVA revealed no significant main effects or interactions, p's $\geq .068$.

Next I conducted paired samples *t*-tests to examine the congruency effects for young and older adults at both levels of block proportionality for the biased and unbiased trials (see Table 3). These *t*-tests revealed no significant differences for older adults, but a significant difference in congruency for the biased trials in the young adults for both the mostly congruent block, $F(1, 25) = 5.13$, $p = .032$, and the mostly incongruent block, $F(1, 25) = 4.81$, $p = .038$. These *t*-tests indicated the need for a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean amplitude for the biased trials. This ANOVA revealed no significant main effects or interactions, p's $\geq .078$. I then split this ANOVA to analyze young and older adults separately. The 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean amplitude for the biased trials revealed no significant main effects nor a significant interaction for the older adults, p's $\geq .455$, nor a significant block proportionality main effect or block proportionality x congruency interaction for young adults, p's $\geq .258$. However, the ANOVA did reveal a significant main effect of congruency for young adults, $F(1, 25) = 6.57$, $p = .017$. The aforementioned *t*-tests indicated that for the biased trials, the young adults exhibited a significant congruency effect for both blocks of trials. The incongruent trials were more negative than the congruent trials in both blocks, indicating that a significant early frontal component was present for the young adults (i.e., an N2 congruency effect; Figure 11; Hypothesis 3 was supported). The data were then collapsed across block proportionality since the congruency effect did not depend on block proportionality manipulations. The 2 (age: young adult, older adult) x 2 (congruency: congruent, incongruent) ANOVA on biased trials mean amplitude revealed

Table 3

Mean Amplitudes and p-Values at Electrode FCZ from 200-300 ms

	Young Adults		Older Adults	
Block Congruency	*M (SD)*	*p*	*M (SD)*	*p*
		Biased		
Mostly Congruent		**.032**		.877
Congruent	1.86 (3.42)		3.07 (3.36)	
Incongruent	0.61 (3.44)		2.95 (4.73)	
Mostly Incongruent		**.038**		.847
Congruent	1.05 (3.99)		2.70 (4.15)	
Incongruent	0.14 (3.90)		2.59 (4.41)	
		Unbiased		
Mostly Congruent		.188		.837
Congruent	0.97 (4.62)		3.93 (4.33)	
Incongruent	2.15 (4.63)		3.76 (4.23)	
Mostly Incongruent		.096		.939
Congruent	2.17 (3.81)		2.83 (4.73)	
Incongruent	0.68 (3.45)		2.78 (4.65)	

Note. $N = 42$ (Young Adults $n = 26$; Older Adults $n = 16$). *p*-values reflect paired samples *t*-tests between the congruent and incongruent trials in the specific block types for both biased and unbiased trials.

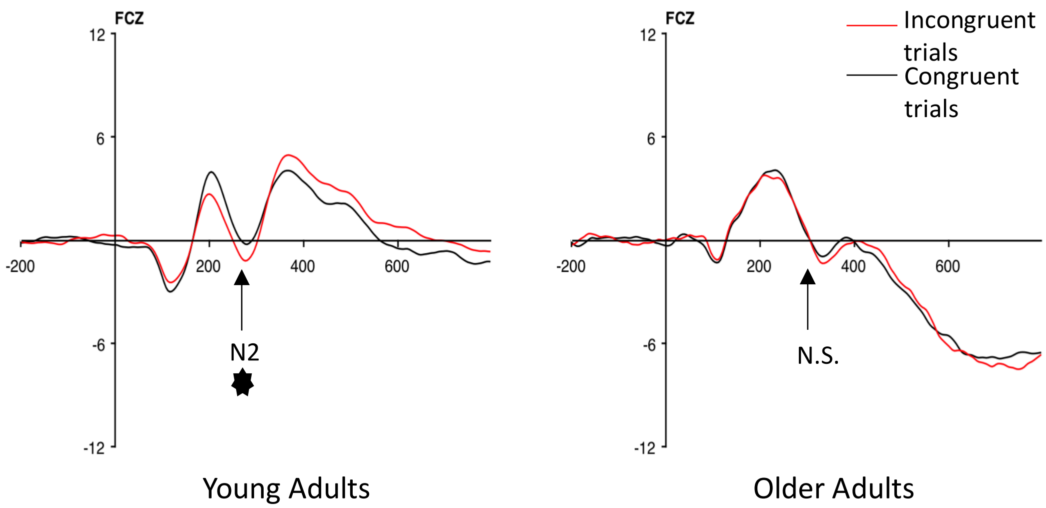

Figure 11. Average ERP waves for biased (red and blue) trials for young and older adults at electrode FCZ collapsed across block proportionality. Young adults showed evidence for a significant N2-like ERP component during the time window 200-300 ms. Incongruent trials for the young adults were significantly more negative than the congruent trials. Older adults did not show evidence for a significant difference between congruent and incongruent trials for this electrode during this time window. The age x congruency interaction was not significant (p = .15). N.S. = non-significant. * p < .05.

no significant main effects nor a significant interaction, p's ≥ .078. Follow-up t-tests examining congruency effects for young adults and older adults separately revealed a significant congruency effect for young adults only, $F(1, 25) = 6.56$, $p = .017$ (older adults $p = .819$). This pattern indicates that for young adults, this early ERP effect was likely tied to conflict detection since it was significantly related to congruency only with no effect of block proportionality.

3.3.2. Late ERP effect. Similarly, to investigate the late positivity component, I conducted a 2 (age: young adult, older adult) x 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (bias: biased, unbiased) x 2 (congruency: congruent, incongruent) ANOVA on ERP mean amplitude at electrode PZ in the time window 500 ms to 650 ms. The ANOVA revealed a main effect of bias, $F(1, 40) = 8.67$, $p = .005$, a main effect of age, $F(1, 40) = 4.50$, $p = .04$, a main effect of congruency, $F(1, 40) = 4.47$, $p = .041$, and a bias x age interaction, $F(1, 40) = 15.27$, $p < .001$. No other main effects or interactions were significant, p's $\geq .086$. In order to examine the nature of the interaction, the ANOVA was broken down into separate ANOVAs based on bias and age. The 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean amplitude for biased trials revealed no significant main effects or interactions for older adults (p's $\geq .155$) or young adults (p's $\geq .093$).

The 2 (block proportionality: mostly congruent, mostly incongruent) x 2 (congruency: congruent, incongruent) ANOVA on mean amplitude for unbiased trials revealed no significant main effects nor a significant interaction for the older adults (p's $\geq .721$), but a significant block proportionality x congruency interaction for the young adults, $F(1, 25) = 6.97$, $p = .014$ (main effects were not significant for the young adults, p's $\geq .084$). Examination of this interaction revealed that a significant congruency effect was only present in the mostly congruent block, $F(1, 25) = 13.20$, $p = .001$, not in the mostly incongruent block, $F(1, 25) = .13$, $p = .721$ (Figure 12). Thus, the driver of the late positivity effect seemed to appear only for the young adults in the mostly congruent block for the unbiased items (Hypothesis 4 was supported). Rather than showing attenuated ERP markers, older adults did not show evidence of any significant ERP components in the early time window or late time window for the electrodes of interest; therefore, Hypothesis 5 was not supported.

