2019

Age-Related Differences in Inhibitory Function: Investigation of Simon and Flanker Conflicts in Erps

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Age-related differences in inhibitory function: Investigation of Simon and flanker conflicts in ERPs

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A Thesis presented to the Graduate Faculty of The College of William & Mary in Candidacy for the Degree of
Master of Science

Psychological Sciences

College of William & Mary
May 2019

APPROVAL PAGE

This Thesis is submitted in partial fulfillment of
the requirements for the degree of

Master of Science

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Approved by the Committee April/2019

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COMPLIANCE PAGE

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Protocol number : PHSC-2018-04-03-12639-pdkieffaber

Date of approval: 2018-04-15

ABSTRACT

It is unclear whether or not older adults experience more difficulty managing cognitive conflict by inhibiting distracting stimuli and/or ignoring irrelevant information than younger adults. A common procedure used to measure inhibitory function is through the use of congruent and incongruent stimuli. Specifically, past literature that used tasks like the Simon and flanker have found differing effects on reaction times and various event-related potential (ERP) amplitudes and latencies, suggesting that either inhibitory function is a unitary mechanism or multifaceted. Moreover, research exhibits uncertainty for whether or not age influences deficits to inhibitory function. Another way to measure inhibitory deficits with these two tasks is through the use and measurements of conflict adaptation. Previous literature that have used such tasks support the notion that higher-conflict trials that precede lower-conflict trials result in smaller congruency effects, or what is known as conflict adaptation. While conflict processing has been associated with activity in the medial prefrontal cortex, it is typically considered a measure of the lateral prefrontal cortex and cognitive control. To date, no study has investigated age-related conflict processing and conflict adaptation effects between the Simon and Flanker tasks simultaneously. Therefore, the present study utilized an original combined Simon and flanker task to measure age-related inhibitory differences by measuring reaction time, accuracy, and various ERP (P1, N1, N2, P3) amplitudes to determine if older adults experience inhibitory deficits during the Simon and flanker tasks and whether inhibitory function is a unitary mechanism. Results of the present study indicate that older adults experience greater inhibitory deficits during cognitive conflict as compared to younger adults. Additionally, it was found that the combination of Simon and flanker effects significantly modulated inhibitory deficits for both age groups, but especially for older adults, as seen through both behavioral and electrophysiological means. Specifically, such deficits were most prominent during later processing (i.e. N2 and P3) as compared to early processing. Therefore, the study provides support for age-related changes in inhibitory function and conclude that inhibitory function is comprised of a unitary mechanism. Although these findings deem promising, future research should be conducted to provide conclusive evidence. Regardless, these findings are an important step towards better understanding how inhibitory function manifests and how older adults experience inhibitory deficits. Further, these results provide an initial framework into the identification and understanding of age-related changes during the normal aging process for the field of cognitive neuroscience.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Paul Keiffaber for his guidance throughout this entire research project. Without his help, this important investigation of age-related differences in inhibitory function would not have been possible. I would also like to thank Dr. Jennifer Stevens and Dr. Cheryl Dickter for their careful reading and criticism of the manuscript. Lastly, I would also like to thank the many undergraduate research assistants who helped me with data collection.

This Master's thesis is dedicated to Seth McCullock, who has always been willing to read and re-read drafts. Thank you for your support throughout the entire process.

Chapter 1

Introduction

The population of older adults worldwide is steadily increasing. Estimates indicate that the older adult population will grow upwards of 60 percent by 2030, averaging over one billion older adults across the world (He, Goodkind, & Kowal, 2016). Moreover, life expectancy is also increasing. For example, Kontis et al. (2017) estimates that across 35 industrialized countries, life expectancy will be higher than 90 years of age for women by 2030. This is important because the risk of developing Alzheimer's Disease and other dementing conditions increases steadily after the age of 83 (Plassman et al., 2011). Due to these increases, there is a growing concern for elder health and well-being. Therefore, it is critical to develop strategies to address the physical and mental health of the growing elderly population for an improved understanding of the cognitive changes that occur with age and how those changes may be related to daily activities and functional independence. Even in the absence of dementing illness, many older adults will experience some level of cognitive decline or deficit, often including the loss of executive function (Schuch, 2017). Thus, an important goal in the field of cognitive neuroscience is to develop an improved understanding of particular mechanisms involved in executive function and to identify those components that are most susceptible to age-related cognitive decline during the normal aging process so they can then be used as benchmarks for the measurement of cognitive change and deficit identification.

Executive processes are often defined as those involved in executing goal-directed and purposeful behavior (Schuch, 2017). As compared to constituent cognitive functions, executive functions are typically considered higher-level cognitive functions that regulate and control lower-levels of cognition. Thus, executive functions not only guide goal-directed behavior, but future-oriented behavior as well (Alvarez & Emory, 2006; Spreng, Shoemaker & Turner, 2017). This suggests that executive functions manage the variety of components involved with accurately and efficiently completing tasks. Therefore, executive functions can be identified as an important contributing factor to age-related cognitive deficits seen in older adults.

It is important to note, however, that there are individual differences that contribute to greater or lesser cognitive deficits (Gilsky, 2007), creating a continuum of age-related cognitive decline. These cognitive differences, especially seen between younger and older adults, have been linked to both brain structure and functional differences. Specifically, the frontal lobes and their interactions with the parietal lobes are associated with executive functioning. As humans age, cortical and white matter volume tends to decrease within the frontal lobes, which has been connected to cognitive deficits older adults (Spreng et al., 2017). This association is supported by West's (1996) extension of the frontal lobe hypothesis which states that both the frontal lobe and prefrontal cortex (located within the frontal lobe) contribute to executive function. Other research suggests that older adults have increased activation in the lateral and medial sections of the frontal lobes as compared to younger adults during cognitively taxing tasks, like inhibitory tasks, suggesting that older adults recruit from more brain areas to accommodate for age-related deficits experienced during executive functions. This deterioration has been called the frontal aging hypothesis (Greenwood, 2000). In addition, poor goal-directed inputs can be a result of reduced functional connectivity with the frontal and posterior regions of the brain, creating cognitive dysfunction from occurring distractions and unrelated behaviors exhibited by older adults (Spreng et al., 2017).

Inhibitory function is an important component of executive function (Gilsky, 2007), or one's ability to effectively perform goal-directed behavior through automatic processes that control “the contents of consciousness” (Lustig, Hasher, & Zacks, 2007, pp. 152). One major contributor involved in inhibitory function is working memory (Gilsky, 2007). Working memory is activated during situations that require mental representations to be retrieved into focus (Lustig & Jantz, 2015) and is thought to be a function of the prefrontal cortex (West, 1996). Working memory consists of several dimensions which include language, long-term memory, problem solving, and decision making. Its specific relation to executive function is through its ability to store important information needed to complete complex tasks, supporting higher-levels of cognitive function such as problem solving, planning, and reasoning (Gilsky, 2007).

There are three main theoretical concepts that are related to working memory’s influence on age-related cognitive decline. First, attentional-related decline, which refers to the reduction of an older adult’s ability to process resources from mental fatigue that accrues over time; when tasks require higher levels of attentional demand, cognitive impairments may be exhibited. Second, processing speed may slow as individuals age, leading to delayed responses to cognitive tasks. Lastly, inhibitory control may account for age-related cognitive deficits due to older adults’ inability to ignore irrelevant information to effectively complete a task (Gilsky, 2007). Furthermore, context processing, as first proposed by Braver et al. (2001), also plays a role in modulating age-related cognitive deficits by accounting for impairments to attention, working memory, and inhibition. As described by Braver and West (2008), the lateral prefrontal cortex assists in cognitive control through top-down processing. This type of processing refers to the notion that encoding and decoding information that results in a behavioral response relies more heavily on expectations from previous experience and on acquired knowledge versus bottom-up processing, which is merely stimulus driven (Engel, Fries, & Singer, 2001). Context processing thus assists in planning appropriate responses to future presented stimuli, and can modulate working memory performance (Braver & West, 2008).

As it has been alluded to, attention is an important factor that is involved with all aspects of working memory. Attention, in this context, can be defined as a process that occurs when additional retrieval is not needed to focus on what is at hand (Lustig & Jantz, 2015). There are several types of attention that can impact the ability to effectively complete a cognitive task. One important type is selective attention, which refers to attending to relevant stimuli while ignoring irrelevant stimuli. Differences in appropriate task completion may be found when the difficulty of a task increases. For example, when there are more irrelevant information, attending to relevant information may become more difficult. Regarding age-related deficits, it has commonly been found that older adults experience slower information processing as compared to younger adults (Gilsky, 2007), which is known as the processing-speed theory proposed by Timothy A. Salthouse in 1996. However, this deficit generally does not impact the accuracy of their performance (Gilsky, 2007). In this sense, selective attention is related to target detection performance, which involves bottom-up processing. Therefore, the more difficult it is to find relevant information, the more age-related deficits will impact performance (Lustig & Jantz, 2015). It is the integration of both processing types, though, (top-down and bottom-up) that impact target detection, linking attention to working memory performance (Melloni, Leeuwen, Alink, & Müller, 2011). Relatedly, attention can be voluntary or involuntary. It is important to understand the distinction between the two because research suggests that they are separate mechanisms; reaction time (RT) and accuracy results differ depending on the attention being voluntary or involuntary. When the attention is voluntary, perceptual representation is altered, influencing both RT and accuracy during the task. Involuntary attention, on the other hand, only affects RT due to the absence of perceptual representation change (Prinzmetal, McCool, & Park, 2005).

Therefore, inhibition is particularly important for understanding age-related cognitive deficits due to its involvement in working memory and attention. According to Lustig et al. (2007), there are three functions of inhibition included in the inhibitory deficit theory that help to explain age-related cognitive impairment: access, deletion, and restraint. In order to accomplish a task effectively, distracting stimuli should not be mistaken for the relevant stimuli. If this occurs, it results in access control deficits. Older adults are particularly susceptible to access control deficits when irrelevant information is placed in unpredictable locations. This deficit can lead to slower processing speeds, as explained through Salthouse's processing-speed theory (1996). For example, Castel, Balota, Hutchison, Logan, and Yap (2007) used an inhibitory task and found that younger adults exhibited a reduced conflict effect when RTs were slower, but an enhanced effect when RTs were faster. However, regardless of how quickly or slowly older adults responded, a significant effect was present. Furthermore, when older adults responded more slowly, they displayed an increased effect. As Castel et al. (2007) explains, these findings suggest that older adults display inhibitory deficits regarding the ability to select and control response pathways during slower RTs as compared to younger adults. Thus, it is more difficult for older adults to ignore distracting stimuli and focus on relevant information.

To ignore distracting stimuli more effectively, Lustig et al. (2007) discusses that deletion can be used. In deletion, irrelevant information is intentionally ignored so the focus of attention can be placed on relevant information or stimuli. This concept can be applied to novel situations where previous irrelevant information may now be relevant. The deletion function is particularly linked to working memory and its capacity to hold a certain amount of information. Specifically, implicit and explicit approaches are used to forget some information that allow for detecting relevant information. Older adults, however, are less able to delete information that no longer applies to new tasks, which can lead to age-related cognitive deficits. Lastly, restraint is the action taken to inhibit an inappropriate behavioral response. Classically, restraint can refer to the Go/no-go task that requires participants to withhold a response on randomized trials. However, restraint can also be applied to inhibiting an incorrect response that may at first appear correct. Thus, this component can be applied to both easier and more difficult tasks. In such tasks, older adults tend to have age-related cognitive deficits related to restraining a response when restraint is required (Lustig et al., 2007).

However, it is important to understand that there is a distinct difference between healthy and abnormal age-related differences in older adults during inhibitory function. In particular, previous research suggests that inhibitory deficits may be especially impacted in conditions like mild cognitive impairment (MCI) and Alzheimer's Disease. According to Albert et al. (2011), MCI has multiple criteria that must be met in order to be diagnosed. For instance, adults must experience impairment in one or more cognitive domains, deficits in functional independence, and they must not be demented. Although MCI is related to dementia and can decline into it, MCI is thought to be a cognitive state between normal and abnormal aging (Savica & Peterson, 2011). Unlike MCI, those with Alzheimer's Disease experience a gradual decline in various cognitive aspects, including cognitive dysfunction, behavior, and functional ability. Eventually, these individuals will need to depend on a caregiver to help compensate for their inabilities (Obisesan et al., 2012). Previous research has found that older adults with cognitive impairment like MCI have increased response inhibition and selective attention deficits (Traykov et al., 2007). Moreover, inhibitory differences during cognitive conflict between healthy older adults and those with abnormal cognitive impairment have been demonstrated through behavioral responses where reaction times (RTs) and errors were significantly increased for older adults with abnormal impairment (Bélanger, Belleville, & Gauthier, 2010). Therefore, inhibitory function further declines with the presence of cognitive impairment in older adults. For these reasons, research has found support for the use of the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005), a commonly used measure to assist in the detection of MCI.

In general, one way to measure inhibition is through the use of electrophysiological measurement tools. The electroencephalogram (EEG) is a non-invasive, cost-effective, and versatile tool (Luck, 2014) that can be used to measure electrical activity in the brain. The development of this tool for human usage was discovered by a German psychiatrist, Hans Berger, in the mid 1920's when the first recording was taken (Millett, 2001). To do so, numerous electrodes that are situated in a cap are placed on the scalp to capture and record electrical activity created by electrical and magnetic fields. These fields are produced from neuronal responses (Mulert, & Lemieux, 2009) to presented stimuli. Due to the EEG's high temporal resolution, such recordings can include neuronal responses before, during, and after trials that contain some type of stimulation (Dickter & Kieffaber, 2014). Within EEG data, researchers can use event-related potentials (ERPs) to measure and determine forms of cognitive function that occur in response to stimuli. ERPs are identified by isolating sections of the recorded EEG data into positive or negative electrical peaks formed within a specific time window. Researchers can use this data to evaluate group differences in cognitive function (Luck & Kappenman, 2011), making EEG an appropriate measurement tool to evaluate brain functionality on inhibitory tasks between younger and older adults (Spreng et al., 2017).