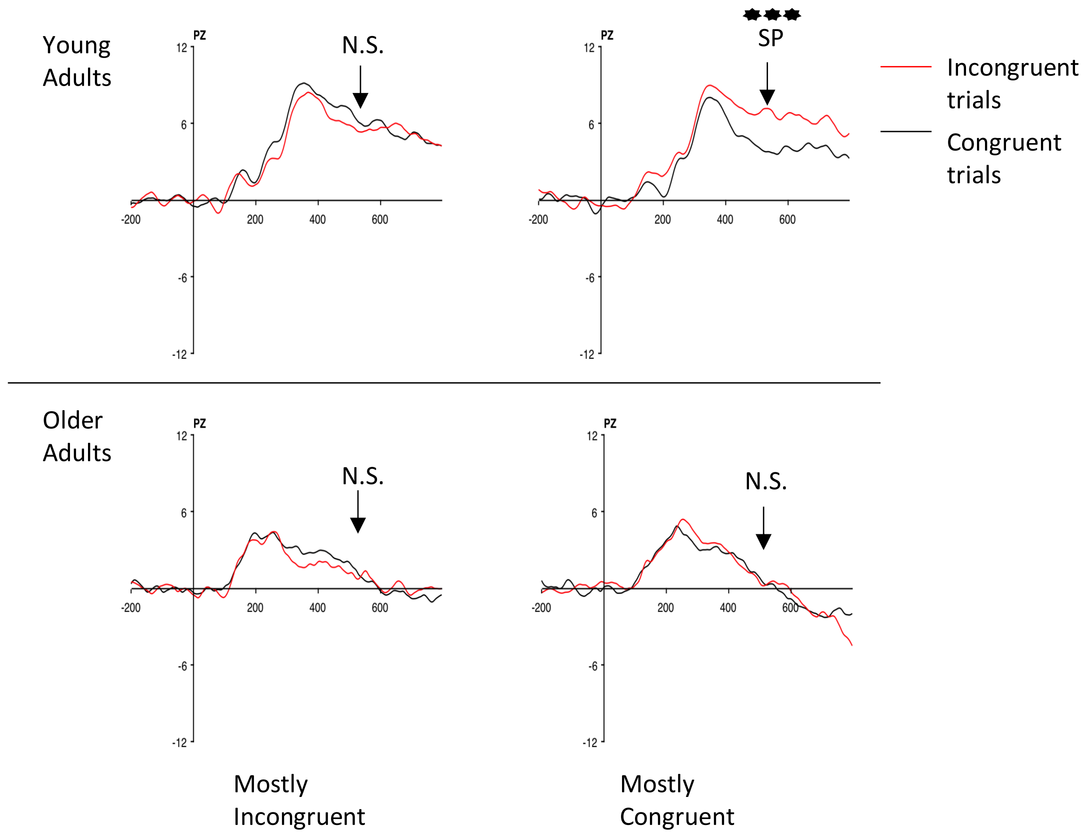

Figure 12. Average ERP waves for unbiased (green) trials for young and older adults at electrode PZ during the time window 500-650 ms. Whereas the older adults did not show evidence for a significant difference between the congruent and incongruent trials in either the mostly congruent or mostly incongruent block, the young adults did show evidence for a significant late positivity effect in the mostly congruent block. This effect indicates that the incongruent trials were significantly more positive than the congruent trials in the mostly congruent block. N.S. = non-significant. *** $p = .001$.

CHAPTER 4: DISCUSSION

The aims of the current study were to further test whether attention and working memory operate under the same control system, to what extent the DMC theory can explain patterns found in the internal Stroop task, and determine to what extent aging shows differences behavioral and electrophysiological markers found in response to this task. Like past research (Gonthier et al., 2016; Kiyonaga & Egner, 2014), young adults exhibited evidence of a reduced Stroop interference effect with the manipulation of the proportion of incongruent trials in a block. Specifically, by adjusting to the level of task-relevant distractor information in the task with a forward-looking mechanism (Braver, 2012), young adults seemed to exhibit evidence of proactive control by having a smaller Stroop effect in the mostly incongruent block compared to the mostly congruent block when examining all trial types or the biased trials alone (Bugg, 2014a; Gonthier et al., 2016; Tillman & Wiens, 2011). This pattern provides partial support for Hypothesis 1 since the modulation was found only for young adults (but not for older adults as hypothesized). This pattern suggests that congruency manipulation effects that influence the traditional external Stroop task are also found in some behavioral patterns in the internal Stroop task, at least for young adults (consistent with Kiyonaga & Egner, 2014). Similarities between the internal and external Stroop also indicate similar processing mechanisms used for attention and working memory (Engle, 2018; Kiyonaga & Egner, 2013). Contrarily, older adults did not show evidence of a modulated Stroop interference effect that was influenced by block proportionality (cf. Bugg, 2014a). Therefore, the significant block proportionality x congruency interaction (Figure 6) was driven by the young adults rather than the older adults. Thus, the similarities between the traditional external Stroop task and the internal Stroop task may be limited to specific task manipulations and age groups. However, rather than reflecting different processing between attention and working memory, differences found between the internal and external Stroop task may reflect use of different cognitive control mechanisms or level of cognitive control exerted in response to the task. Whereas young adults seem to modulate their cognitive control resources based on proportionality manipulations (i.e., they seem to upregulate their cognitive control dependent on task demands), older adults do not seem to modulate their cognitive control based on current task demands. Older adults may be saving cognitive resources by responding in a reactive manner, rather than modulating control based on forward-looking proactive control that would heighten cognitive resources used across a block. Differential modulation of control between young and older adults in response to the current experiment could reflect overutilization of resources by older adults at low task demands that young adults wait to recruit until higher task demands (Grady, 2012; Park & Reuter-Lorenz, 2009).

The second aim of the study was to determine the extent to which the DMC theory could explain patterns found in the internal Stroop task. The current study included an experimental design meant to heighten use of proactive control through the use of the list-wide congruency manipulations. Contrary to past researchers (Gonthier et al., 2016), I did not find evidence of proactive control through the presence of transferring task goals or congruency costs to the unbiased items (i.e., Hypotheses 2a and 2b were not supported). I did present modest evidence for the upregulation of cognitive control among young adults evidenced by the significant block proportionality x congruency interaction. This effect is likely due to proactive control that results in the modulation of the Stroop effect for young adults between the mostly congruent and mostly incongruent block (for biased trials and collapsing across trial type). Researchers have sought to isolate the effect of proactive control by examining its unique advantages and costs with unbiased items embedded in a block of biased proportionality (Gonthier et al., 2016). Young adults did not show evidence of a reduced Stroop interference effect in the mostly incongruent block compared to the mostly congruent block for the unbiased (50% congruency) trials. A reduced Stroop interference effect for the unbiased trials would indicate that the task goals were being transferred to an unbiased set of items. The current study also did not show evidence of a congruency cost for the unbiased items in the mostly incongruent block. Young adults did not show evidence for a slowing of responses to the congruent trials in the mostly incongruent block compared to the mostly congruent block.

The lack of transfer effects and congruency costs in the current study could be due to the congruency proportionalities used in the current study, the number of stimuli used, the separation of the word and color dimensions, or low power. Unlike Gonthier and colleagues (2016) who used 75% and 25% congruency as the overall proportionalities for their mostly congruent and mostly incongruent blocks, I used 67% and 33% congruency as my block proportionalities. The overall block proportionality was also diluted more than 67% and 33% due to the inclusion of the 50% congruent items. Thus, the block proportionality manipulation may not have been strong enough to show evidence of transfer and congruency costs in mean response times. Further, the current study used three color words and colors in order to simplify the task and due to the constraint of a three-color button box. Gonthier and colleagues (2016) used four distinct stimuli in the biased and unbiased trial types (eight stimuli overall). Thus, the current study could have utilized too few stimuli resulting in contingency learning effects that could have interfered with the traditional proactive control patterns found. Finally, the fact that the word and color dimension were separate in this study may have influenced the extent to which participants attend to the irrelevant dimension and their subsequent control mechanism used. The internal Stroop task may be distinct enough from traditional external Stroop tasks to limit extension of traditional patterns of control from external to internal tasks. Future studies utilizing the same congruency manipulations with a traditional Stroop task are needed to delineate the reasons for differences found between the current study and past researchers.