Specific ERPs have been identified to be associated with inhibitory function due to elicited cognitive processes from presented stimuli. First, the P1 component, which is the first positive peak that occurs between 80 to 130 milliseconds (ms) in the occipital cortex, is thought to reflect early visual processing. Specifically, studies have found that the peak amplitude is enlarged when attention is directed towards the stimulus location. Similarly, the N1 component, which is the first negative peak that occurs between about 150 and 200 ms in the occipital cortex, has been shown to represent sustained covert attention to stimuli within the peripheral visual fields. Like the P1, the N1 has also been shown to be enlarged when attention is directed towards the stimulus location (Di Russo, Martínez, & Hillyard, 2003). During presented visual stimuli, the N2 component represents cognitive control related to monitoring or regulating one's strategy to perform a given task. The N2 refers to the second negative peak seen in an averaged ERP waveform and appears approximately 180 ms after stimuli onset. When visual stimuli are used, this component appears in the temporo-occipital lobe and is measured over the frontal midline, which has been associated with visual attention. Particularly, such context resolution is due to the detection of novel stimuli before a behavioral response is made (Folstein & Van Petten, 2008). When incongruent stimuli are presented, the amplitude of the N2 component enhances. This enhancement is due to the increased inhibitory function needed to perform during incongruent trials. Therefore, it is thought that the N2 component is associated with control mechanisms that activate when cognitive conflict appears (Yeung, Botvinick, & Cohen, 2004). Lastly, the P3 is thought to convey context-updating depending on if presented stimuli are novel or not. When novel stimuli appear, the anterior aspect of the frontal lobe is activated, but when stimuli are no longer novel, the network diminishes (Friedman, Cycowicz, & Gaeta, 2001). This component korsch appears as the third positive peak in an averaged ERP waveform, approximately 300 ms after stimulus onset (Picton, 1992).

In addition to the EEG's ability to measure group differences, it can also help to determine whether inhibition is a unitary mechanism involved in working memory. Previous research that has investigated inhibitory function, particularly to measure differences between younger and older adults, used a variety of cognitive tasks. Such methodological variation has resulted in mixed results and interpretations regarding inhibitory function. Specifically, the Simon (Simon, 1969) and flanker (Eriksen & Eriksen, 1974) tasks are commonly used in inhibition research due to their inclusion of cognitive conflict. However, as an example, one study found that older adults exhibit greater Simon conflict as compared to flanker conflict. This brought the researchers to suggest that inhibition is comprised of multiple, distinct mechanisms that may create differences in susceptibility to conflict in older adults (Kawai, Kubo-Kawai, Kubo, Terazawa, & Masataka, 2012). To further study this phenomenon, Korsch, Frühholz, & Herrmann (2016) combined the Simon and flanker conflicts into one task and used the EEG to measure age-related inhibitory function. They too found that older adults experience inhibitory deficits specific to conflict type, supporting the notion that inhibition is not a unitary mechanism. Despite these results, age-related inhibitory deficits measured using the Simon and flanker tasks and EEG specifically needs further investigation to better understand the mechanisms involved in inhibitory function to make more conclusive interpretations about age-related cognitive control. Thus, the present study seeks to explore age-related inhibitory differences within a uniquely combined Simon and flanker task. The use of the EEG will allow the researchers to investigate physiological differences in brain activity that may occur during task performance to uncover whether inhibition is or is not a unitary mechanism and whether age modulates inhibitory function.

Chapter 2

Literature Review

Simon task.

The Simon effect was first discovered by J. Richard Simon and Alan P. Rudell in 1967. Although the task has been modified since the first experiment, the concept is still being used to explore the behavioral and psychophysiological effects cognitive conflict has in humans. In the original task, participants were instructed to press a button with either their left or right hand depending on the verbal instruction given into a pair of headphones. The researchers manipulated whether the verbal command was presented to the right or left ear. It was found that when the verbal command was presented congruently with the hand needed to press the button (i.e. the verbal command was presented to the left ear and verbalized “left”), RTs were significantly faster than incongruent trials. Therefore, RTs were faster when stimuli were presented in the same location. When they were not, the Simon effect occurred; participants responded significantly slower to trials containing distracting stimuli.

In 1969, Simon extended and modified the original Simon task to better understand inhibitory function. This task sought to measure the difference in RT between moving a control handle toward or away from an auditory stimulus presented in either the left or right ear. It was found that despite the change in task instruction and method, RTs were longer when the participants had to move the handle in the opposite direction from where they heard the stimulus. It was concluded that information was processed more slowly during incongruent trials due to the presented cognitive conflict (Simon, 1969), suggesting that conflict represented through auditory incongruence negatively impacted inhibitory function.

These findings, however, are not the first to explore the effect of stimulus and response congruence in a visual search task. As described by Hommel and Prinz (1997), stimulus-response compatibility, discovered and coined in 1951 by Small, includes the influence of both stimuli and response congruent features which systematically affect performance regarding response selection. This is due to both automatic activation and modified intention that results from specific rules given for a particular task. In terms of the Simon task, participants have a tendency to automatically respond towards the presented stimulation, which is described as unconditionally automatic. In trials where conflict is not present, RTs are shorter as compared to trails that require transformation or recoding of the information to adjust for the task's rules; this is known as conditionally automatic. Thus, these two components make-up the dual-process model involved in spatial stimulus-response correspondence effects (De Jong Liang, & Lauber, 1994), or what makes up the Simon task.

After the original (Simon & Rudell, 1967) and modified (Simon, 1969) Simon conflict findings, researchers became interested in exploring age-related differences between younger and healthy older adults on their inhibitory function to evaluate whether older adults are more susceptible to the Simon effect. Specifically, they measured inhibitory function using auditory tones where older participants were instructed to button press after high tones and inhibit button pressing during low tones. Over the course of four years, older adults increased RT and decreased in accuracy (Fozard et al., 1994), suggesting a negative relationship between age and inhibitory function. These results correspond to results later found in a longitudinal study; older adults continually cognitively decline overtime, particularly regarding inhibitory function (Fozard, Vercruyssen, Reynolds, Hancock, & Quitter, 1994). Two years later, Salthouse proposed the processing-speed theory of cognitive aging in 1996, which discusses that there is an association between decreased processing-speed and cognitive functioning impairments in older adults. One important factor weighed into this theory is described as the limited time mechanism. Importantly, Salthouse discusses that when a cognitive task is more difficult to complete due to multiple operations needed in an amount of time (e.g. rehearsals and elaborations), quality and/or accuracy of responses can be negatively impacted in older adults, describing this mechanism as the complexity effect. At this time, however, the theory discussed that future research needs to further investigate how processing-speed and specific, unidentified mechanisms result in slower and impaired cognitive performance in older adults. Moreover, although the inhibitory deficit theory (Lustig et al., 2007) discusses that older adults are more susceptible to distracting information and have deficits regarding their ability to delete information that was once relevant, it is unclear under what specific circumstances such deficits present themselves.

One of the first studies conducted to measure age-related differences between younger and older adults on RT through the use of the auditory-accessory Simon task was by Simon and Pouraghabagher (1978). In this study, participants were instructed to button press with either their left or right hand depending on the image that appeared (either an X or an O). Simultaneously, a tone was delivered to either or both ears to produce relevant or irrelevant information between the hands' assigned image and the tone's location. It was found that the older adult group took longer to respond than the younger group, and both age groups took longer to respond during irrelevant trials. Moreover, older adults responded significantly slower in both the relevant and irrelevant trial types as compared to the younger adults. Across both age groups, when the auditory tone presented itself congruently with the hand to make the button press, RTs were significantly faster than incongruent trials. However, this study found no indication of age-related differences on the Simon effect. Therefore, it was concluded that only the stimulus encoding stage negatively impacted older adults' ability to process information via increased RT. In other words, older adults processed information in the same way younger adults did, thus the researchers suggested that inhibitory function does not decline with age.

More recently, however, Proctor, Pick, Vu, and Anderson (2005) conducted a replication of Simon and Pouraghabagher's (1978) study to measure potential age-related differences between an auditory-accessory Simon task and a solely visual Simon task to understand if context of irrelevant information impacts behavior. As noted by Guerreiro, Murphy, and Van Gerven (2010), visual stimuli in the Simon task can consist of a color, shape, or direction (i.e. arrows). Proctor et al.'s (2005) visual component contained a red or a green circle in which participants were asked to button press using either their left or right index finger depending on what appeared on the screen and which finger corresponded to either colored circle. During the auditory-accessory trials, participants additionally heard a tone in either their right or left ear while the visual stimulus appeared in the center of the screen. It was found that, overall, RTs were longer for older adults as compared to younger adults during all conditions in both the visual and auditory-accessory trials. However, during the visual Simon task, older adults had significantly larger Simon effects than younger adults, but there was no significant difference of age during the auditory-accessory Simon task. In addition to measuring RT, it was later found that the Simon effect can increase the tendency to make more errors as compared to trials containing congruent information (i.e. Lu & Proctor, 1995). Although Proctor et al. (2005) found that the auditory-accessory Simon task elicited more errors as compared to the visual Simon task overall, older adults made significantly more errors in the visual Simon task as compared to younger adults. This study therefore suggests that older adults are more influenced by visually irrelevant location information than younger adults, depicting that context significantly impacts inhibitory function.

This age-related finding has been replicated by other researchers who have used different variations of the visual Simon task. For example, Kubo-Kawai and Kawai (2010) utilized a color visual Simon task in which participants used a response box to respond to the color of the stimulus regardless of where it appeared on the screen. They found that older adults had significantly longer RTs overall, longer RTs for incongruent trials, larger Simon effects, and more errors as compared to younger adults. Similarly, Aisengerg, Sapir, d'Avossa, and Henik (2014) also found that older adults had significantly longer RTs for all trial types and larger Simon effects when using a color visual Simon task. Importantly, when both studies controlled for general slowing of RT between the two groups, the Simon effect was still significantly larger in older adults. This indicates that general slowing does not provide an explanation for these age-related differences (Aisengerg et al., 2014; Kubo-Kawai & Kawai; 2010). Moreover, even when arrows were used as visual stimuli instead of color, older adults still responded significantly more slowly in all trial types and had larger Simon effects before and after controlling for general slowing (Castel, Balota, Hutchison, Logan, & Yap, 2007). Interestingly, Kubo-Kawai and Kawai (2010) included a Go/no-go component to their visual Simon task to explore age-related differences between the two tasks. They found that the visual Simon task with the Go/no-go component did not influence older adults to have significantly larger Simon effects as compared to younger adults regardless of older adults' slow RTs. This finding further supports the notion that general slowing does not explain the behavioral age-related differences found during inhibitory tasks since older adults do not always display an increased Simon effect. As Kubo-Kawai and Kawai (2010) discuss, this could be due to the fact that older adults have more difficulty processing information when the same stimuli presents both relevant and irrelevant information (i.e. color and location). Therefore, Kubo-Kawai & Kawai's (2010) study supports the processing-speed theory (Salthouse, 1996). Due to the results discussed above, the following hypotheses were made:

H1[1]a: RTs for the Simon task will be significantly longer for trials that exhibit congruent as compared to incongruent information.

H1b: Older adults will exhibit larger Simon effects in RTs as compared to younger adults.

In addition to behavioral data being assessed during the Simon task, it is also important to consider neurophysiological responses to cognitive conflict. In particular, early processing helps researchers understand age-related differences during visual cognitive conflict tasks, for visual processing occurs as early as 50 ms (Hillyard & Anllo-Vento, 1998). For this reason, the P1 component is an important ERP to evaluate due to its onset at approximately 80 ms (Di Russo et al., 2003). As research has found, the P1 can be elicited when attention is drawn to the stimulus location, where larger amplitudes represent increased attention (e.g. Di Russo et al., 2003; Hillyard, Mangun, Woldorff, & Luck, 1995). However, when stimuli are presented in unpredictable locations, the amplitude is less enhanced in comparison (Hillyard & Anllo-Vento, 1998). In regards to the Simon task, the P1 component represents spatially selective attention; irrelevant location information must be ignored while relevant information (e.g. direction) portrayed by the target stimuli must be attended to in order for the task to be successfully completed. Research has found that spatial task complexity modulates the P1 amplitude. Specifically, P1 amplitudes are increased during more spatially complex tasks (Johannes, Münte,

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[1] This abbreviation stands for "hypothesis".

Heinze, & Mangun, 1995). However, previous research findings suggest that there is no evidence to believe that age-related differences are seen at this early processing stage (Zanto & Gazzaley, 2014). To our knowledge, though, research has not investigated P1 amplitude differences between younger and older adults during a visual Simon task. Regardless, the following hypotheses are proposed due to previous age-related findings on P1 amplitudes in younger and older adults:

H2a: Incongruent Simon trials will elicit significantly larger P1 amplitudes than congruent Simon trials.

H2b: There will be no significant age-related differences between younger and older adults in P1 amplitude during the Simon task.

Similar to the P1, the N1 component is elicited when attention is drawn towards the visual stimulus location, where larger N1 amplitudes indicate increased attention (Di Russo et al., 2003). Despite this similarity, research discriminates the two components from one another. Particularly, Luck, Heinze, Mangun, & Hillyard (1990) discusses that the P1 may reflect early sensory processing that occurs when attention is already directed towards a certain location that then the stimulus appears in. On the other hand, the N1 seems to represent the orientation of attention to stimuli that are task-relevant, thus making these components distinct from one another. Moreover, research has also found that the N1 is elicited only when discrimination occurs and is absent when only detection of the stimulus occurs, making it associated with selective attention to visually relevant information (Mangun & Hillyard, 1991). As supported by previous studies, the N1's amplitude can be modulated depending on the congruence of information. For instance, Beaucousin et al. (2013) found that N1 amplitudes were significantly larger during visually incongruent trials as compared to congruent trails. However, research has not measured how congruency effects modulate the N1 amplitude during visual Simon-like tasks without priming or cueing. One study did measure inhibitory differences in an auditory distractor task between younger and older adults, where either distracting tones were present or not. It was found that older adults had significantly enhanced N1 amplitudes as compared to younger adults during the distractor task (Chao & Knight, 1997), suggesting that older adults experience greater inhibitory deficits during target discrimination. Based on these findings, the following hypotheses were made:

H3a: Incongruent Simon trials will elicit significantly larger N1 amplitudes than congruent trials.

H3b: Older adults will elicit significantly larger N1 amplitudes during incongruent Simon trials than younger adults during the Simon task.