The third aim of the current study was to determine the extent to which aging exhibited differences in behavioral and electrophysiological patterns found in response to the internal Stroop task. Surprisingly, older adults showed a significantly smaller Stroop interference effect than the young adults. This effect is contrary to the traditional established aging effects found in the Stroop task (Bugg, 2014b; West, 2004; Zurron, Lindin, Galdo-Alvarez, & Diaz, 2014) and even past investigation of the internal Stroop with older adults in which young and older adults exhibited similar Stroop interference effects (Faust, Multhaup, & Manning, 2016). Reasons for the difference in the Stroop effect found for older adults could be explained by the demographics of the older adult participants or the simplified design in the current study. The older adults included in the current study may not be representative of a typical community-dwelling population as the participants were highly educated (i.e., the average education level was a college degree). Regarding the design, the current study used a single color patch instead of three color patches in the previous study (Faust et al., 2016). The lower task demands in the current study may have allowed older adults to save cognitive resources during the patch response by suspending rehearsal of the word during the color response. This aligns with a reactive control account of older adult responses, as task goals would be reactivated after presentation of the target. If older adults are not maintaining the word during the color patch response, it makes sense that they would be less affected by interference than the young adults. The fact that young adults also showed a significantly larger Stroop interference effect than the older adults also could point to young adults maintaining the word information over the entire trial, which suggests utilizing proactive control.

Examination of the word recognition memory test response times also points to the fact that older adults may not be holding the word as active as young adults. Young adults showed a significant Stroop interference effect on their memory recognition when the word recognition test both matched and mismatched the word held in memory. Specifically, young adults were slower to respond to the memory test when the word followed an incongruent trial compared to when the word followed a congruent trial. Thus, young adults' prior attention to the color patch interfered with how quickly they could respond to the memory test. However, older adults only showed a Stroop interference effect when the word mismatched with the word held in memory. Older adults were slower to respond to the memory test when they had previously faced an incongruent patch compared to a congruent patch only for the trials that the word recognition memory test did not match the original word (i.e., trials in which they must respond with a "no" in the memory test). If older adults are reactivating the word goals after presentation of the word, these trials would be more cognitively demanding because of the higher level of conflicting information present for these trials. Thus, the heightened cognitive demand on incongruent mismatch trials significantly impaired older adults' response times during this trial type and may reflect their use of reactive control.

When looking at the ERP markers, like past work (Faust et al., 2017; 2018) and in support of Hypothesis 3, I found evidence of an earlier ERP component (N2) for the young adults in which the incongruent trials were significantly more negative than the congruent trials. This effect was significant for the biased (red and blue) trials in the time window 200 – 300 ms in both the mostly congruent and mostly incongruent blocks. The early frontal ERP effect was not influenced by block proportionality manipulations and seemed to reflect an early conflict detection mechanism (Larson et al., 2014). An early N2 effect is typically elicited by a Flanker task rather than the traditional Stroop ERP (N450; Larson et al., 2014; Tillman & Wiens, 2011). However, other researchers examining the Stroop effect in older adults with two color options (Ramos-Goicoa et al., 2016) or in young and older adults using a congruent-incongruent color judgement (instead of naming the color; Zurron et al., 2014) also found evidence of an N2 effect. Larson and colleagues (2014) suggest that the N450 and N2 both reflect conflict detection components that are elicited by the ACC. Therefore, rather than proposing that the internal Stroop task results in a distinct ERP component from traditional external Stroop tasks, the current appearance of the earlier component may reflect only differences in experimental manipulations rather than distinct processing between the two components. Thus, further examination of the nuances of attention and working memory is warranted.

Our past work also indicated that the external Stroop task is the only one that shows evidence for a late posterior positivity effect (Faust et al., 2018). However, I found a significant SP effect for the unbiased trials in the mostly congruent block for young adults (in support of Hypothesis 4). This ERP effect shows that the incongruent trials were significantly more positive than the congruent trials in this block. Individuals may be sensitive to the fact that the green trials do not follow the same congruency manipulations of the biased trials in the mostly congruent block. With low levels of cognitive resources needed for the mostly congruent block, the presence of conflicting information in these differently manipulated items could result in extended processing of these trials, especially if the cognitive system is geared away from processing incongruent trials due to their rarity in the block. Thus, late cognitive processing may occur in the internal Stroop task depending on task manipulations. Rather than showing attenuated electrophysiological effects as hypothesized (Hypothesis 5), older adults did not show any significant ERP effects in the investigated time windows or electrodes of interest. Therefore, their processing of congruency seems to differentiate from young adults and may reflect different control mechanisms being used between the two groups. ERP results allow greater temporal clarity than other neuroimaging measures and may be better equipped to detect differences in processing than behavioral measures. Further, ERP markers have been used to identify those at risk for unhealthy aging (e.g., Alzheimer’s disease; Newsome, Pun, Smith, Ferber, & Barense, 2013). By identifying typical electrophysiological patterns for young and older adults in response to tests of cognitive control, benchmark patterns can be established to understand normal and diseased cognitive aging differences.

The current study was not without limitations. The biggest limitation was related to sample size. Although 50 total participants were recruited, due to memory retrieval abilities and electrical artifacts in the ERP data, eight total participants were lost. Thus, the study could have been underpowered to find small, but significant, effects. Also, the group distributions were not equal, as 30 young adults and 20 older adults were initially recruited, with 26 young adults and 16 older adults remaining in final analyses. The unequal distribution of groups limited the strength of the ANOVAs. However, the data were analyzed separately by age group to strengthen group analyses. Young and older adults also were not always tested during their peak time of performance which could have influenced their ability to respond at maximum capacity. Additionally, our ERP analyses are limited because we relied strongly on specific electrodes of interest (i.e., FCZ and PZ). Further investigation of the data using broader regions of interest consistent with the scalp maps may enhance our ability to detect significant electrophysiological components by averaging across specific regions of electrodes which could increase the signal-to-noise ratio. Finally, the current study was limited to analysis of ERP mean amplitudes. Examination of latency could further enhance understanding of electrophysiological patterns found in the task.

Future research could directly examine the external Stroop with the same task manipulations as the current study to determine whether the behavioral and electrophysiological patterns found here are unique to the current study design. Future research could also manipulate working memory load to explicate whether the Stroop pattern found for older adults is dependent on task load. Modifications to the study design could also be implemented. Specifically, level of block congruency could be changed to strengthen proportionality effects, number of stimuli could be increased to determine if three stimuli is too few to elicit traditional Stroop patterns, and examination of a truly item-specific block could be included to further delineate proactive and reactive control patterns found in response to the task. Future research could also examine the internal Stroop task taking into consideration individual differences in working memory capacity, as this could influence individuals' responses to this task (Engle, 2018; Meier & Kane, 2017).

4.1. Conclusion

The current study replicated past research partially with young adults exhibiting evidence of a modulated Stroop interference effect in the mostly incongruent block compared to the mostly congruent block. However, this difference was only present when including the biased trials in the examination and did not extend to older adults. Therefore, the upregulation of cognitive control to more complex task demands seem to be present for young adults but limited in older adults. Additionally, like past research, the current study revealed in the ERP components an N2 congruency effect instead of a traditional N450 effect (although differentiation of the N2 and N450 needs further investigation). Thus, the replicability of traditional Stroop patterns to an internal Stroop task may be limited. An unanticipated finding was the presence of a smaller Stroop interference effect for the older adults compared to the young adults. This pattern may provide evidence for reduced maintenance of the word information over the color patch response which would indicate older adults are using reactive control. The current study did not replicate all the measures of proactive control proposed by Gonthier and colleagues (2016). However, by examining the electrophysiological markers of the internal Stroop task in addition to behavioral measures, the appearance of unique congruency and proportionality effects on ERP markers in young adults indicate that the internal Stroop task may be more sensitive to detect nuanced proactive control declines in the aging population. Further examination of the relationship between working memory and attention, the internal Stroop task, and the DMC are warranted.

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APPENDIX A: EMAIL FOR RECRUITMENT

Email or Listserv for Recruitment – send to Faculty/Staff

Hi there! As part of a master's thesis project, the Psychology Department at the University of North Carolina at Charlotte is looking for participants aged 60 and up to participate in research.

Task:

In this study, you will be asked to respond to two simple tasks administered on a computer. In one, you will be asked to remember a word for a few seconds. In the other, you will be asked to identify the color of a rectangle. While you are performing these tasks, you will also be wearing an EEG cap which is like a swim cap. The cap allows us to measure brain activity from outside of the head. To make the cap work, we have a salt-based gel that we will put in your hair so that we can strengthen the signal from your brain to the cap. The gel is easily washed out but hardens over time like a hair gel. You will be able to wash the gel out of your hair after the session, or you can bring a hat to put on after the session so that you can wash your hair once you get home.

Time Requirement:

The session will last approximately two hours.

Eligibility Criteria:

Participants must (a) be at least 60 years of age, (b) have no history of epilepsy or seizures, (c) be right handed, and (d) not be color-blind.

Incentives:

Participants will receive parking validation for the day if they park in visitor parking and will receive a $25 gift card for their participation in the study.

Please see the attached flyer for more information. If you have any questions, please contact Monica Nelson at 910-599-4270 or mnelso49@uncc.edu or Dr. Mark Faust (faculty advisor) at 704-687-1341 or mefaust@uncc.edu.

This project has been approved by the UNC Charlotte IRB, Protocol #: 15-0111

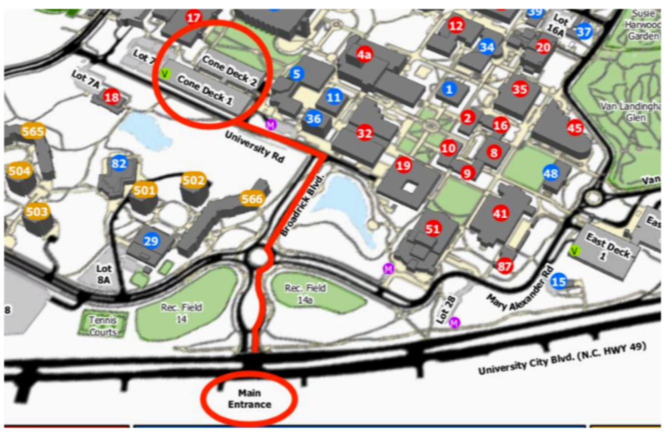
APPENDIX B: STUDY FLYER

UNC CHARLOTTE

Age-Related Differences in Cognitive Control

Come participate in research!

The study is designed to investigate age differences in behavioral (response times and accuracy) and neural (electroencephalogram; EEG) correlates of attention and working memory tasks. Participants will have an EEG cap placed on their head, then respond to cognitive tasks administered via a computer screen. The session will take approximately 2 hours.



Parking Directions:

- Enter UNCC's Main entrance (from University City Blvd)
- Take 2nd exit in traffic circle
- Go to stop sign and make a left
- Cone Deck 1 will be on the right directly after a short-term parking lot
- After you turn right, you will take the first entrance to the Cone Deck which is on your left
- I or another research assistant will meet you at ground level of the Cone Deck

Learn about EEG research!

For participants aged 60 and up!

Receive a $25 gift card for participation!

Parking validated!

IRB Protocol #:

15-0111

MONICA NELSON
UNC Charlotte

Cone Deck 1 Address: 8919 University Rd, Charlotte, NC 28223

910-599-4270

mnelso49@uncc.edu

Please park in the Cone Deck 1 (see map insert to left).

Sessions will take place in Colvard 4116.

Please contact me for more information!

APPENDIX C: OLDER ADULT CALLING SCRIPT

Older Adult Participant Calling Script for EEG and Cognitive Control Study

*Have a calendar, the Older Adult Volunteer notebook, and the direction sheet ready.

Hi, my name is ________________ *and I'm calling from the Aging research lab in the Psychology Department at Davidson College.*

Your name is on a list of people who said they might be interested in participating in research about aging. We have a project going on right now *that is a collaboration with UNCC and takes place at UNCC. Would you like me to tell you about it?*

If no, ask if they would like their name removed from the list (unless it's clear that they want to participate, but can't).

Thank them for their time. If yes, proceed:

Because this study is done with specialized equipment that measures brain electrical activity, we need to make sure you are eligible to participate. First, are you right-handed?

If no*, unfortunately, we must have a uniform sample of right-handed individuals. Thank you for your time, we will let you know when there are future studies you can participate in!*

If yes, *Great! Also, are you able to see the colors red, green, and blue with normal or corrected-to-normal vision?*

If no*, unfortunately, in order to respond to the task, you must be able to accurately distinguish between these colors. Thank you for your time, we will let you know when*

there are future studies you can participate in!

If yes, *Great! One final question: Do you have any history of epilepsy or seizures?*

If yes, *Unfortunately, our task on the computer with a continually flashing screen could induce a seizure. At this time, we are not able to include you, but we will let you know when there are other studies you can participate in. Thank you for your time!*

If no, *Great! Let me tell you a little more about the study:*

In this study, you will be asked to respond to two simple tasks administered on a computer. In one, you will be asked to remember a word for a few seconds. In the other, you will be asked to identify the color

of a rectangle. While you are performing these tasks, you will also be wearing an EEG cap which is like a swim cap. The cap allows us to measure brain activity from outside of the head. To make the cap work, we have a salt-based gel that we will put in your hair so that we can strengthen the signal from your brain to the cap. The gel is easily washed out but hardens over time like a hair *gel. You will be able to wash the gel out of your hair after the session, or you can bring a hat to put on after the session so that you can wash your hair once you get home. You will be compensated for your time with a $25 gift card.*

The study will take around two hours to complete, and we will be having participants come in (dates). Would you be interested in participating?

If no, thank them for their time.
If they are busy, ask if there is a better time to call (later in the spring...)

If yes, set up a MORNING appointment (starting between 8 and 11 a.m.)

We are doing this project in the Colvard Building on the UNC Charlotte Campus. I ask that you please park in the Cone Deck, so that I can meet you there to bring you to the Colvard Building. Do you know where the Cone Deck is?

If no, *I'll give you directions over the phone and will email or mail you a copy as well. Could I have your address?* (If we already have the address: *Are you still at [address listed in notebook]?) (Give directions*: Directions Sheet)

If yes, and don't have address, *Great. Then I won't need to mail you directions, but could I get your email or mailing address so we can send you a summary of the project when we're finished?*

Once you park in the Cone Deck, please go to the ground level of the Cone Deck. I or another research assistant will wait for you on the ground level of the Cone Deck. You will receive a parking validation after your session is complete, so please make sure to get a ticket from the deck.