The N2 component is also an important ERP to investigate in order to determine if cognitive conflict elicits significantly different waveforms between congruence types for younger and older adults. Folstein and Van Petten (2008) state that the N2 can be defined as cognitive control that occurs during monitoring or regulating strategy during a task. Moreover, Jodo and Kayama (1992) found that the N2 component is also related to motor cortices. Specifically, cognitive control inhibits both attention and motor responses towards irrelevant information. During such inhibitory tasks, the N2 represents cognitive control when inhibiting attention away from the target information, eliciting greater amplitudes when distracting or irrelevant information must be ignored. Therefore, the N2's amplitude is significantly emphasized during incongruent trials due to the increased cognitive control needed (Folstein & Van Petten, 2008; Yeung et al., 2004) to seek the target information (Hillyard & Anllo-Vento, 1998), which has been found during incongruent Simon trials specifically (e.g. Melara, Wang, Vu, & Proctor, 2008). Results found in a study conducted by Strack, Kaufmann, Kehrer, Brandt, and Stürmer (2013) further emphasizes the influence of the N2 component on cognitive conflict by comparing cued and uncued preparation information before trials in the Simon task. Here, the N2 component was significantly enhanced during non-cued conflict trials while no significant difference was found during cued-trials. Additionally, incongruent trials elicited a significantly enhanced N2 as compared to congruent trials. Further, in regard to age-related differences, a trend was found suggesting that younger adults have significantly enhanced N2 amplitudes as compared to older adults (Korsch et al., 2016), suggesting that cognitive processing may be diminished in older adults. Despite these results,very few studies have assessed the N2 component in the Simon task to evaluate age-related effects. However, the following hypotheses were formed based off of prior research:

H4a: N2 amplitude will be significantly enhanced during incongruent Simon trials as compared to congruent Simon trials.

H4b: N2 amplitude will be significantly enhanced for younger adults during incongruent Simon trials as compared to older adults.

The last ERP of interest is the P3. This component is elicited during cognitive tasks that require participants to attend to and discriminate between different stimuli before a behavioral response is made. When this occurs, the P3 amplitude increases by its association with cognitive function taking place, rather than perceptual discrimination (Polich & Kok, 1995). In other words, P3 amplitude increases when response inhibition is required (Groom & Cragg, 2015). Therefore, the P3 represents both selection and categorization in order to implement a required response (Luck, 2005). Moreover, research suggests that its amplitude is related to the complexity of the task, where more enhanced P3 amplitudes resembol increased attention in the task or stimulus. However, when more mental resources are needed or the task is too difficult, there is evidence to also support the notion that amplitudes will decrease (Kok, 2001). For example, Galashan, Wittfoth, Fehr, and Herrmann (2008) found that incongruent stimuli in a location-based task elicited significantly smaller P3 amplitudes than congruent stimuli. This finding has been demonstrated with amplitude differences between incongruent and congruent trial types within the Simon task in relation to age-related differences. For instance, Van der Lubbe and Verleger (2002) found that older adults elicited significantly smaller P3 amplitudes during incongruent trials as compared to congruent trials, and that the P3 was overall smaller in older adults than younger adults. However, younger adults experienced increased P3 amplitudes during incongruent trials as compared to congruent trials. Wild-Wall et al. (2008) also found that incongruent Simon trials elicited significantly larger P3 amplitudes than congruent Simon trials in healthy younger adults. These results provide evidence that older adults have a more difficult experience with cognitive conflict than younger adults, and if the task is not too cognitively challenging, P3 amplitudes will be increased within Simon tasks. From these findings, the following hypotheses were made:

H5a: Incongruent Simon trials will elicit significantly larger P3 amplitudes than congruent trials for younger adults and significantly smaller P3 amplitudes for older adults.

H5b: Older adults will exhibit significantly smaller P3 amplitudes overall than younger adults.

Flanker task.

Unlike the Simon task, the flanker task, which was first developed by Eriksen and Eriksen in 1974, is a non-search congruence task used to measure inhibitory function through visual cognitive conflict. Similarly to the Simon task, the original flanker task incorporated congruence effects, which were labeled as compatible and incompatible trials. Here, the researchers used flankers; six distracting stimuli *flanked* to the right and left side of the target stimulus. Three flankers always appeared on both sides of the target letter in every trial. Participants were asked to hold a lever and move it left or right depending on the target letter (two in total) that randomly appeared in the center of the lateralized stimulus. If the flankers were compatible to the target letter, the other letter target was flanked on both sides. If the flankers were incompatible, this meant that two other letters not used as the target were flanked on both sides. Identically to the Simon task, congruncy effects are measured by comparing congruent trials to incongruent trials and evaluating whether the two trial types significantly differ (e.g. Verbruggen, Notebaert, Liefooghe, & Vandierendonck, 2006). It was found that RTs were longest during incompatible trials and shortest during trials where flankers were identical to the target letter, followed by compatible trials. Moreover, participants experienced more errors during incompatible trials (Eriksen & Eriksen, 1974).

Eriksen and Eriksen (1974) noted that the inhibitory process must be activated during the task in order to prevent the flankers from influencing incorrect responses, despite them not being the center of attention. They speculated, however, that the flankers do not elicit a distraction effect. Rather, the flankers are simultaneously processed along with the target stimulus. Therefore, this task supports the notion that input processing is an important component to inhibitory function, for compatibility effects influence and modulate RT and accuracy of behavioral responses depending upon the amount of similarities between the target and flankers. This conclusion was later thought of as the noise-compatibility effect, where incompatible noise negatively impacts behavioral responses. Thus, unlike the Simon effect, the flanker task very much relies on visual processing of information (Eriksen & Schultz, 1979), an aspect unrelated to visual searching. Further, Hsieh, et al. (2012) found evidence to support that the flankers' influence occurs at the perceptual level, and concluding that this is possibly the most critical aspect to the flanker effect.

There are some factors that could influence the severity of the noise-compatibility effect. For instance, the original flanker task (Eriksen & Eriksen, 1974) measured the modulation of the effect when stimuli were farther apart or closer together. It was found that when the lateralized stimuli were closer together, the RTs were significantly slower than when they were farther apart. Another study found that despite the flanker task relying on time sensitivity, the congruence effect can be altered depending on the participant's experience. Specifically, when one study evaluated the fastest RTs during incompatible trials, more errors were made as compared to slower overall RTs. This demonstrates that the flanker effect is most prominent when there is less time to decipher the cognitive conflict (Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). According to Cohen, Servan-Schreiber, and McClelland (1992), the presence of incompatible flankers significantly influence the response process due to the mediation of appropriate responses that impact spatial attention. However, as more attention is applied to the target stimulus, the influence of the flankers on the appropriate response diminish gradually over time, thus more effective inhibitory functioning occurs. Generally though, such a task relies on automatic processing of information that can then be altered gradually through practice.

Despite these factors influencing different experiences with the flanker effect, later studies have shown that flanker congruence effects impact inhibitory function through differences in behavioral data. For example, Korsch et al. (2016) used target arrows that either pointed left or right with flanker arrows pointing in the same or opposite direction. It was found that incongruent flanker trials resulted in significantly longer RTs than congruent trials.

However, there were no significant differences in error rates across conditions. Another study found that RTs were longer during incongruent trial types as compared to congruent trials types and that more errs were made during incongruent trial types (Wild-Wall, Falkenstein, & Hohnsbein, 2008). This finding suggests that flanker conflict interferes with inhibitory function. In other studies that used arrow stimuli, incongruent trials had significantly longer RTs than congruent and neutral trials, where congruent trials were significantly faster than neutral trials. Moreover, it was reported that there were significantly more incorrect responses as compared to correct responses for incongruent trials (e.g. Hsieh, Liang, & Tsai, 2012; Jennings, Dagenbach, Engle, & Funke, 2007). For these reasons, the following hypothesis was formed:

H6: Incongruent flanker trials will result in significantly longer reaction times than congruent flanker trials.

On the other hand, several studies have found mixed age-related behavioral results for the flanker effect, suggesting inconclusive inhibitory differences. First, only a handful of studies have found evidence that supports age-related inhibitory decline in the flanker task. For example, Zeef and Kok (1993) found that younger adults overall had significantly faster RTs and committed less errs as compared to older adults, especially during incongruent trials. But more importantly, there was a significant interaction found between age and compatibility, indicating that older adults are more sensitive to cognitive conflict during early processing stages of information in the flanker task than younger adults. This interaction was again later found in another study conducted by Zeef, Sonke, Kok, Buiten, and Kenemans (1996). A second trend found implies that flanker congruency effects do not exacerbate with age. For instance, several studies have failed to find a significant interaction between age and RT even though older adults had significantly longer RTs in both congruent and incongruent conditions. Moreover, as previously discussed, younger adults made significantly more errors in both condition types and had shorter RTs overall (Korsch et al., 2016; Wild-Wall et al., 2008). However, other studies have found the direct opposite effect where younger adults displayed a significantly larger flanker effect as opposed to older adults, despite both age groups exhibiting a significant flanker effect and younger adults having overall faster RTs. As discussed by the researchers, this finding could be due to older adults' use of strategic emphasis on accuracy, more so than younger adults. Thus, RTs were longer for older adults to provide more time for strategic processing (Hsieh, et al., 2012), possibly over the idea of Lustig p1et al.'s (2007) inhibitory deficit theory. Another study found that only younger adults showed significant flanker effects as compared to older adults. The researchers suggest that because older adults took significantly longer overall to execute all trials types, they were more effective at resolving the cognitive conflict. This idea was supported in that older adults made significantly less errors as compared to younger adults during incongruent trials (Fernandez-Duque & Black, 2006). Due to the inconclusivity of age-related differences in the flanker effect, the following research question was proposed:

RQ[2]1: Will older adults exhibit significantly larger flanker effects than younger adults in terms of RT?

Similar to the Simon task, research has also measured ERP differences in the flanker task. Like the Simon task, it is also thought that the early components of P1 and N1 during the flanker task are thought to represent sensory processing (Pires, Leitão, Guerrini, & Simões, 2014). Particularly, one study found that P1 amplitudes were enlarged during incongruent flanker trials as compared to congruent trials (Wild-Wall et al., 2008). Additionally, another study found that P1 amplitudes were significantly enhanced when the arrow flanker task was used, but

[2] This abbreviation stands for "research question".

significantly decreased when another inhibitory task was introduced within the flanker task, suggesting that the increased presence of irrelevant information negatively impacted inhibitory function but small amounts of conflict increased the P1 amplitudes (Pratt, Willoughby, & Swick, 2011). Moreover, one study found no evidence to support that flanker interference elicits significant age-related differences within early processing, for the P1 (Wild-Wall et al., 2008). However, some studies report that N1 amplitudes were significantly enhanced in older adults as compared to younger adults (Pires et al., 2014). Specifically, Hsieh and Fang (2012) found that older adults exhibited significantly larger N1 amplitudes during all trial types (congruent, incongruent, and neutral) as compared to younger adults, where both congruency types elicited significantly larger N1 amplitudes than the neutral trials. But, incongruent trials elicited larger N1 amplitudes than congruent trials. As discussed by the researchers, this finding suggests that older adults allotted more attention to presented stimuli due to increased top-down processing. Therefore, the following hypotheses were formed:

H7a: The flanker task will elicit significantly larger P1 amplitudes during incongruent trials as compared to incongruent trials.

H7b: There will be no significant difference in P1 amplitude in the flanker task between younger and older adults.

H8a: The flanker task will elicit significantly larger N1 amplitudes during incongruent trials as compared to congruent trials.

H8b: Older adults will exhibit significantly larger N1 amplitudes than younger adults during incongruent flanker trials.

In regards to later processing during the flanker task, the N2 component has been found to be significantly enhanced with a more negative deflection during incongruent flanker trials as compared to congruent flanker trials. This result demonstrates that during trials where irrelevant information is presented, more cognitive control is needed in order to allocate attention towards the target stimulus by filtering out the unneeded information (Alguacil, Tudela, & Ruz, 2013; Van't Ent, 2002; Xie, Ren, Cao & Li, 2017). Studies have also reported findings of age-related differences with N2 amplitudes during the flanker task. For example, studies found that incongruent flanker conditions elicited significantly larger N2 amplitudes than congruent trials, but only for younger adults. This amplitude increase was related to younger adults' increased error rates as compared to older adults, demonstrating that older adults put great emphasis on performance by allocating more attention towards the center of the screen where the target was presented each trial. Thus, older adults did not experience greater cognitive conflict during incongruent flanker trials as compared to younger adults (Hsieh & Fang, 2012; Hsieh et al., 2012; Wild-Wall et al., 2008). Concerning P3 amplitude, results found in the flanker task are similar to those found in the Simon task. Specifically, studies have found that incongruent flanker trials elicited significantly larger P3 amplitudes. The researchers discussed that it was due to the presence of response inhibition needed to effectively evaluate the stimulus to make an appropriate behavioral response (e.g. Gohil, Bluschke, Roessner, Stock, & Beste, 2017; Xie et al., 2017). Moreover, Wild-Wall et al., 2008 found that older adult had significantly larger P3 amplitudes during the flanker task as compared to younger adults. Due to these findings, the following hypotheses were formed:

H9a: Incongruent flanker trials will elicit significantly larger N2 amplitudes than congruent flanker trials.

H9b: Younger adults will exhibit significantly larger N2 amplitudes during the flanker task as compared to older adults.

H10a: Incongruent flanker trials will elicit significantly larger P3 amplitudes than incongruent flanker trials for younger adults and significantly smaller P3 amplitudes for older adults.

H10b: Older adults will have significantly smaller overall P3 amplitudes during the flanker task as compared to younger adults.

Combined Simon and flanker task.

Despite decades of research investigating the nature of cognitive inhibition and conflict processing, very few studies have measured both the Simon and flanker effects within the same sample. In one study, Kawai et al., (2012) determined that the flanker effect was not modulated by age but the Simon effect was. Moreover, it was found that brain activity measured with the EEG differed between tasks and age. Specifically, only the younger adults were found to have significantly more brain activity overall during congruent flanker conditions as compared to incongruent conditions. Additionally, older adults' brain activity was situated in the left hemisphere in the superior frontal gyrus and middle frontal gyrus during the flanker task, while brain activity was situated in the bilateral superior frontal gyrus during the Simon task. Therefore, the researchers concluded that the two tasks tap into distinct inhibitory mechanisms that alter age-related inhibitory differences (Kawai et al., 2012). Another study that measured inhibitory differences between the Simon and flanker task found that older adults experienced a significantly larger Simon effect even after controlling for age-related slowing as compared to younger adults. However, this study also found that the flanker effect was not significantly different between younger and older adults (de Bruin & Della Sala, 2017). Thus, these results together suggest that deficits in age-related inhibitory function are task dependent and are modulated by task demands, but one study alone cannot provide substantial evidence to support that inhibitory function is comprised of multiple facets.

Although the above studies seem promising in understanding age-related inhibitory deficits, they are limited in their interpretations; because the tasks were separate, the experimental design does not permit interaction analyses between congruity on both tasks, limiting the understanding of their influence on behavioral and electrophysiological measures. Therefore, combining the tasks within a novel task is an important methodological advancement for research. One reason this that the factorial combination of Simon and flanker effects can lead to a better understanding about the nature of potential differences between the cognitive processes engaged by these tasks in both younger and older adults. Combining Simon and flanker tasks may also help to elucidate questions about whether or not the two types of conflict processing are accomplished by distinct or common underlying cognitive and/or neural processes. Moreover, when combined with the investigation of age-related changes in cognitive function, researchers can identify which processes contribute to age-related differences during inhibitory functioning.