Let me give you my phone number just in case you need to reach me. You can leave me a message anytime at 910-599-4270.

APPENDIX D: GENERAL HEALTH AND HANDEDNESS QUESTIONNAIRE

BIOGRAPHICAL INFORMATION FORM

STUDY: ________________________________ PARTICIPANT NUMBER: ________

GENDER: ________________ ETHNICITY (ASK): __________________ AGE: _________

EDUCATION (YEARS): __________

Modified from Edinburgh Handedness Inventory (Revised)					
Please mark the box that best describes which hand you use for the activity in question					
	Always Left	*Usually Left*	*No Preference*	*Usually Right*	*Always Right*
Writing					
Throwing					
Toothbrush					
Spoon					

MEDICAL

Do you have a condition that would substantially reduce your performance reading words or images presented on a computer screen? Y / N

Have you ever experienced a seizure or lost consciousness due to injury? Y / N

Has a doctor every diagnosed you with a brain disorder? Y / N

Are you taking any medications that might affect your performance during computerized testing? Y / N

Do you need glasses to see a computer screen (Farsighted)? Y / N

If yes, is the participant wearing . . . GLASSES / CONTACTS/ NONE

OTHER COMMENTS:

rev. 4/25/16

APPENDIX E: MATLAB SCRIPTS

```
% Clear memory and the command window and open eeglab
clc;
eeglab;

% This defines the set of subjects
 % subject_list = {'101A'};

% This defines the set of subjects
%subject_list = {'101A', '101B', '102A', '102B', '103A', '103B',
'104A', '104B', '105A', '105B', '106A', '106B', '107A', '107B', '108A',
'108B', '109A', '109B', '110A', '110B', '111A', '111B', '112A', '112B',
'113A', '113B', '114A', '114B', '115A', '115B', '116A', '116B', '117A',
'117B', '118A', '118B', '119A', '119B', '120A', '120B', '121A', '121B',
'122A', '122B', '123A', '123B', '124A', '124B', '125A', '125B', '126A',
'126B', '127A', '127B', '128A', '128B', '129A', '129B', '130A', '130B',
'201A', '201B', '202A', '202B', '203A', '203B', '204A', '204B', '205A',
'205B', '206A', '206B', '207A', '207B', '208A', '208B'};
subject_list = {'209A', '209B', '210A', '210B', '211A', '211B', '212A',
'212B', '213A', '213B', '214A', '214B', '215A', '215B', '216A', '216B',
'217A', '217B', '218A', '218B', '219A', '219B', '220A', '220B'};


nsubj = length(subject_list); % number of subjects

% Path to the parent folder, which contains the data folders for all
subjects,
home_path  = 'F:\MonicaThesisBackup';

% Path to the folder containing the current subject's data and new
folder
% for EEGLab sets
datain_path  = [home_path '\EEGData\'];
dataout_path  = [home_path '\EEGLabSets\'];

% Set the save_everything variable to 1 to save all of the intermediate
files to the hard drive
% Set to 0 to save only the initial and final dataset and ERPset for
each subject
save_everything  = 0;

% Loop through all subjects
for s=1:nsubj

    fprintf('\n******\nProcessing subject %s\n******\n\n',
subject_list{s});

    % Check to make sure the Neuroscan continuous file exists
    % Initial filename = path plus Subject# plus .cnt
    sname = [datain_path subject_list{s} '.cnt'];
    if exist(sname, 'file')<=0

            fprintf('\n *** WARNING: %s does not exist *** \n', sname);
```

```
            fprintf('\n *** Skip all processing for this subject ***
\n\n');

    else

        %
        % Load original Neuroscan continuous file and save as EEGLAB
dataset
        %
        fprintf('\n\n\n**** %s: Loading dataset ****\n\n\n',
subject_list{s});
        EEG = pop_loadcnt(sname , 'dataformat', 'auto', 'memmapfile',
'');
        [ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG,
0,'gui','off');
        EEG = eeg_checkset( EEG );
        %
        % Remove missing electrodes
        %
        EEG = pop_select( EEG,'nochannel',{'CB1' 'O1' 'OZ' 'O2'
'CB2'});
        [ALLEEG EEG CURRENTSET] = pop_newset(ALLEEG, EEG,
1,'gui','off');
        %
        % Filter at 0.1 and 30 Hz;
        %
        fprintf('\n\n\n**** %s: Band-pass filtering EEG at 0.1 and 30
Hz ****\n\n\n', subject_list{s});
        EEG  = pop_basicfilter( EEG,  1:61 , 'Boundary', 'boundary',
'Cutoff', [0.1 30], 'Design', 'butter', 'Filter', 'bandpass', 'Order',
2, 'RemoveDC', 'on' );
        %
        % Resample to 250 Hz
        %
        EEG = pop_resample( EEG, 250);
        %
        % Add the channel locations using file 'standard-10-5-
cap385.elp' copied from plugins/dipfit2.2/standard_BESA/
        %
        fprintf('\n\n\n**** %s: Adding channel location info
****\n\n\n', subject_list{s});
        EEG = pop_chanedit(EEG, 'lookup','standard-10-5-cap385.elp');
        %
        % Save dataset with _FiltDownChan suffix
        %
        EEG.setname = [subject_list{s} '_FiltDownChan'];
        EEG = pop_saveset(EEG, 'filename', [EEG.setname '.set'],
'filepath', dataout_path);


        % EEG = pop_saveset( EEG, 'filename',[subject_list{s}
'.set'],'filepath',dataout_path);
        [ALLEEG EEG] = eeg_store(ALLEEG, EEG, CURRENTSET);


    end % end of the "if/else" statement that makes sure the file
exists
```

```
end % end of looping through all subjects


fprintf('\n\n\n**** FINISHED ****\n\n\n');


% Clear memory and the command window and open eeglab
clc;
eeglab;

% This defines the set of subjects
% subject_list = {'101A'};
% nsubj = length(subject_list); % number of subjects

% This defines the set of subjects in AR (100) on 12 electrodes of
interest. No greater than 25%
% trials rejected overall
%dropped 212 & 215 due to low memory retrieval
% subject_list = {'101A', '102A', '103A', '104A', '105A', '106A',
'107A', '108A', '109A', '110A'}
% subject_list = {'111A', '112A', '113A', '114A', '115A', '116A',
'117A', '118A', '119A', '120A', '121A', '122A', '123A', '124A', '125A',
'126A', '127A', '128A', '129A', '130A'};
% subject_list = {'101B', '102B', '103B', '104B', '105B', '106B',
'107B', '108B', '109B', '110B'},
% subject_list = {'111B', '112B', '113B', '114B', '115B', '116B',
'117B', '118B', '119B', '120B', '121B', '122B', '123B', '124B', '125B',
'126B', '127B', '128B', '129B', '130B'};
% subject_list = {'201A', '202A',  '203A',  '204A',  '205A',  '206A',
'207A',  '208A',  '209A',  '210A',  '211A',  '213A',  '214A',  '216A',
'217A',  '218A',  '219A',  '220A'};
 subject_list = {'201B', '202B', '203B', '204B', '205B', '206B',
'207B', '208B', '209B', '210B', '211B', '213B', '214B', '216B', '217B',
'218B', '219B', '220B'};
 nsubj = length(subject_list); % number of subjects

%results of this revealed that 104,106,112,121,214,220 must be dropped
due
%to excessive artifacts

% Path to the parent folder, which contains the data folders for all
subjects
home_path  = 'F:\MonicaThesisBackup';

% Path to the folder containing the current subject's data and new
folder
% for EEGLab sets
datain_path  = [home_path '\EEGLabSets\'];
dataout_path  = [home_path '\EEGLabSets\'];

% Set the save_everything variable to 1 to save all of the intermediate
files to the hard drive
% Set to 0 to save only the initial and final dataset and ERPset for
each subject
save_everything  = 0;
```

```
% Loop through all subjects
for s=1:nsubj

    fprintf('\n******\nProcessing subject %s\n******\n\n',
subject_list{s});

    % Check to make sure the Neuroscan continuous file exists
    % Initial filename = path plus Subject# plus .cnt
    sname = [datain_path subject_list{s} '_FiltDownChan.set'];
    if exist(sname, 'file')<=0

            fprintf('\n *** WARNING: %s does not exist *** \n', sname);
            fprintf('\n *** Skip all processing for this subject ***
\n\n');

    else


      % Load original dataset
        %
        fprintf('\n\n\n**** %s: Loading dataset ****\n\n\n',
subject_list{s});
        EEG = pop_loadset('filename', [subject_list{s}
'_FiltDownChan.set'], 'filepath', datain_path);
        EEG.setname = [subject_list{s} '_FiltDownChan'];



        %
        % Add the channel locations
        % We're assuming the file 'standard-10-5-cap385.elp' is
somewhere
        % in the path.  This can be copied from
        % plugins/dipfit2.2/standard_BESA/ inside the eeglab
        % folder.
        %
        %fprintf('\n\n\n**** %s: Adding channel location info
****\n\n\n', subject_list{s});
     %   EEG = pop_chanedit(EEG, 'lookup','standard-10-5-cap385.elp');
        % Save dataset with _Chan suffix instead of _EEG
    %    EEG.setname = [subject_list{s} '_Chan']; % name for the
dataset menu
     %   if (save_everything)
     %       EEG = pop_saveset(EEG, 'filename', [EEG.setname '.set'],
'filepath', datain_path);
     %   end



        %
        % Create EVENTLIST and save (pop_editeventlist adds _elist
suffix)
        %
        fprintf('\n\n\n**** %s: Creating eventlist ****\n\n\n',
subject_list{s});
```

```
        EEG = pop_creabasiceventlist( EEG , 'AlphanumericCleaning',
'on', 'Newboundary', { -99 }, 'Stringboundary', { 'boundary' },
'Warning', 'on' );
        % EEG  = pop_creabasiceventlist( EEG , 'Eventlist',
'elist.txt', 'BoundaryNumeric', { -99 } ...
        %                             , 'BoundaryString', { 'boundary' },
'Warning', 'on' );
        EEG.setname = [EEG.setname '_Elist']; % name for the dataset
menu

        if (save_everything)
            EEG = pop_saveset(EEG, 'filename', [EEG.setname '.set'],
'filepath', datain_path);
        end




        %
        % Use Channel operations to re-reference to the average of the
        % mastoids.  Save output with _ref suffix.
        %

        EEG = pop_eegchanoperator( EEG, { 'nch1 = ch1 - ( (ch33 +
ch43)/2 ) Label FP1',  'nch2 = ch2 - ( (ch33 + ch43)/2 ) Label FPZ',
'nch3 = ch3 - ( (ch33 + ch43)/2 ) Label FP2',...
            'nch4 = ch4 - ( (ch33 + ch43)/2 ) Label AF3',  'nch5 = ch5
- ( (ch33 + ch43)/2 ) Label AF4',  'nch6 = ch6 - ( (ch33 + ch43)/2 )
Label F7',  'nch7 = ch7 - ( (ch33 + ch43)/2 ) Label F5',...
            'nch8 = ch8 - ( (ch33 + ch43)/2 ) Label F3',  'nch9 = ch9 -
( (ch33 + ch43)/2 ) Label F1',  'nch10 = ch10 - ( (ch33 + ch43)/2 )
Label FZ',  'nch11 = ch11 - ( (ch33 + ch43)/2 ) Label F2',...
            'nch12 = ch12 - ( (ch33 + ch43)/2 ) Label F4',  'nch13 =
ch13 - ( (ch33 + ch43)/2 ) Label F6',  'nch14 = ch14 - ( (ch33 +
ch43)/2 ) Label F8',  'nch15 = ch15 - ( (ch33 + ch43)/2 ) Label
FT7',...
            'nch16 = ch16 - ( (ch33 + ch43)/2 ) Label FC5',  'nch17 =
ch17 - ( (ch33 + ch43)/2 ) Label FC3',  'nch18 = ch18 - ( (ch33 +
ch43)/2 ) Label FC1',  'nch19 = ch19 - ( (ch33 + ch43)/2 ) Label
FCZ',...
            'nch20 = ch20 - ( (ch33 + ch43)/2 ) Label FC2',  'nch21 =
ch21 - ( (ch33 + ch43)/2 ) Label FC4',  'nch22 = ch22 - ( (ch33 +
ch43)/2 ) Label FC6',  'nch23 = ch23 - ( (ch33 + ch43)/2 ) Label
FT8',...
            'nch24 = ch24 - ( (ch33 + ch43)/2 ) Label T7',  'nch25 =
ch25 - ( (ch33 + ch43)/2 ) Label C5',  'nch26 = ch26 - ( (ch33 +
ch43)/2 ) Label C3',  'nch27 = ch27 - ( (ch33 + ch43)/2 ) Label C1',...
            'nch28 = ch28 - ( (ch33 + ch43)/2 ) Label CZ',  'nch29 =
ch29 - ( (ch33 + ch43)/2 ) Label C2',  'nch30 = ch30 - ( (ch33 +
ch43)/2 ) Label C4',  'nch31 = ch31 - ( (ch33 + ch43)/2 ) Label C6',...
            'nch32 = ch32 - ( (ch33 + ch43)/2 ) Label T8',  'nch33 =
ch33 - ( (ch33 + ch43)/2 ) Label M1',  'nch34 = ch34 - ( (ch33 +
ch43)/2 ) Label TP7',...
            'nch35 = ch35 - ( (ch33 + ch43)/2 ) Label CP5',  'nch36 =
ch36 - ( (ch33 + ch43)/2 ) Label CP3',  'nch37 = ch37 - ( (ch33 +
ch43)/2 ) Label CP1',...
```

```
                'nch38 = ch38 - ( (ch33 + ch43)/2 ) Label CPZ',  'nch39 =
ch39 - ( (ch33 + ch43)/2 ) Label CP2',  'nch40 = ch40 - ( (ch33 +
ch43)/2 ) Label CP4',  'nch41 = ch41 - ( (ch33 + ch43)/2 ) Label
CP6',...
                'nch42 = ch42 - ( (ch33 + ch43)/2 ) Label TP8',  'nch43 =
ch43 - ( (ch33 + ch43)/2 ) Label M2',  'nch44 = ch44 - ( (ch33 +
ch43)/2 ) Label P7',  'nch45 = ch45 - ( (ch33 + ch43)/2 ) Label P5',...
                'nch46 = ch46 - ( (ch33 + ch43)/2 ) Label P3',  'nch47 =
ch47 - ( (ch33 + ch43)/2 ) Label P1',  'nch48 = ch48 - ( (ch33 +
ch43)/2 ) Label PZ',  'nch49 = ch49 - ( (ch33 + ch43)/2 ) Label P2',...
                'nch50 = ch50 - ( (ch33 + ch43)/2 ) Label P4',  'nch51 =
ch51 - ( (ch33 + ch43)/2 ) Label P6',  'nch52 = ch52 - ( (ch33 +