Korsch et al. (2016) did just that and combined the Simon and flanker task into a novel inhibitory task to measure age-related differences through reaction time as well as ERPs when both effects were simultaneously presented. Regarding reaction time, it was again found that older adults exhibited a significantly larger Simon effect but not a significantly larger flanker effect during the novel task. However, there was a significant interaction between Simon and flanker congruency, such that when Simon and flanker incongruency were simultaneously presented within the same trial, congruency effects were significantly larger overall than when congruity effects were separated by task type. The researchers used these results to conclude that conflict processing is specific to conflict type. During early processing, ERP results indicated that task type influenced significant differences on inhibitory function between age groups. Specifically, both younger and older adults experienced an enhanced P2 amplitude during incongruent as compared to congruent trials. However, only older adults exhibited a significantly enhanced P2 amplitude during the Simon task, where incongruent trials elicited a larger amplitude. On the other hand, the N2's amplitude did not significantly differ between age, but did reveal that it was most prominent over the frontocentral and electrodes in the elderly as compared to younger adults where it was most prominent over the midline. Lastly, the researchers found that both age groups displayed a significantly larger P3 amplitude for incongruent trials types for both task types (Korsch et al., 2016). One can argue that these results demonstrate that both tasks elicit the same ERP components that have been found to be associated with inhibitory function, but it is unclear whether the tasks themselves or the task's demands modulate the seen differences.

Despite the fact that Korsch et al.'s (2016) study combined both tasks together, there are impeding limitations in their presented task. First, it is important to note that the Simon effect refers to the difference between the incongruity and congruity of the response location and the location of the stimulus (e.g. Simon, 1990). However, Korsh et al.'s (2016) study presented the target arrow in the center of the screen for both the flanker and Simon task. To indicate congruency effects in the Simon conditions, the target was either filled blue or red where participants were required to remember that the left response button was indicated by blue and the right response button was indicated by red. Due to this modification, it is difficult to make direct comparisons with prior research measuring the Simon effect. The task used by Korsh et al. (2016), also requires an increase in working memory processing (Lustig & Jantz, 2015), requiring participants to remember the color-response mapping, making it a more difficult task especially for older individuals. Due to these reasons, research needs to better replicate both tasks to measure inhibitory differences between them before concluding that inhibitory function is not a unitary mechanism. Based on the above discussion and prior sections on the Simon and flanker tasks, the following research questions were made:

RQ2: Will behavioral and ERP results be significantly different between the Simon and flanker task among younger and older adults?

RQ3: Will congruency effects be significantly exacerbated when both incongruent task types are paired within the same trial?

RQ4: Will older adults make significantly more errors overall as compared to younger adults?

Conflict adaptation.

Although measuring differences in RT and/or neural activity on congruent and incongruent trials of the Simon and flanker tasks are the most commonly used approach to assess conflict processing and inhibitory function, some have also used differences between specific trial sequences to measure the dynamics (e.g. trial-to-trial) of cognitive control during conflict processing tasks. Specifically, research has found that greater cognitive conflict is experienced when congruent trials precede incongruent trials (C → I). It is thought that participants allot more focus on task-relevant information after having a more cognitively challenging trial, making the transition to another taxing trial easier. Therefore, participants make adjustments for later tasks dependent on the type of trial (i.e. congruent or incongruent) that was just presented, a phenomenon known as conflict adaptation (Gratton, Coles, & Donchin, 1992; Ullsperger, Bylsma, & Botvinick, 2005). This concept has been support for the conflict monitoring theory proposed by Botvinick, Braver, Barch, Carter, and Cohen (2001), which states that conflict adaptation engages in cognitive control. Although conflict adaptation seems identical to priming, Ullsperger et al. (2005) discusses that they are distinct from one another. Their study evaluated how time sensitivity evoked behavioral changes during conflict adaptation trials. They found evidence to support that priming effects can be significantly decreased when stimuli are briefly displayed versus prolonged, thus the ability to better solely capture conflict adaptation.

Previous research has measured conflict adaptation in the visual Simon and flanker tasks. For instance, Chen and Melara (2009) found that cognitive conflict was greatest in the Simon task when congruent trials preceded the current trial and was smallest when incongruent trials preceded the current trial due to the significant reduction in RT. This result was also found in another study that utilized the Simon task. However, they also measured the frequency of congruent and incongruent trials to determine if the effect would modulate based on experience. The researchers found that the more congruent trials there were preceding incongruent trials, the significantly larger the effect. Similarly, when incongruent trials preceded congruent trials when congruent trials were more frequent, the effect was significantly enlarged (Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). In regards to age-related differences on conflict adaptation in the Simon task, two studies found that there were no significant differences (Lemaire & Hinault, 2013; Yano, 2011), but Lemaire and Hinault (2011) did see significant differences when using a strategic mathematics task. Therefore, they suggest that age-related differences on conflict adaptation can be modulated by task type based on top-down processing differences. This insinuation of task type modulation was measured in another study with the use of a pseudo-combined Stroop (i.e. a spatial cognitive task) and Simon task as compared to a Stroop and flanker task. It was found that conflict adaptation was significantly greater during the Stroop and flanker task as compared to the Stroop and Simon task. The researchers explained that the Stroop and flanker task contributed more conflict than the Stroop and Simon task due to the presence of both spatial and response information that needed to be processed to make a response as compared to spatial information in general (Freitas & Clark, 2015). Despite this finding, no study has evaluated the combination of the Simon and flanker task on conflict adaptation to explore age-related differences, nor extensively measured age-related differences in conflict adaptation within the Simon task (Puccioni & Vallesi, 2012). Due to these findings and gaps in the literature, the following hypotheses and research questions were made:

H11a: Incongruent trials that precede congruent trials within the Simon task will result in significantly shorter RTs and congruent trials that precede incongruent trials will result in significantly longer RTs.

H11b: Older adults and younger adults will experience conflict adaptation effects equally within the Simon task.

RQ5: Will conflict adaptation effects be significantly greater during a combined Simon and flanker task overall?

RQ6: Will older adults experience significantly greater conflict adaptation effects than younger adults in a combined Simon and flanker task?

However, other research has evaluated the flanker task alone and found evidence of conflict adaptation. Similar to the Simon conflict adaptation findings, RTs were significantly shorter and less errors were made during I → C trials as compared to C → I trials (Ullsperger et al., 2005). Nieuwenhuis et al. (2006) also found that conflict adaptation was present in the flanker task and that greater conflict was present when the frequency of trial types increased. Additionally, they found that older adults experienced significant conflict adaptation effects, which were significantly increased when the frequency of trial type was. However, their results did not statistically compare whether older adults experienced greater conflict adaptation than younger adults. One study that did compare age found that there were no significant age-related differences on conflict adaptation within the flanker effect despite both age groups displaying significant conflict adaptation effects (Larson et al., 2016). Therefore, the following hypotheses were formed:

H12a: Incongruent trials that precede congruent trials within the flanker task will result in significantly shorter RTs and congruent trials that precede incongruent trials will result in significantly longer RTs.

H12b: Older adults and younger adults will experience conflict adaptation equally within the flanker task.

In addition to behavioral responses to conflict adaptation, research has also evaluated ERP amplitude differences. Due to Botvinick et al.'s (2002) claim that cognitive control is involved during conflict adaptation, ERP amplitudes that represent later processing have been measured for conflict adaptation. Of particular interest is the N2 component for its association with monitoring or regulating strategy to perform a given task (Folstein & Van Petten, 2008). For example, Chen and Melara (2009) found that N2 amplitudes were most enhanced during C → I trials, demonstrating a significant conflict adaptation effect in the Simon task. However, to our knowledge, this is the only study that has measured the N2 during conflict adaptation in the Simon task. Although similar tasks like the Stroop task found that N2 amplitude significantly increases during conflict adaptation (e.g. Kerns et al., 2004), more research needs to evaluate the Simon task specifically in addition to measuring age-related differences. On the other hand, the N2 has been more heavily studied in the flanker task. For instance, research has found that N2 amplitudes were significantly larger during C → I when congruent trials preceded incongruent trials even after accounting for repetition priming as an influencing factor (Clayson & Larson, 2011). Conflict adaptation effects were also found by Larson et al. (2016), indicating that N2 amplitudes were significantly smaller during I → C trials. However, their study did not find that the N2 significantly differed between younger and older adults. To our knowledge, this is the only study that has considered age-related differences on N2 amplitudes during conflict adaptation in the flanker task. Therefore, further research needs to be conducted to confirm that age does not modulate the effect.

In addition to the N2, the P3 is another important component to measure due to its association with context updating (Friedman et al., 2001). Despite this notion, research has not evaluated the P3 during Simon conflict adaptation trials nor age-related differences, insinuating a need for investigation. The P3 has been studied during flanker conflict adaptation trials, however. For example, one study found that P3 amplitude was significantly larger during C → I trials as compared to I → C trials, supporting conflict adaptation effects. In another study, Larson et al. (2016) found that the P3 amplitude was significantly greater during I → C trials than during C → C trials. But when evaluating age-related differences, only the younger adults displayed significantly smaller P3 amplitudes during I → I trials as compared to C → I trials. However, more research needs to be conducted to more confidently confirm that P3 amplitudes during conflict adaptation in the flanker task differ between age. Additionally, is it also important to note that research has also not measured differences in N2 and P3 amplitude during conflict adaptation in a combined Simon and flanker task. Thus, due to the above findings, the following hypotheses and research question were made:

H13: N2 amplitudes will be significantly enhanced during conflict adaptation trials for both the Simon and flanker tasks separately.

H14: P3 amplitudes will be significantly enhanced during conflict adaptation trials for the flanker task.

RQ7: Will P3 amplitudes be significantly different for conflict adaptation trials during the Simon task?

RQ8: Will conflict adaptation effects elicit significant N2 and P3 amplitude differences during a combined Simon and flanker task?

RQ9: Will conflict adaptation effects elicit significantly different N2 and P3 amplitudes in older adults as compared to younger adults for the Simon and flanker task separately and for a combined Simon and flanker task?

Given all of the above evidence, the overarching goal of the present study was to investigate age-related differences between younger and older adults' inhibitory function by introducing an original task that combined both Simon and flanker effects. The researchers were interested in measuring differences in RT, accuracy, and ERP amplitudes (P1, N1, N2, and P3) that have been shown to be associated with inhibitory conflict. The results will allow the field to better conclude whether inhibitory function is or is not a unitary mechanism by comparing age-related differences between the two tasks. Additionally, the present study sought to measure differences in conflict adaptation through behavioral and electrophysiological means (N2 and P3) using the novel task between younger and older adults to determine if Simon and flanker adaptation trials elicit different responses.

Chapter 3

Materials and Method

Participants.

After the study received Institutional Review Board (IRB) approval from the university, younger adults aged 18 years or older were recruited from a small public liberal arts university on the East Coast using the SONA participant pool system. College-aged participants received between one and three course credits for their participation dependent on the total amount of time they were in the lab. Additionally, they received a button or a sticker with the lab's logo on it. Older adults aged 65 years or older were recruited primarily through either word of mouth or flyer distribution. Flyers were posted at the town's local libraries, recreation center for those aged 65 and older, downtown, around campus, or online to various local Facebook groups. Additionally, a researcher emailed or distributed flyers to local assisted living communities or retirement homes. Older adults were asked to either contact the research assistant via email or phone to better understand the study's procedures and sign up for a timeslot. At the conclusion of the study, older adults were given tote bags, a sticker, and a button with the lab's logo on it for their participation. Exclusion criteria for all participants included a history of neurological disorders (i.e. epilepsy) within the past year and a diagnosis of dementia for older adults.

In total, 56 adults participated in the present study. Several participants were excluded from data analysis for the following reasons: fewer than seven trials in any of the task conditions ($n = 5$), poor ERP data quality ($n = 2$), and accuracy less than 80% on the task ($n = 1$). After these exclusions, the analysis included 48 participants, where 24 were older adults (15 female) and 24 were younger adults (13 female). The majority of the sample was White ($n = 42$) and right handed ($n = 38$)[3]. Additionally, almost all of the included older adults obtained higher education where ($n = 7$) completed an Associates degree, ($n = 8$) completed a Bachelor's degree, ($n = 6$) completed a Master's degree, and ($n = 3$) completed just high school. Other demographic variables such as information on vision and hearing impairment, prescription medication, as well as history of concussion, seizure, and stroke were collected[4]. All demographic information can be found in Table 1.

Experimental task and stimuli.

The present study used a novel cognitive conflict task that combined both Simon and flanker conflicts (Figure 1). Stimuli consisted of three arrows that pointed either left or right. The present study also included neutral conditions for both task types that provided no directional information. Specifically, two rectangles (arrow with arrowhead removed) represented neutral flankers and neutral Simon was depicted when the target arrow appeared in the middle of the screen. Previous research has used neutral stimuli in both Simon and flanker tasks (e.g. de Bruin & Sergio Della Sala, 2017) and showed that participants respond faster during congruent trials as compared to neutral trials because additional relevant information is provided. The stimulus condition with both Simon and flanker neutrality was used as a baseline for comparison with each of the four stimulus conditions that were designed to elicit Simon (congruent/incongruent) and flanker (congruent/incongruent) effects. For the analysis of RT and accuracy, this baseline subtraction permits isolation of the conflict processing effects while controlling for general slowing in the older adult participants. For the event-related potential analysis, this baseline

[3] In order to ensure that handedness did not significantly influence the Simon and flanker effects in the present study, left handed participants were filtered out from the data and the 3x3x2 mixed measures ANOVA was rerun. It was found that all main effects and interactions were still statistically significant, indicating that handedness had no effect.

[4] Demographic questions can be found in Appendix B.

subtraction is recommended practice in clinical contexts where groups may differ and permits the isolation of conflict processing effects (Kappenman & Luck, 2016) while controlling for general ERP amplitude reductions commonly seen in older adult populations (Luck & Kappenman, 2011). The target arrow in each trial was filled white while the flankers were filled gray. These stimuli were similar to those used in previous studies of Simon and Flanker effects (e.g. Korsch et al, 2016; Hsieh et al., 2012).

For each trial, three stimuli appeared horizontally on a black computer screen to depict a white target arrow and gray flankers or neutral gray rectangles. Target arrows that pointed in the same direction as the flankers represented the congruent flanker condition, while target arrows that pointed in the opposite direction as the flankers represented the incongruent flanker condition. Likewise, target arrows that appeared on the side of the screen as it was pointing represented the congruent Simon condition, while target arrows that appeared on the opposite side of the screen represented the incongruent Simon condition. In total, there were nine experimental conditions: congruent Simon and flanker (SCFC), incongruent Simon and congruent flanker (SIFC), neutral Simon and congruent flanker (SNFC), congruent Simon and incongruent flanker (SCFI), incongruent Simon and incongruent flanker (SIFI), neutral Simon and incongruent flanker (SNFI), congruent Simon and neutral flanker (SCFN), incongruent Simon and neutral flanker (SIFN), and lastly neutral Simon and neutral flanker (SNFN).

Experimental stimuli were programmed using PsychoPy2 (Peirce et al., 2019). Following 18 practice trials (one of each stimulus type), participants completed a single block of 360 experimental trials presented in random order. Each trial began with a blank screen for a random interval between one and two seconds. Then, stimuli were laterally presented until the participant made a response.

Participants sat approximately 60 cm away from the computer screen on a comfortable, wheel-less chair in a dimly lit, magnetically shielded room. They were provided written instruction as well as verbally asked to press the left button on their game controller with their index finger when the white target arrow pointed left, and press the right button with their right index finger when the white target arrow pointed right. Participants were told to just respond to the direction of the white target arrow despite it possibly appearing on the opposite side of the screen. Researchers made sure participants knew to respond as quickly and accurately as possible throughout the entire task which lasted approximately 15 minutes.

Neuropsychological measures.

Assessed mild cognitive impairment. MCI was assessed in older adults with the use of the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005). The MoCA requires participants to provide written and verbal responses to various orally administered tasks. For example, one item asks participants to perform a clock-drawing task while another asks them to count backwards from 100 by seven until they reach the number 65. The measure consists of eight categories used to evaluate cognitive function: visuospatial/executive, naming, memory, attention, language, abstraction, delayed recall, and orientation. In total, there are 23 items/tasks totaling 30 points. If older adults score above or equal to 26 points, they are categorized as having “normal” cognitive function while those who score below 26 points are categorized as displaying mild cognitive impairment. The measure takes approximately 10 minutes to complete[5]. All participants were given a pencil with an eraser for the written portion of the assessment. As reported by Smith, Gildeh, and Holmes (2007), the MoCA is a valid measure to detect mild cognitive impairment in older adults; they reported significant difference scores

[5] The MoCA assessment is located in Appendix C.

between older adults who were diagnosed with either dementia, MCI, or MCC (experiences cognitive impairment unrelated to mild cognitive impairment). However, this measure is not a diagnostic tool.

Perceived cognitive impairment. Participants were asked to complete the Cognitive Functioning Self-Assessment Scale CFSS (Annunziata, Muzzatti, Giovannini, & Lucchini, 2012) in order to assess their perceived cognitive impairment. The CFSS has a total of 18 items (e.g. “Difficult in recalling recent information”) in which participants are asked to rate each one on a Likert scale that ranges from 1 (*Never*) to 5 (*Always*) in regard to how often they experience said item[6]. This measure has excellent reliability and validity; researchers found that it has a Cronbach’s alpha that ranged from 0.878 to 0.924, and divergent validity with strong correlations of $r = .455$ and $r = .351$ (Annunziata, Muzzatti, Flaiban, Giovannini, & Lucchini, 2018). In conjunction, the present study found that these items have high reliability ($\alpha = .869$).

EEG recording and processing.

Electrophysiological data were recorded at a sampling rate of 2000 Hz using a high-impedance DBPA-1 Sensorium bio-amplifier (Sensorium Inc., Charlotte, VT) with an analog high-pass filter of 0.01 Hz. All recordings were made using an extended 10/20 cap system with 65 Ag-AgC1 sintered electrodes with the reference electrode placed at the tip of the nose and the ground (i.e., common) electrode placed at the center of the forehead.

EEG data were analyzed using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014). Raw data were resampled at 1000 Hz and were visually inspected for extreme artifacts. Channels containing excessive artifact were interpolated using a spherical spline and epochs containing excessive artifact across channels were removed from the

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[6] The CFSS measure is located in Appendix D.

continuous data. For each participant, no more than five channels were interpolated. For all stimulus-locked ERPs, baseline correction was performed over a 200 ms prestimulus interval and for all response-locked ERPs, baseline correction was performed over the interval between 400 and 700 ms. Following segmentation of the continuous EEG data, blink and horizontal eye-movement artifacts were corrected using Independent Components Analysis (Hyvärinen & Oja, 2000). Finally, the data were smoothed using an IIR Butterworth band-pass filter of 0.2-30 Hz, and trials containing voltages in excess of +/- 100 μV were removed. Participants with fewer than seven usable trials in any of the experimental conditions were excluded from the data analysis (Van Meel & Van Heijningen, 2010).

Data analysis.

Behavioral RT.

Behavioral RT measures for each participant were computed using the arithmetic mean of the set of RTs after removing extreme outliers. Outlier RTs were defined for each participant as those more than two times the interquartile range below or above the first and third quartile (respectively) of the set of observed RTs. Although the present design was fully crossed, conflict processing effects were isolated by subtracting the mean RT on FNSN trials from each of the FCSC, FCSI, FISC, and FISI trials. The effects of Simon and flanker conflict were then analyzed using a 2 (Flanker: congruent/incongruent) x 2 (Simon: congruent/incongruent) x 2 (Age: younger/older) mixed measures analysis of variance (ANOVA). Conflict adaptation effects were also evaluated using the differenced RTs using a 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Type: flanker/Simon) x 2 (Age: younger/older) mixed measures ANOVA. In addition to streamlining the analysis, this strategy permits direct comparisons between analyses of the RT and ERP data. Note that including an equal number of the FNSC, FNSI, FCSN, and FISN trials created a balanced phenomenological experience with all experimental stimuli. Analysis of conflict processing effects using the complete 3x3x2 design with RTs prior to subtraction is provided for reference in Appendix E.

ERPs.

It is well understood that the ERP waveform is the sum voltage produced by *all* neural activity elicited by a time-locking stimulus (Dickter & Kieffaber, 2014). In order to isolate the components of the electrophysiological response most closely related to the experimental manipulations of Simon and flanker conflict, the ERP analysis was conducted using difference waves which were computed by subtracting the average waveform elicited by the FNSN stimulus from the average waveforms elicited by the FCSC, FCSI, FISC, and FISI stimuli for each participant. These difference waveforms were used in both the analysis of conflict processing and conflict adaptation effects. In addition to streamlining the analysis, using difference waveforms can also help to eliminate the possibility of interpreting the effects due to chance (Kappenman & Luck, 2016). For all components, grand-average waveforms and topographies were made for each participant to inform the choice of latency intervals for ERP measurement. Latency windows and isolation techniques used for measurement of each component are provided in Table 2. (Reference Figure 6 and 7 for visual representations of component measurement locations.)

Analyses.

Once ERP amplitudes were computed, all data (ERP and behavioral) were analyzed using jamovi 0.9.6.1 (jamovi project, 2018). First, overall accuracy data were analyzed using a paired samples t-test with Age (old vs. younger) as the grouping variable. Then, RT data were analyzed using a 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/ incongruent) mixed measures ANOVA with a between-subjects factor of age (younger/older). Additionally, another 2 (Simon:

congruent/incongruent) x 2 (Flanker: congruent/incongruent) mixed measures ANOVA with a between-subjects factor of Age (younger/older) was used after left handed participants were filtered out in order to determine whether handedness influenced the effects. To assess each the Simon and flanker conflict adaptation data without crossing effects on task type, a 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Type: Simon/flanker) mixed measures ANOVA with a between-subjects factor of Age (younger/older) was used for both the Simon and flanker tasks. Another 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Type: Simon/flanker) mixed measures ANOVA with a between-subjects factor of Age (younger/older) was used to analyze conflict adaptation RT data with crossing effects on task type.

$P1_D$[7] and N1 ERP amplitude data were analyzed using a 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) mixed measures ANOVA with a between-subjects factor of Age (younger/older) over the occipital lobe. Modeling region after Korsch et al. (2016) (who found that older adults show greater activation in the frontal region during top-down processing compared to younger adults), $N2_D$ and earlier and later $P3_D$ were analyzed using a 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) x 2 (Region: frontal/central) mixed measures ANOVA with a between-subjects factor of Age (younger/older). ERP amplitude data for conflict adaptation without crossing effects on task type for $P1_D$ and $N1_D$ were analyzed using a 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Type: Simon/flanker) mixed measures ANOVA with a between-subjects factor of Age (younger/older) over the occipital lobe. ERP amplitude data for conflict adaptation without crossing effects on task type for $N2_D$ and earlier and later P3 were analyzed

[7] This symbol denotes that difference waves were used.

using a 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Region: frontal/central) x 2 (Type: Simon/flanker) mixed measures ANOVA with a between-subjects factor of Age (younger/older). Additionally, ERP amplitude data for conflict adaptation with crossing effects on task type for $P1_D$ and $N1_D$ were analyzed using a 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Type: Simon/flanker) mixed measures ANOVA with a between-subjects factor of Age (younger/older) over the occipital lobe while $N2_D$ and earlier and later $P3_D$ were analyzed using a 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Region: frontal/central) x 2 (Type: Simon/flanker) mixed measures ANOVA with a between-subjects factor of Age (younger/older). All post-hoc analyses utilized Bonferroni corrections (e.g. Bland, & Altman, 1995).

Procedure.

When participants first arrived to the lab, the researchers provided them with two copies of the informed consent (one for them to take home) and asked them to read the document over. Additionally, the researchers verbally explained what was going to take place and made sure the participants knew they could stop the study at any time. After participants signed the informed consent form, a researcher brought the participant to an inclosed room where they were asked to answer various demographic questions in addition to completing the CFSS and then the MoCA for older adults. Once finished, the researchers setup the EEG equipment and ensured the connection was adequate. The participants then received written and verbal instructions for the task and completed it in an inclosed, magnetically shielded room. Once participants were finished, the researchers removed the EEG cap and provided them with a sink and paper towels to wash out the gel. They were then given a debriefing form as a researcher verbally explained the purpose of the study and handed them their compensation for their participation.

Chapter 4

Results

MoCA scores.

Only (n = 4) older adults scored lower than the threshold of 26 points on the MoCA where 25 points indicates MCI detection (Nasreddine et al., 2005). However, these individuals were included in the analysis because none were given formal diagnosis of MCI and their exclusion did not have any qualitative impact on the nature of the results (see Appendix A). In total, the mean and standard deviation for the MoCA score was (M = 27.40, SD = 2.14). Moreover, older participants scored (M = 1.710, SD = 0.312) out of five possible points on the perceived cognitive impairment measure used, which indicates that this sample of older participants positively perceived their cognitive ability on average.

Conflict (behavioral / ERP).

Overall accuracy.

Across all trial and task types, it was found that there was no significant difference in accuracy percentage between younger (M = 0.984, SD = 0.012) and older adults (M = 0.978, SD = 0.024), $t(23) = 2.03$, $p = 0.054$.

Overall RT.

After RT[8] differences (RT_D) were computed, a 2 (Flanker: congruent/incongruent) x 2 (Simon: congruent/incongruent) x 2 (Age: younger/older) mixed measures ANOVA was run. It was found that there was a significant main effect of Simon conflict, $F(1,47) = 216.39$, p = < .001, $\eta^2 = 0.290$, such that RT_Ds were significantly delayed on SI trials (M = 116, SE = 4.33) compared with SC trials (M = 52.70, SE = 4.33), providing support for H1a. There was also a

[8] All RTs were measured in milliseconds (ms).

significant main effect of Flanker conflict, $F(1,47) = 214.13$, $p < .001$, $\eta^2 = 0.216$, such that RTs were slower on FI trials ($M = 111.60$, $SE = 4.20$) compared with FC trials ($M = 57.10$, $SE = 3.73$), supporting H6. Finally, there was also a significant main effect of Age, $F(1,47) = 35.90$, $p < .001$, $\eta^2 = 0.148$, wherein older adults ($M = 106.90$, $SE = 5.32$) demonstrated significantly larger conflict-related RT_Ds than younger adults ($M = 61.80$, $SE = 5.32$).

However, these main effects were qualified by a significant three-way interaction found between Simon, Flanker, and Age $F(1,47) = 4.33$, $p = 0.043$, $\eta^2 = 0.002$. Separate 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) ANOVAs were run for each age group. First, it was found that younger adults exhibited significant main effects of Flanker ,$F(1,47) = 152.44$, $p < .001$, $\eta^2 = 0.292$, and Simon conflict, $F(1,47) = 95.32$, $p < .001$, $\eta^2 = 0.317$. There was also a significant interaction between Simon and Flanker, $F(1,47) = 7.66$, $p < .011$, $\eta^2 = 0.003$, reflecting over-additivity of conflict effects when both Simon and Flanker conflict were present in the stimulus. This pattern of results was qualitatively identical in older adults, with significant main effects of Simon, $F(1,47) = 124.10$, $p < .001$, $\eta^2 = 0.381$, and Flanker, $F(1,47) = 96.10$, $p < .001$, $\eta^2 = 0.247$ conflict and a significant two-way interaction between Simon and flanker effects, $F(1,47) = 10.60$, $p < .003$, $\eta^2 = 0.012$. Taken together, these results indicate that both Simon and flanker incongruency produced significant RT_D delays in both younger and older groups and that these conflict processing effects interact with one another producing over-additive RT_D delays when Simon and flanker incongruencies were combined in the same trial. In is also noteworthy that effect sizes (η^2) were larger for flanker conflict in younger compared with older adults whereas effect sizes were larger for Simon conflict in older compared with younger adults. (See Figure 2).

Overall ERP amplitudes.

$P1_D$.

A 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) x 2 (Age: younger/older) mixed measures ANOVA over the occipital lobe was run on difference waveforms. The results revealed that there were no significant main effects of Age, Simon, or Flanker ($p > .05$), resulting in no support for H2a and H7a, but support for H2b and H7b. Additionally, there were no significant interactions between Simon and Flanker, nor a three-way interaction between Simon, Flanker, and Age ($p > .05$).

$N1_D$.

A 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) x 2 (Age: younger/older) mixed measures ANOVA over the occipital lobe was run on difference waveforms. It was found that there was a significant main effect of Flanker, $F(1,43) = 9.0676$, $p = 0.004$, $\eta^2 = 0.009$, where FI trials ($M = -0.430$, $SE = 0.139$) elicited significantly larger negative $N1_D$ amplitudes than FC trials ($M = -0.215$, $SE = 0.139$), supporting H8a. There were no significant effects of Simon conflict on the $N1_D$, failing to support H3a. Additionally, there was a significant main effect of Age, $F(1,43) = 8.01$, $p = 0.007$, $\eta^2 = 0.113$, where older adults ($M = -0.7022$, $SE = 0.190$) had significantly larger negative $N1_D$ amplitudes than younger adults ($M = 0.0575$, $SE = 0.190$). However, there were no significant interactions found between Simon and Flanker, nor between Simon, Flanker, and Age ($p > .05$), providing no substantial support for H3b and H8b.