ch43)/2 ) Label P8',  'nch53 = ch53 - ( (ch33 + ch43)/2 ) Label
PO7',...
                'nch54 = ch54 - ( (ch33 + ch43)/2 ) Label PO5',  'nch55 =
ch55 - ( (ch33 + ch43)/2 ) Label PO3',  'nch56 = ch56 - ( (ch33 +
ch43)/2 ) Label POZ',  'nch57 = ch57 - ( (ch33 + ch43)/2 ) Label
PO4',...
                'nch58 = ch58 - ( (ch33 + ch43)/2 ) Label PO6',  'nch59 =
ch59 - ( (ch33 + ch43)/2 ) Label PO8',  'nch60 = ch60 - ( (ch33 +
ch43)/2 ) Label HEO',...
                'nch61 = ch61 - ( (ch33 + ch43)/2 ) Label VEO'} ,
'ErrorMsg', 'popup', 'Warning', 'on' );

        [ALLEEG EEG] = eeg_store(ALLEEG, EEG, CURRENTSET);
        EEG.setname = [EEG.setname 'Ref'];
        if (save_everything)
            EEG = pop_saveset(EEG, 'filename', [EEG.setname '.set'],
'filepath', datain_path);
        end



        %
        % Use Binlister to sort the bins and save with _bins suffix
        % We are assuming that 'binlister_demo_1.txt' is present in the
        % home folder.
        %
        fprintf('\n\n\n**** %s: Running BinLister ****\n\n\n',
subject_list{s});
        EEG  = pop_binlister( EEG , 'BDF',
'F:\MonicaThesisBackup\Scripts\binlister1.txt', 'ImportEL', 'no',
'Saveas', 'off', 'SendEL2', 'EEG', 'Warning', 'off' );
        EEG.setname = [EEG.setname 'Bins'];

        if (save_everything)
            EEG = pop_saveset(EEG, 'filename', [EEG.setname '.set'],
'filepath', datain_path);
        end


        %
        % Extracts bin-based epochs (200 ms pre-stim, 800 ms post-stim.
Baseline correction by pre-stim window)
        % Then save with _be suffix
        %
```

```
        % fprintf('\n\n\n**** %s: Bin-based epoching ****\n\n\n', 
subject_list{s});
        EEG = pop_epochbin( EEG , [-200.0  800.0],  'pre');
        EEG.setname = [EEG.setname 'Epochs'];
        if (save_everything)
            EEG = pop_saveset(EEG, 'filename', [EEG.setname '.set'], 
'filepath', datain_path);
        end



        % Artifact detection, then
        % Save the processed EEG to disk because the next step will be 
averaging
        fprintf('\n\n\n**** %s: Artifact detection (moving window peak-
to-peak and step function) ****\n\n\n', subject_list{s});
        %
        % Artifact detection. Moving window. Test window = [-200
        % 596]; Threshold = 100 uV; Window width = 200 ms;
        % Window step = 50 ms; Channels = 1 to 61; Flags to be 
activated = 1 & 4
        %

        % EEG  = pop_artmwppth( EEG , 'Channel', [ 8:12 17:21 26:30 
36:40 46:50], 'Flag',  1, 'Threshold',  100, 'Twindow', [ -200 798], 
'Windowsize',  200, 'Windowstep',  50 );

        % EEG.setname = [EEG.setname '_ar'];
        % EEG = pop_saveset(EEG, 'filename', [EEG.setname '.set'], 
'filepath', datain_path);
        % EEG = pop_exporteegeventlist(EEG, [datain_path 
subject_list{s} '_eventlist_ar.txt']);

        EEG  = pop_artmwppth( EEG , 'Channel', [18:20 27:29 37:39 
47:49], 'Flag',  1, 'Threshold',  100, 'Twindow', [ -200 798], 
'Windowsize',  200, 'Windowstep',  50 );

        EEG.setname = [EEG.setname '_ar'];
        EEG = pop_saveset(EEG, 'filename', [EEG.setname '.set'], 
'filepath', datain_path);
        EEG = pop_exporteegeventlist(EEG, [datain_path subject_list{s} 
'_eventlist_ar.txt']);

        % Report percentage of rejected trials (collapsed across all 
bins)
        artifact_proportion = getardetection(EEG);
        fprintf('%s: Percentage of rejected trials was %1.2f\n', 
subject_list{s}, artifact_proportion);



        %
        % Averaging. All trials.  Include standard error.  Save to 
disk.
        %
        fprintf('\n\n\n**** %s: Averaging ****\n\n\n', 
subject_list{s});
```

```
        ERP = pop_averager( EEG, 'Criterion', 'good', 'SEM', 'on');
        ERP.erpname = [subject_list{s} '_ERPs'];  % name for erpset
menu
        pop_savemyerp(ERP, 'erpname', ERP.erpname, 'filename',
[ERP.erpname '.erp'], 'filepath', datain_path, 'warning', 'off');




        % Save this final ERP in the ALLERP structure.  This is not
        % necessary unless you want to see the ERPs in the GUI or if
you
        % want to access them with another function (e.g.,
pop_gaverager)
        % CURRENTERP = CURRENTERP + 1;
        % ALLERP(CURRENTERP) = ERP;

        % if (plot_PDFs)
        %     pop_ploterps(ERP, [1 2], 1:34, 'Style', 'ERP1');
        %     pop_fig2pdf([datain_path subject_list{s} '.pdf']);
        % end

    end % end of the "if/else" statement that makes sure the file
exists

end % end of looping through all subjects


fprintf('\n\n\n**** FINISHED ****\n\n\n');


% Clear memory and the command window and launch EEGLab
clc
[ALLEEG EEG CURRENTSET ALLCOM] = eeglab;

% Initialize the ALLERP structure and CURRENTERP
ALLERP = buildERPstruct([]);
CURRENTERP = 0;

% This defines the set of subjects
% subject_list = {'101A'};
% nsubj = length(subject_list); % number of subjects

% This defines the set of subjects
% subjects 212 and 215 were dropped due to low memory retrieval
% subjects 104, 106, 112, 121, 214, 220 were dropped due to excessive
% artifacts

% subject_list = {'101A', '102A', '103A', '105A', '107A', '108A',
'109A', '110A', '111A', '113A', '114A', '115A', '116A', '117A', '118A',
'119A', '120A', '122A', '123A', '124A', '125A', '126A', '127A', '128A',
'129A', '130A'};
% subject_list = {'101B', '102B', '103B', '105B', '107B', '108B',
'109B', '110B', '111B', '113B', '114B', '115B', '116B', '117B', '118B',
```

```
'119B', '120B', '122B', '123B', '124B', '125B', '126B', '127B', '128B',
'129B', '130B'};
% subject_list = {'201A', '202A',  '203A',  '204A',  '205A',  '206A',
'207A',  '208A',  '209A',  '210A',  '211A',  '213A', '216A',  '217A',
'218A',  '219A'};
 subject_list = {'201B', '202B', '203B', '204B', '205B', '206B',
'207B', '208B', '209B', '210B', '211B', '213B', '216B', '217B', '218B',
'219B'};
nsubj = length(subject_list); % number of subjects

% Path to the parent folder, which contains the data folders for all
subjects
home_path  = 'F:\MonicaThesisBackup\EEGLabSets\';

% Set the save_everything variable to 1 to save all of the intermediate
files to the hard drive