$N2_D$.

A 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) x 2 (Region: frontal/central) x 2 (Age: younger/older) mixed measures ANOVA was run on difference waveforms. A significant main effect of Simon was found, $F(1,43) = 8.0469$, $p = 0.007$, $\eta^2 =$

0.008, where SI trials (*M* = -0.576, *SE* = 0.103) elicited significantly larger $N2_D$ amplitudes than SC trials (*M* = -0.398, *SE* = 0.103), supporting H4a. No other main effects were significant ($p > .05$), providing evidence to reject H9a. However, there was a significant interaction found between Flanker and Age, $F(1,43) = 4.7291$, $p = 0.0035$, $\eta^2 = 0.004$. Post hoc tests revealed that there were no significant differences found between the means of the crossed factors ($p > .05$). Despite this, it was found that younger adults had larger $N2_D$ amplitudes during incongruent trials (*M* = -0.645, *SE* = 0.145) as compared to older adults (*M* = -0.294, *SE* = 0.145). These results indicate that H4b was not supported but H9b was partially supported. No other interactions were statistically significant ($p > .05$).

Earlier $P3_D$.

A 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) x 2 (Region: frontal/central) x 2 (Age: younger/older) mixed measures ANOVA was run on difference waveforms. Results indicated that there was a significant main effect of Simon, $F(1,43) = 23.82255$, $p < .001$, $\eta^2 = 0.020$, where SI trials (*M* = 0.3905, *SE* = 0.105) elicited significantly larger earlier $P3_D$ amplitudes as compared to SC trials (*M* = 0.0351, *SE* = 0.105). There was also a significant main effect of Flanker, $F(1,43) = 21.04795$, $p < .001$, $\eta^2 = 0.019$, where FI trials (*M* = 0.3836, *SE* = 0.105) elicited significantly larger earlier $P3_D$ amplitudes as compared to FC trials (*M* = 0.0420, *SE* = 0.105), providing partial support for both H5a and H10a. There was no significant main effect of age ($p > .05$).

The significant main effects were qualified by a significant two-way interaction between Simon and Flanker, $F(1,43) = 4.49480$, $p = 0.039$, $\eta^2 = 0.003$. Post hoc tests revealed that SIFI trials (*M* = 0.6304, *SE* = 0.116) elicited significantly larger earlier $P3_D$ amplitudes than SCFC trials (*M* = -0.0666, *SE* = 0.116), $t(92.0) = -6.693$, $p < .05$, SCFI trials (*M* = 0.1368, *SE* = 0.116), *t*(90.90) = -5.050, $p < .001$, and SIFC trials (*M* = 0.1506, *SE* = 0.116), *t*(90.40) = -4.848, $p < .001$.

Although the results did not reveal a significant three-way or four-way interaction with Simon and Flanker on Region and/or Age ($p > .05$), there were two significant three-way interactions found between Region and Age separately for Simon ($F(1,43) = 15.17821$, $p < .001$, $\eta^2 = 0.018$) and Flanker ($F(1,43) = 27.05417$, $p < .001$, $\eta^2 = 0.020$) (See Figure 3 and 4, respectively).

First, the Simon task was analyzed. For older adults, results revealed that SI trials over the frontal region (*M* = 0.965, *SE* = 0.211) elicited significantly larger earlier $P3_D$ amplitudes as compared to SI trials over the central region (*M* = -0.513, *SE* = 0.211), *t*(63.30) = 4.941, $p < .001$. It was also found that SI trials over the frontal region elicited significantly larger amplitudes than SC trials over the central region (*M* = -0.382, *SE* = 0.211), *t*(58.80) = -4.610, $p < .001$. For younger adults, it was only found that SI trials over the central region (*M* = 0.782, *SE* = 0.211) elicited significantly larger amplitudes than SC trials over the central region (*M* = 0.254, *SE* = 0.211), *t*(89.70) = -3.324, $p = 0.036$. There were also significant differences found between younger and older adults. In particular, it was found that SI trials over the central region in younger adults elicited significantly larger amplitudes than SI trials over the central region in older adults, *t*(121.60) = -4.347, $p < .001$ and SC trials over the central region in older adults, *t*(121.60) = -3.908, $p = 0.004$.

Identical results were found for the flanker task. For older adults, it was found that FI trials over the frontal region elicited significantly larger than FI trials over the central region (*M* = -0.393, *SE* = 0.208), *t*(56.80) = 4.5744, $p < .001$. Additionally, FI trials over the frontal region elicited significantly larger amplitudes than FC trials over the central region (*M* = -0.503, *SE* =

0.208), *t*(59.3) = -4.8929, $p < .001$. In regards to younger adults, it was found that FI trials over the central region (*M* = 0.816, *SE* = 0.208) elicited significantly larger amplitudes than FC trials over the central region (*M* = 0.219, *SE* = 0.208), *t*(91.00) = -4.2174, $p = .002$. For both age groups, it was revealed that FI trials over the central region in younger adults elicited significantly larger amplitudes than FC trials over the central lobe in older adults (*t*(115.80) = -4.4944, $p < .001$) and FI trials over the central region in older adults (*t*(115.8) = -4.1192, $p = .002$).

Later $P3_D$.

A 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) x 2 (Region: frontal/central) x 2 (age: younger/older) mixed measures ANOVA was run on difference waveforms. It was found that there was a significant main effect of Simon, $F(1,43) = 15.6035$, $p < .001$, $\eta^2 = 0.016$, where SI trials (*M* = 0.2383, *SE* = 0.101) elicited significantly larger later $P3_D$ amplitudes than SC trials (*M* = -0.0472, *SE* = 0.101). There was also a significant main effect of Flanker, $F(1,43) = 11.3022$, $p = 0.002$, $\eta^2 = 0.009$, where FI trials (*M* = 0.2058, *SE* = 0.100) elicited significantly larger amplitudes than FC trials (*M* = -0.0146, *SE* = 0.100). However, there was the main effect of Age did not reach significance ($p > .05$).

There were two significant two-way interactions found. First, there was a significant interaction between Simon and Flanker, $F(1,43) = 8.4181$, $p = 0.006$, $\eta^2 = 0.005$. However, this finding was qualified by a significant three-way interaction between Simon, Flanker, and Age, $F(1,43) = 4.4513$, $p = 0.040$, $\eta^2 = 0.003$ (See Figure 5). Separate 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) ANOVAs were run for each age group.

For older adults, it was found that there was a main effect of Simon, $F(1,23) = 14.904$, $p < .001$, $\eta^2 = 0.070$, where SI trials ($M = 0.133$, $SE = 0.148$) elicited significantly larger amplitudes than SC trials ($M = -0.292$, $SE = 0.148$). There was also a significant main effect of Flanker, $F(1,23) = 17.051$, $p < .001$, $\eta^2 = 0.047$, where FI trials ($M = 0.0937$, $SE = 0.143$) elicited significantly larger amplitudes than FC trials ($M = -0.2526$, $SE = 0.143$). Thus, these findings countered both H5b and H10b. However, there was no significant two-way interaction between Simon and Flanker ($p > .05$).

Unlike older adults, younger adults only had a significant interaction between Simon and Flanker, $F(1,23) = 9.887$, $p = 0.005$, $\eta^2 = 0.034$. Specifically, results revealed that SIFI trials ($M = 0.532$, $SE = 0.155$) elicited significantly larger amplitudes than SCFI trials ($M = 0.104$, $SE = 0.155$), $t(45.90) = -3.300$, $p = 0.010$, and SIFC trials ($M = 0.156$, $SE = 0.155$), $t(45.40) = -2.789$, $p = 0.037$.

The second significant two-way interaction was Flanker by Region, $F(1,43) = 11.2839$, $p = 0.002$, $\eta^2 = 0.007$. However, this finding was qualified by a significant three-way interaction between Flanker, Region, and Age. First, older adults were analyzed. It was found that FI trials over the frontal region ($M = 0.359$, $SE = 0.194$) elicited significantly larger amplitudes than FC trials over the frontal region ($M = -0.120$, $SE = 0.194$), $t(89.20) = -3.968$, $p = 0.004$. No other significant differences were found in older adults ($p > .05$). For younger adults, it was found that FI trials in the central region ($M = 0.862$, $SE = 0.194$) elicited significantly larger amplitudes than FI trials in the frontal region ($M = -0.226$, $SE = 0.194$), $t(54.50) = -4.090$, $p = 0.004$, and FC trials in the central region ($M = 0.265$, $SE = 0.194$), $t(89.20) = -4.932$, $p < .001$. However, FC trials in the central region elicited significantly larger amplitudes than FI trials in the frontal region ($M = -0.226$, $SE = 0.194$), $t(89.20) = 3.370$, $p = 0.031$. With both age group, it was found that FI trials over the central region in younger adults were elicited significantly larger amplitudes than FI trials over the central region in older adults (*M* = -0.172, *SE* = 0.194), $t(111.10) = -3.761$, $p = 0.008$, FC trials in the central region in older adults (*M* = 0.265, *SE* = 0.194), $t(111.10) = -4.536$, $p < .001$, and FC trials over the frontal region in older adults, $t(111.10) = -3.572$, $p = 0.015$.

The last significant interaction found was a three-way interaction between Simon, Region, and Age, $F(1,43) = 17.7443$, $p < .001$, $\eta^2 = 0.019$. Identical findings to the significant three-way between Flanker, Region, and Age were found between and within each age group. First, older adults were analyzed. It was found that FI trials over the frontal region (*M* = 0.359, *SE* = 0.194) elicited significantly larger amplitudes than FC trials over the frontal region (*M* = 0.120, *SE* = 0.194), $t(89.20) = -3.968$, $p = 0.004$. No other significant differences were found for older adults ($p > .05$). For younger adults, it was found FI trials over the central region (*M* = 0.862, *SE* = 0.194) elicited significantly larger amplitudes than FC trials over the central region (*M* = -0.265, *SE* = 0.194), $t(89.20) = -4.932$, $p < .001$. No other significant differences were found for younger adults ($p > .05$). (See Figures 6 and 7 for visual representations of the ERP data for all condition types.)

Conflict adaptation without crossing effects on task type.

Conflict Adaptation effects were evaluated in both RT_D and each of the ERP measures using a 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Type: Simon/flanker) x 2 (Age: younger/older) mixed measures ANOVA while the ERP measures included the factor Region (frontal/central). Because adaptation effects are reflected in the two-way (Previous x Current) interaction, only the group of interactions involving both Previous and Current factors were evaluated.

RT.

It was first found that there was a significant three-way interaction between Previous, Current, and Type, $F(1,47) = 19.7816$, $p < .001$, $\eta^2 = 0.026$. Separate 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) ANOVAs were run for each task type. For the Simon task, a significant two-way interaction was found between Previous and Current, $F(1,47) = 34.38$, $p < .001$, $\eta^2 = 0.058$. Of particular importance, it was found that C → C trials ($M = 31.70$, $SE = 6.74$) had significantly faster RT_Ds than I → C trials ($M = 121.70$, $SE = 6.74$), $t(93.60) = -4.99$, $p < .001$. It was also found that I → I trials ($M = 100.70$, $SE = 6.74$) had significantly faster RT_Ds than C → I trials ($M = 121.70$, $SD = 6.74$), $t(93.60) = 3.04$, $p = .0019$, providing support for H11a. For the flanker task, there was no significant interaction between previous and current congruence type, $F(1,47) = 1.95$, $p = 0.169$, $\eta^2 = 0.006$. However, the direction of one effect was in the same direction as the Simon task; C → C trials ($M = 56.10$, $SD = 6.21$) has faster RTs than I → C trials ($M = 57.50$, $SD = 6.21$). I → I trials ($M = 117.90$, $SD = 6.21$) however had a reversal effect suggesting that they resulted in longer RT_Ds than C → I trials ($M = 99.70$, $SD = 6.21$), resulting in the rejection of H12a These findings suggest that only Simon conflict adaptation effects were present in the current study and that age did not modulate the interaction, supporting both H11b and H12b.

ERPs.

$N2_D$.

The results revealed that there was no significant main effect of Age nor a significant two-way interaction between Previous and Current ($p > .05$), but there was a significant three-way interaction found between Previous, Current, and Region, $F(1,47) = 4.23223$, $p = 0.045$, $\eta^2 = 0.001$. Separate 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent)

ANOVAs were run for each region. However, both two-way ANOVAs resulted in nonsignificant findings ($p > .05$).

Additionally, there was a significant four-way interaction found between Previous, Current, Type, and Age, $F(1,47) = 9.07968$, $p = 0.004$, $\eta^2 = 0.009$. Separate 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Type: Simon/flanker) ANOVAs were run for each age group. For younger adults, neither a 2-way interaction between Previous and Current nor a three-way interaction were statistically significant ($p > .05$). However, there was a significant three-way interaction found for older adults, $F(1,23) = 6.6248$, $p = 0.017$, $\eta^2 = 0.035$. Therefore, separate 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) ANOVAs were run for each task type for older adults. It was found that there was a significant interaction between Previous and Current for Simon, $F(1,23) = 9.6431$, $p = 0.005$, $\eta^2 = 0.058$, indicating a significant conflict adaptation effect (See Figure 8). Although post hoc results revealed that there were no significant differences between the means ($p > .05$), it is important to note that $N2_D$ amplitudes were larger during C → I trials ($M = -5.05$, $SD = 0.142$) as compared to I → I trials ($M = -0.243$, $SD = 0.142$).

Earlier $P3_D$.

Results revealed that there was no significant main effect of age, nor a two-way interaction between Previous and Current ($p > .05$). However, there was a significant three-way interaction between Previous, Current, and Region, $F(1,47) = 7.26345$, $p = 0.010$, $\eta^2 = 0.003$. Separate 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) ANOVAs were run for each region. Although there was no significant two-way interaction within the frontal region ($p > .05$), there was for the central region, $F(1,47) = 7.5449$, $p = 0.009$, $\eta^2 = 0.005$.

Although post hoc tests revealed no significant mean differences pertaining to conflict adaptation releancy ($p > .05$).

There was also a significant four-way interaction found between Previous, Current, Type, and Age, $F(1,47) = 5.67251$, $p = 0.021$, $\eta^2 = 0.004$. Separate 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Type: Simon/flanker) ANOVAs were run for each age group. However, the results indicated that there were no significant interactions between Previous and Current, nor Previous, Current, and Type for either age group ($p > .05$).

Later $P3_D$.

Findings revealed that there was no significant main effect of age or interactions that would indicate that conflict adaptation effects elicited significantly different later $P3_D$ amplitudes overall or between groups ($p > .05$). Thus, earlier and later $P3_D$ amplitudes do not provide support for H14.

Conflict adaptation with crossing effects on task type.

RTs.

Results indicated that there was a significant main effect of Age, $F(1,47) = 22.40$, $p < .001$, $\eta^2 = 0.146$, where older adults had significantly longer RTs ($M = 102.40$, $SE = 6.10$) than younger adults ($M = 61.50$, $SE = 6.01$). Unlike the conflict adaptation ANOVA without interaction effects on task type, there was no significant main effect of Type ($F(1,47) = 0.40014$, $p = 0.530$, $\eta^2 = 0.000$).

These main effects are qualified by a significant four-way interaction between Previous, Current, Type, and Age, $F(1,47) = 5.39112$, $p = 0.025$, $\eta^2 = 0.005$. Separate 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) x 2 (Type: Simon/flanker)

ANOVAs were run for each age group. For younger adults, neither a three-way interaction between Previous, Current, and Type, $F(1,47) = 1.07351$, $p = 0.311$, $\eta^2 = 0.002$, nor a two-way interaction between Previous and Current were statistically significant, $F(1,47) = 0.000422$, $p = 0.984$, $\eta^2 = 0.000$. However, there was a significant three-way interaction between Previous, Current, and Type found in older adults, $F(1,47) = 4.3204$, $p = 0.049$, $\eta^2 = 0.011$. Separate 2 (Previous: congruent/incongruent) x 2 (Current: congruent/incongruent) ANOVAs were run for both the Simon and flanker tasks in older adults. Results revealed that there was no significant interaction between Previous and Current congruity types during the Simon task, $F(1,47) = 0.908$, $p = 0.351$, $\eta^2 = 0.003$. However, there was a significant interaction between Previous and Current congruity types during the flanker task, $F(1,47) = 4.540$, $p = 0.044$, $\eta^2 = 0.024$. However, unlike what is typically expected with conflict adaptation, there was no significant difference found when congruent trials preceded congruent trials ($M = 64.60$, $SE = 10.0$) and when incongruent trials preceded congruent trials ($M = 142.50$, $SE = 10.0$), $t(45.80) = -1.34$, $p = 1.000$, nor when incongruent trials preceded incongruent trials ($M = 122.0$, $SE = 10.0$) and when congruent trials preceded incongruent trials ($M = 80.10$, $SE = 10.0$), $t(45.80) = 1.77$, $p = .496$.

ERPs.

There was no significant main effect of age nor significant interactions involving Previous and Current congruency types on $N2_D$, earlier $P3_D$, nor later $P3_D$ ($p > .05$) to indicate that conflict adaptation elicited significantly different amplitudes overall or between age groups.

Chapter 5

Discussion

The present study sought to investigate age-related differences in inhibitory function by utilizing a novel visual task combining the Simon and flanker effects. With this task, the researchers measured differences between younger and older adults on accuracy, RT, and various ERP amplitudes (P1, N1, N2, and P3) while controlling for general slowing through the use of difference waves. Although previous research has previously measured both Simon and flanker effects to investigate age-related changes in cognitive conflict (e.g. Korsch et al., 2016), none have effectively combined the two in a way that could reveal potential interactions between the two types of conflict processing. This methodological advancement allowed the researchers to directly determine (1) whether there are selective changes in Simon and/or flanker effects in older adults and (2) whether, by virtue of their interaction, the two measures of conflict processing rely on overlapping cognitive resources. Additionally, the present study aimed to measure conflict adaptation differences with the combined task through RT and ERP measures. This additional cognitive measure allowed the researchers to further investigate the integrity of cognitive control by analyzing age-related differences between trial-specific sequence effects among and between the two task types.

It was important to first ensure that the present study replicated both the Simon and flanker effects observed by previous research. As found by Simon and Rudell (1967), RTs were significantly longer during incongruent trials as compared to congruent trials, resulting in a significant Simon effect within the present study. Similarly, there was also a significant flanker effect, wherein RTs were longer to incongruent than congruent trials (e.g. Eriksen & Eriksen, 1974). Also replicating prior research, it was found that older adults had significantly larger Simon effects than younger adults, but that flanker effects were larger in younger adults.

These results are consistent with the findings of previous research. For instance, many studies have found that older adults are more susceptible to the visual Simon effect than younger adults, even after controlling for general slowing (Aisengerg et al., 2014; Castel et al., 2007; Kubo-Kawai & Kawai, 2010; Proctor et al., 2005). However, age-related differences within the flanker effect are more inconclusive. Identical to the present study's findings, Hsieh, et al. (2012) found that younger adults displayed larger flanker effects than older adults. As noted by Hsieh et al. (2012), this may be due to older adults' increased overall RT during the task to emphasize accuracy through strategic processing. The present study did find that older adults had significantly longer overall RTs while performing equivalently to younger adults, providing support for the notion that older adults' increase in RT may have been strategic in nature. Another explanation provided by Kubo-Kawai and Kawai (2010) is that older adults are less able to discern relevant and irrelevant information from the same stimulus. Unlike the flanker task, the Simon task utilizes one stimulus to portray relevant and irrelevant information. It is possible that older adults have increased difficulty encoding and decoding such information during top-down processing as compared to younger adults due to the increased task difficulty (Gilsky, 2007).

This potential explanation is further emphasized, for a significant interaction was found between the two tasks and age in the present study. Specifically, RTs for both age groups significantly increased when Simon and flanker incongruent trials were simultaneously presented. This finding indicates that more incongruent information results in greater inhibitory deficits for younger and older adults. However, it was also found that this super-additivity had more impact on older adults, for their RTs were significantly longer during these trials. Therefore, as Gilsky (2007) argues, increased task difficulty induced from the super-additivity of irrelevant information (Kubo-Kawai & Kawai, 2010) negatively influences cognitive control (Gilsky, 2007), especially for older adults. Moreover, Freitas and Clark (2015) discussed that combining spatial conflict with irrelevant information provides more cognitive conflict due to the influence of both conflict types during a trial.

Despite Korsch et al.'s (2016) exclusion of stimulus location within their combined Simon and flanker task, they too found that super-additivity increased RTs for both groups, especially among older adults. Thus, the present study's results provide support for the inhibitory deficit theory through RTs (Lustig et al., 2007). In conjunction, they found age-related differences could also be a result of the deterioration in older adults' frontal lobes, as suggested through the frontal aging hypothesis (Greenwood, 2000), where cortical and white matter volume has been shown to decrease in the brains of older adults (Spreng et al., 2017). However, ERPs can provide further insight as to how brain activity manifested during the present study's task.

First, contrary to the formed hypotheses, results from the present study revealed that $P1_D$ amplitudes were not modulated by the conditions of the Simon and flanker tasks. Although, as hypothesized, no age-related differences on $P1_D$ amplitudes were found for both task types separately and combined, this could have been a byproduct of nonexistent $P1_D$ amplitude changes. These nonsignificant age-related differences support previous findings which conclude that P1 amplitudes during congruency tasks are not modulated by age (Zanto & Gazzaley, 2014; Wild-Wall et al., 2008). Therefore, it can be concluded that age-related differences are not seen during early processing in both the Simon and flanker tasks (Hillyard & Anllo-Vento, 1998).

Unlike $P1_D$, there were significant differences found within the $N1_D$. Specifically, $N1_D$ amplitudes were significantly larger during incongruent flanker trials as compared to congruent flanker trials, but there were no significant differences for incongruent Simon trials. According to Di Russo et al. (2003), N1 is modulated by sustained attention, but towards stimuli that appear in the peripheral visual fields. When amplitudes significantly increase, it is thought to reflect greater cognitive control needed to suppress the irrelevant information that appears peripherally. Additionally, it was found that N1 amplitudes are only elicited when discrimination between stimuli occurs (Mangun & Hillyard, 1991). Because the flanker task includes irrelevant peripheral information, greater cognitive control would be needed in order to successfully identify relevant information, which is supported through the present study's findings as well as previously conducted studies (e.g. Hsieh & Fang, 2012). More importantly, the results also indicate that older adults had significantly larger $N1_D$ amplitudes overall, similar to findings by Hsieh and Fang (2012). These findings indicate that older adults require more cognitive control in order to successfully manage the presence of task-relevant (congruent or incongruent) flankers.

Results also revealed that significant differences for $N2_D$ occurred between the task types. For the Simon task, it was found that incongruent trials elicited significantly larger $N2_D$ amplitudes as compared to congruent trials, but no age-related differences were found. Pertaining to the flanker task, incongruent trials did not significantly elicit enlarged $N2_D$ amplitudes. However, age significantly modulated $N2_D$ amplitudes due to a significant interaction between age on the flanker effect. Results suggested that younger adults had increased $N2_D$ amplitudes during incongruent flanker trials as compared to older adults, but these comparisons were not statistically significant. Previous research has suggested that the enlarged N2 amplitude reflects increased cognitive control needed during cognitive conflict (e.g.Yeung et al., 2004), allowing for the regulation of strategy to perform the task (Folstein & Van Petten, 2008). As discussed by Kubo-Kawai and Kawai (2010), stimulus-location tasks provide two forms of irrelevant information from the same stimulus, making the task more difficult (Gilsky, 2007). Therefore, it can be argued that the Simon task requires additional cognitive control during incongruent trials, which is supported by the present study's findings as well as previous research (e.g. Melara et al., 2008; Strack et al., 2013). Even though age-related differences were not significantly present in the flanker task, younger adults may have experienced greater cognitive control as their strategy to overcome conflict while older adults relied on RT for strategic processing (Hsieh & Fang, 2012; Hsieh et al., 2012; Wild-Wall et al., 2008).

Lastly, results showed that earlier and later $P3_D$ amplitudes were significantly enhanced during incongruent trials for both the Simon and flanker tasks. Additionally, it was found that early $P3_D$ amplitudes were significantly larger when Simon and flanker incongruency were combined within the same trial, as found by Korsch et al. (2016). This super-additivity finding aligns with Grilsky's (2007) argument which states that cognitive conflict requires additional cognitive control to effectively perform a difficult task (Gilsky, 2007). Regarding later $P3_D$, there were significant age-related differences found, in that only older adults exhibited significantly increased later $P3_D$ amplitudes during incongruent Simon and flanker trials separately. However, only younger adults exhibited significantly increased later $P3_D$ amplitudes during trials that contained both Simon and flanker incongruency simultaneously. As Kok (2001) notes, decreased P3 amplitudes during cognitive conflict indicates that additional mental resources are needed to accomplish the difficult task. Because older adults exhibited greater $P3_D$ amplitudes when conflict was presented separately for each task and younger adults did not, older adults displayed increased cognitive control (despite the fact that their RTs were significantly longer overall), indicating that the task was more difficult for older adults as compared to younger adults. When more incongruent information was presented during simultaneously presented Simon and flanker incongruent trials, older adults needed to recruit additional mental resources while younger adults did not. This insinuation is supported by the present study which found that older adults exhibited greater electrical activity during the $P3_D$ time window in the frontal lobe as compared to younger adults who displayed greater electrical activity in the central lobe. It is important to note that P3 amplitude typically appears in the anterior aspect of the frontal lobe (Friedman, Cycowicz, & Gaeta, 2001), which is where the younger adults displayed the greatest amount of activation. Therefore, it can be concluded that older adults experienced greater inhibitory deficits during later processing, especially when super-additivity was presented. Thus, these findings provide ERP support for the inhibitory deficit theory (Lustig et al., 2007); older adults are more susceptible to distracting information, leading to deficits in deletion and impairing their ability to overcome cognitive conflict.

Regarding conflict adaptation findings in RT, the present study found that only significant conflict adaptation was present in the Simon task, where reaction times were shortest when incongruent trials preceded the current trial as compared to when congruent trials preceded the current trial. Previous studies have also found that conflict adaptation occurred during the Simon task (e.g. Chen & Melara, 2009). These findings suggest that adjustments were made for later Simon trials depending upon the conflict type in the current Simon trial (Gratton et al., 1992; Ullsperger et al., 2005). Therefore, it can be thought that conflict adaptation is another assessment of cognitive control during cognitive conflict (Botvinick et al., 2001), in which greater cognitive control was needed during sequential effects in the Simon task. This, again, could be due to the fact that the Simon effect induces greater task difficulty (Gilsky, 2007) with its inclusion of relevant and irrelevant information within the same stimulus (Kubo-Kawai & Kawai, 2010). However, as hypothesized, there were no significant age-related differences during conflict adaptation in either of the two tasks, which have been supported by previous research (e.g. Larson et al., 2016; Lemaire & Hinault, 2013; Yano, 2011).

During combined Simon and flanker trials that contained sequential effects, the present study found that older adults had significantly longer RTs overall as compared to younger adults. However, there were no significant findings to indicate that super-additivity took place during conflict adaptation among or between younger and older adults. This finding could have been a result of the present study's task; Chen and Melara (2009) found that the manipulation of frequency modulated conflict adaptation findings, where fewer incongruent trials significantly enhanced conflict adaptation effects. Therefore, since the present study's task randomized the presentation of trial conditions, it may not have been manipulated to suit conflict adaptation investigation.

Unlike the previous finding, the present study found evidence to support that conflict adaptation significantly influenced $N2_D$ and early $P3_D$ amplitudes. Specifically, older adults exhibited a significant conflict adaptation effect during the Simon task, where $N2_D$ amplitudes were larger when congruent trials preceded incongruent trials. But there were no other significant differences between age or in the flanker task. According to the conflict monitoring theory (Botvinick et al., 2001), conflict adaptation effects are a reflection of of the implementation of cognitive control in response to recent task demands, which could have been increased due to Simon's dual information-relevancy involvement (Kubo-Kawai & Kawai, 2010). Pertaining to early $P3_D$ amplitudes, conflict adaptation was found only in the central region for all participants across task type, but the reported means did not provide evidence to support relevant conflict adaptation effects. However, late $P3_D$ amplitudes among and between younger and older adults for all task type conditions were found to be nonsignificant. This pattern was also found during trials that contained both Simon and flanker congruency effects. These findings again could be due to limitations in the present study's task, for Chen and Melara (2009) discuss that conflict adaptation can be greater elicited through frequency manipulation. However, it is important to note that the age groups showed differences in localization; $N2_D$ and early and late $P3_D$ amplitudes manifested within different regions of the brain for younger and older adults during conflict adaptation that occurred separately for each task type. Particularly, older adults experienced conflict adaptation effects more greatly in the frontal region as compared to the central region, where younger adults seemed to display greatest effects over central recording sites. Thus, it can be argued that older adults recruit additional resources in order to compensate for frontal lobe deterioration (Greenwood, 2000).