% Set to 0 to save only the initial and final dataset and ERPset for
each subject
save_everything  = 0;

% Set the plot_PDFs variable to 1 to create PDF files with the
waveforms
% for each subject (set to 0 if you don't want to create the PDF
files).
plot_PDFs = 0;

% Loop through all subjects
for s=1:nsubj

    fprintf('\n******\nProcessing subject %s\n******\n\n',
subject_list{s});

    % Path to the folder containing the current subject's data
    data_path = home_path;

    % Check to make sure the ERPset file exists
    % Initial filename = path plus Subject# plus .set

    fname = [subject_list{s} '_ERPs.erp'];  % Re-create filename for
unfiltered ERP
    if exist([data_path fname], 'file')<=0

            fprintf('\n *** WARNING: %s does not exist *** \n',
[data_path fname]);
            fprintf('\n *** Skip all processing for this subject ***
\n\n');

    else


        %
        % Load ERPset
        %
        fprintf('\n\n\n**** %s: Loading ERPset ****\n\n\n',
subject_list{s});
        ERP = pop_loaderp( 'filename', fname, 'filepath', data_path );
```

```
        % Now make the difference wave, directly specifying the
        % equation that modifies the existing ERPset
        % ERP = pop_binoperator( ERP, {'b3= b2-b1 label incongruent
minus congruent difference wave' });

        ERP = pop_binoperator(ERP, {'b13= b4-b3 label Incongruent minus
Congruent difference wave'});
        ERP = pop_binoperator(ERP, {'b14= b11-b9 label Unequal
Incongruent minus Unequal Congruent difference wave'});
        ERP = pop_binoperator(ERP, {'b15= b12-b10 label Equal
Incongruent minus Equal Congruent difference wave'});
        %ERP = pop_binoperator(ERP, {'b20= b12-b10 label Incongruent2
minus Congruent2 difference wave'});
        %ERP = pop_binoperator(ERP, {'b21= b16-b14 label Incongruent2
minus Congruent2 difference wave'});


        % ERP.erpname = [ERP.erpname '_Strdiff'];  % name for erpset
menu
        if (save_everything)
            pop_savemyerp(ERP, 'erpname', ERP.erpname, 'filename',
[ERP.erpname '.erp'], 'filepath', data_path, 'warning', 'off');
        end


        % Save the ERP in the ALLERP structure.  This is not
        % necessary unless you want to see the ERPs in the GUI or if
you
        % want to access them with another function (e.g.,
pop_gaverager)
        CURRENTERP = CURRENTERP + 1;
        ALLERP(CURRENTERP) = ERP;


    end % end of the "if/else" statement that makes sure the file
exists

end % end of looping through all subjects

% Path to the parent folder, which contains the group averages
home_path  = 'F:\MonicaThesisBackup\ERPGroupAverage\';

% Make a grand average. The final ERP from each subject was saved in
% ALLERP, and we have nsubj subjects, so the indices of the ERPs to be
averaged
% together are 1:nsubj
% We'll also create a filtered version and save it
ERP = pop_gaverager( ALLERP , 'Criterion', 100, 'ERPindex', [ 1:nsubj]
); %'Criterion', 100 is left over from a previous version


% ERP.erpname = 'YMI_grand_avg';  % GROUP name for erpset menu
% ERP.erpname = 'YMC_grand_avg';  % GROUP name for erpset menu
```

```
% ERP.erpname = 'OMI_grand_avg';  % GROUP name for erpset menu
 ERP.erpname = 'OMC_grand_avg';  % GROUP name for erpset menu

ERP = pop_savemyerp(ERP, 'filename', [ERP.erpname '.erp'], 'filepath',
home_path, 'warning', 'off');
CURRENTERP = CURRENTERP + 1;
ALLERP(CURRENTERP) = ERP;
ERP                   = pop_filterp( ERP, 1:61 , ...
                                     'Cutoff' , 30        , ...
                                     'Design' , 'butter' , ...
                                     'Filter' , 'lowpass', ...
                                     'Order'  , 2        );
ERP = pop_savemyerp(ERP, 'filename', [ERP.erpname '_30Hz.erp'],
'filepath', home_path, 'warning', 'off');
CURRENTERP = CURRENTERP + 1;
ALLERP(CURRENTERP) = ERP;


% Path to the parent folder, which contains the participant amplitude
means
home_path  = 'F:\MonicaThesisBackup\Amplitudes\';


% Measure the mean amplitude from 200-300 ms in bins 1:5, channels 10 &
48.
% Save the results in a variable named "values" and in a file named
% "measures.txt" in the home folder for the experiment.
%values = pop_geterpvalues( ALLERP, [200 300], [3 4 9 10 11 12], [18 19
20 47 48 49] , 'Baseline', 'pre', 'Erpsets', [1:nsubj], 'Filename',
[home_path 'measures_YMI_200_300_FCrowProw.txt'], 'Measure', 'meanbl',
'Resolution',1 );
%values = pop_geterpvalues( ALLERP, [500 650], [3 4 9 10 11 12], [18 19
20 47 48 49] , 'Baseline', 'pre', 'Erpsets', [1:nsubj], 'Filename',
[home_path 'measures_YMI_500_650_FCrowProw.txt'], 'Measure', 'meanbl',
'Resolution',1 );
% values = pop_geterpvalues( ALLERP, [200 300], [3 4 9 10 11 12], [18
19 20 47 48 49] , 'Baseline', 'pre', 'Erpsets', [1:nsubj], 'Filename',
[home_path 'measures_YMC_200_300_FCrowProw.txt'], 'Measure', 'meanbl',
'Resolution',1 );
% values = pop_geterpvalues( ALLERP, [500 650], [3 4 9 10 11 12], [18
19 20 47 48 49] , 'Baseline', 'pre', 'Erpsets', [1:nsubj], 'Filename',
[home_path 'measures_YMC_500_650_FCrowProw.txt'], 'Measure', 'meanbl',
'Resolution',1 );
% values = pop_geterpvalues( ALLERP, [200 300], [3 4 9 10 11 12], [18
19 20 47 48 49] , 'Baseline', 'pre', 'Erpsets', [1:nsubj], 'Filename',
[home_path 'measures_OMI_200_300_FCrowProw.txt'], 'Measure', 'meanbl',
'Resolution',1 );
% values = pop_geterpvalues( ALLERP, [500 650], [3 4 9 10 11 12], [18
19 20 47 48 49] , 'Baseline', 'pre', 'Erpsets', [1:nsubj], 'Filename',
[home_path 'measures_OMI_500_650_FCrowProw.txt'], 'Measure', 'meanbl',
'Resolution',1 );
 values = pop_geterpvalues( ALLERP, [200 300], [3 4 9 10 11 12], [18 19
20 47 48 49] , 'Baseline', 'pre', 'Erpsets', [1:nsubj], 'Filename',
[home_path 'measures_OMC_200_300_FCrowProw.txt'], 'Measure', 'meanbl',
'Resolution',1 );
 values = pop_geterpvalues( ALLERP, [500 650], [3 4 9 10 11 12], [18 19
20 47 48 49] , 'Baseline', 'pre', 'Erpsets', [1:nsubj], 'Filename',
```

```
[home_path 'measures_OMC_500_650_FCrowProw.txt'], 'Measure', 'meanbl',
'Resolution',1 );


fprintf('\n\n\n**** FINISHED ****\n\n\n');
```