Implications.

This study has implications for better assisting and understanding normal aging deficits seen in older individuals. First, the present study found that older adults experience greater inhibitory deficits during cognitively challenging tasks. This is particularly the case when multiple forms of incongruent information is simultaneously presented, where older adults exhibit both significant behavioral and electrophysiological differences during later cognitive processing stages as compared to younger adults. Specifically, both incongruent spatial information and various incongruent stimuli negatively influence cognitive control, as also found by Korsch et al. (2016). The present study also found that older adults heavily rely on time to compensate for their inhibitory deficit. This processing strategy resulted in equivalent performance on the present study's task between the age groups. Therefore, the utilization of time should be promoted as a potential strategy that older adults can use to mitigate cognitive conflict encountered during their everyday lives. For example, allotting more time can help diminish physical harm in older adults. A study by Verrel, Lisofsky, Kühn, and Lindenberger (2016) found that inhibitory deficits can occur when older adults engage in walking activity; when obstacles appear in their field of vision, inhibitory deficits can result in imbalance. This imbalancement could create potential hazard, as poor balance is associated with increased fall risk (Moylan, & Binder, 2007). Although this strategy is naturally occuring, efforts should be made to raise awareness. This is especially important in environments that have many irrelevant stimuli that could cause harm to older adults.

Moreover, results from this study support the notion that inhibitory function is a unitary mechanism, but task demands and task types can modulate deficits seen during inhibition. As found in the present study, inhibitory deficits were greater in the context of Simon conflict as compared to flanker conflict in older adults. Although findings were identical to Korsch et al (2016), they concluded that inhibitory function is comprised of multiple mechanisms due to the different behavioral and electrophysiological findings between the Simon and flanker tasks. However, the present study found that the occurrence of both Simon and flanker conflict effects resulted in super-additivity; inhibitory deficits were greater for both age groups, but especially in older adults. Therefore, more research needs to be conducted to verify the present study's interpretation of the findings. This verification is important for the field of cognitive neuroscience in order conclusively identify the underlying mechanism(s) of inhibitory function to later be used as benchmarks for the measurement of cognitive change and deficit identification.

Limitations and future directions.

The present study is not without limitations. First, younger participants within the study's sample are merely representative of college students. It would be important for future research to include younger participants who are either not college educated or are currently holding a job outside of academia to more holistically represent younger adults. Similarly, future research should include younger adults outside the ages of 18 and 21, which commonly denote the age range of college students. The present study also only included older adults over the age of 65 who had no clinical diagnosis of cognitive impairment (i.e. MCI or dementia). In the future, research should consider measuring inhibitory function during a combined Simon and flanker task between healthy older adults and older adults with a clinical diagnosis of cognitive impairment to further understand abnormal cognitive decline in inhibition. Moreover, more research needs to explore inhibitory function longitudinally to better identify how inhibitory deficits manifest during the aging process. This is especially important considering the present study's sample consisted of highly educated older adults.

Another limitation in the present study was that the novel task used may not have successfully manipulated sequential effects to elicit conflict adaptation. Future research should consider manipulating frequency to better determine if conflict adaptation between and within the Simon and flanker tasks are modulated by age. Moreover, although the present study found significant flanker effects, there were only two flankers that ever appeared simultaneously on the screen. Future research should include more flankers during a combined Simon and flanker task to determine if greater irrelevant information further contributes to inhibitory deficits in younger and older adults.

This study was also limited in that it only measured four types of ERPs (P1, N1, N2, and P3) through amplitude differences. Future research should also explore whether there are age-related differences within ERP latencies by using a combined Simon and flanker task. Furthermore, future research should measure the lateralized readiness potential (LRP) component to investigate motor preparation differences between younger and older adults during a combined Simon and flanker task. Additionally, measuring the error related negativity (ERN) potential would also provide further insight into age-related differences in inhibitory function as well as differences between the Simon and flanker tasks. Lastly, measuring correlations between RTs and ERP amplitudes and/or latencies would provide insight as to how these measures are associated with one another.

Conclusions

Inhibitory function greatly impacts older adults and their ability to effectively perform daily tasks. Therefore, it is important to identify how cognitive conflict manifests in the brain to then detect and measure cognitive impairment in older adults throughout the aging process. Although the present study found evidence to support that inhibitory function is a unitary mechanism through the finding of super-additivity, more research needs to be conducted in order to more conclusively support this proposition.

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Table 1.

Demographic information (%)

Age Group	VI	CE	A	PM	HA	Seizure	Stroke	C
Younger adults	55	50	25	29	0	0	0	25
Older adults	92	93	42	96	4	8	0	21

Note: VI = vision impairment; CE = cognitive eyewear; A = astigmatism; PM = prescription medication; HA = hearing aids; C = Concussion.

Table 2

Electrodes and latency windows for measurement of ERP components

ERP	Latencies (ms)	Isolation Technique
N1	110 to 175	Difference waveform (deviant- standard)
P1	70 to 110	Difference waveform (deviant- standard)
N2	180 to 300	Difference waveform (deviant- standard)
Earlier P3	400 to 600	Difference waveform (deviant- standard)
Later P3	430 to 775	Difference waveform (deviant- standard)

Figure 1. Simon and Flanker Task

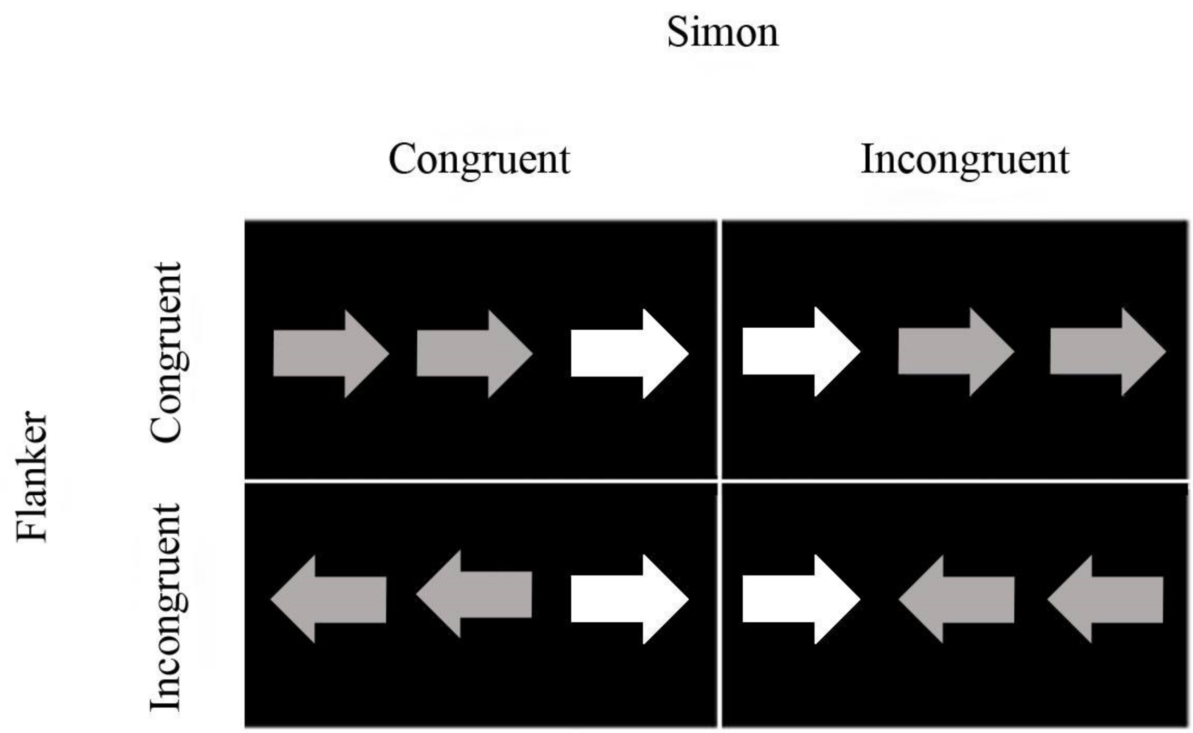


Figure 1. The combined Simon and flanker task used in the present study.

Figure 2. Age-related Differences in Novel Task

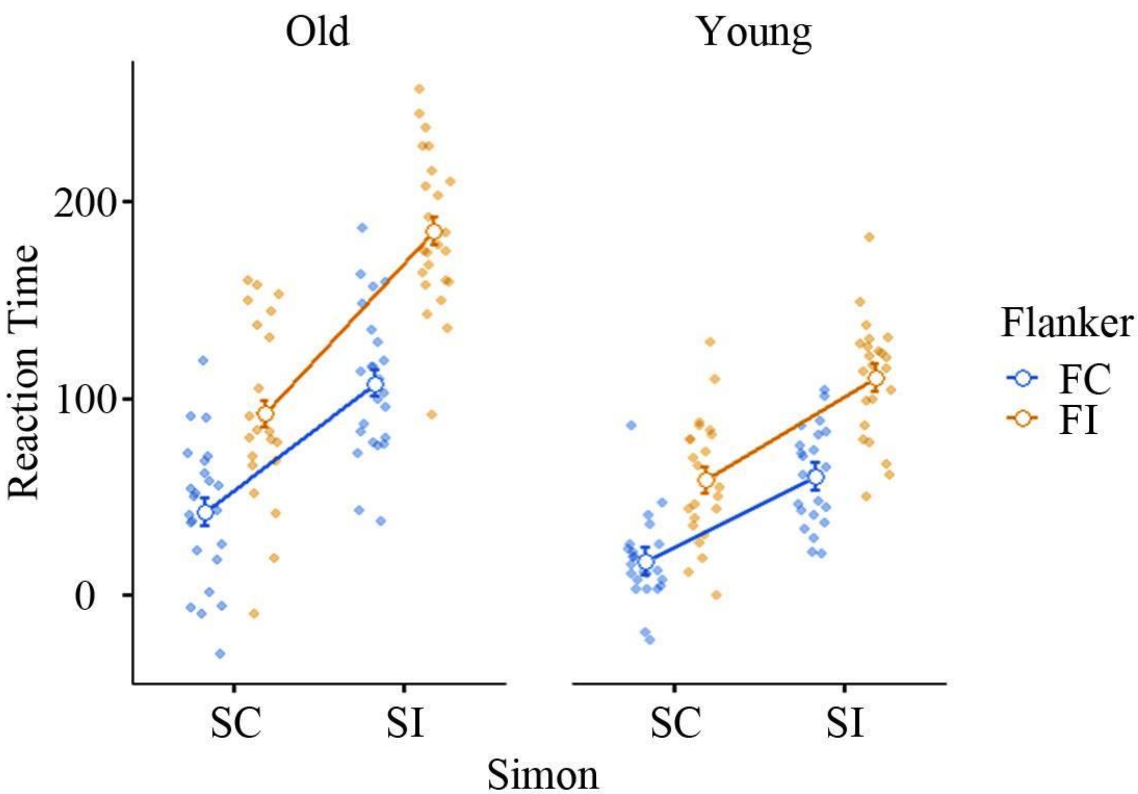


Figure 2. The significant interaction between Simon and flanker congruency between younger and older adults on reaction time. Older adults experienced significantly greater SIFI conflict as compared to younger adults.

Figure 3. Age-related Differences in Earlier P3 Amplitude on Simon

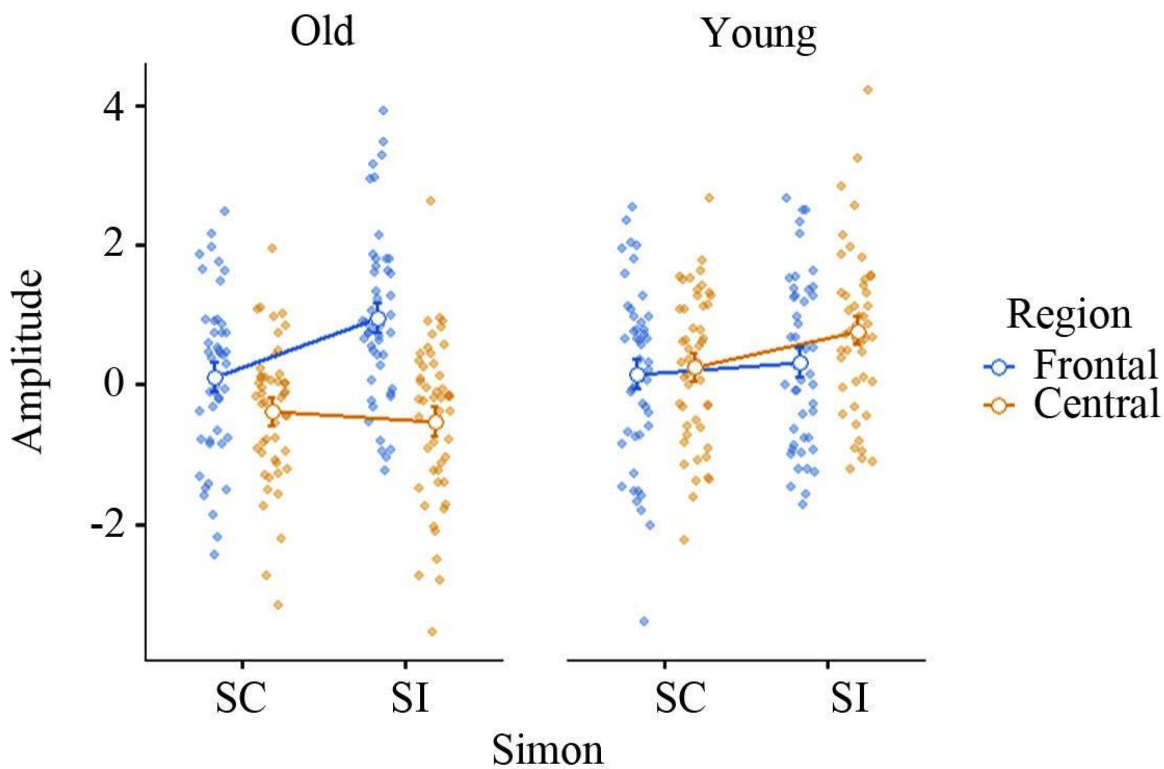


Figure 3. The significant three-way interaction between Simon, Region, and Age on the overall early P3 amplitude. Importantly, older adults experienced more cognitive conflict in the frontal region as opposed to the central region, while younger adults experienced greater cognitive conflict in the central region.

Figure 4. Age-related differences in Earlier P3 Amplitude on Flanker

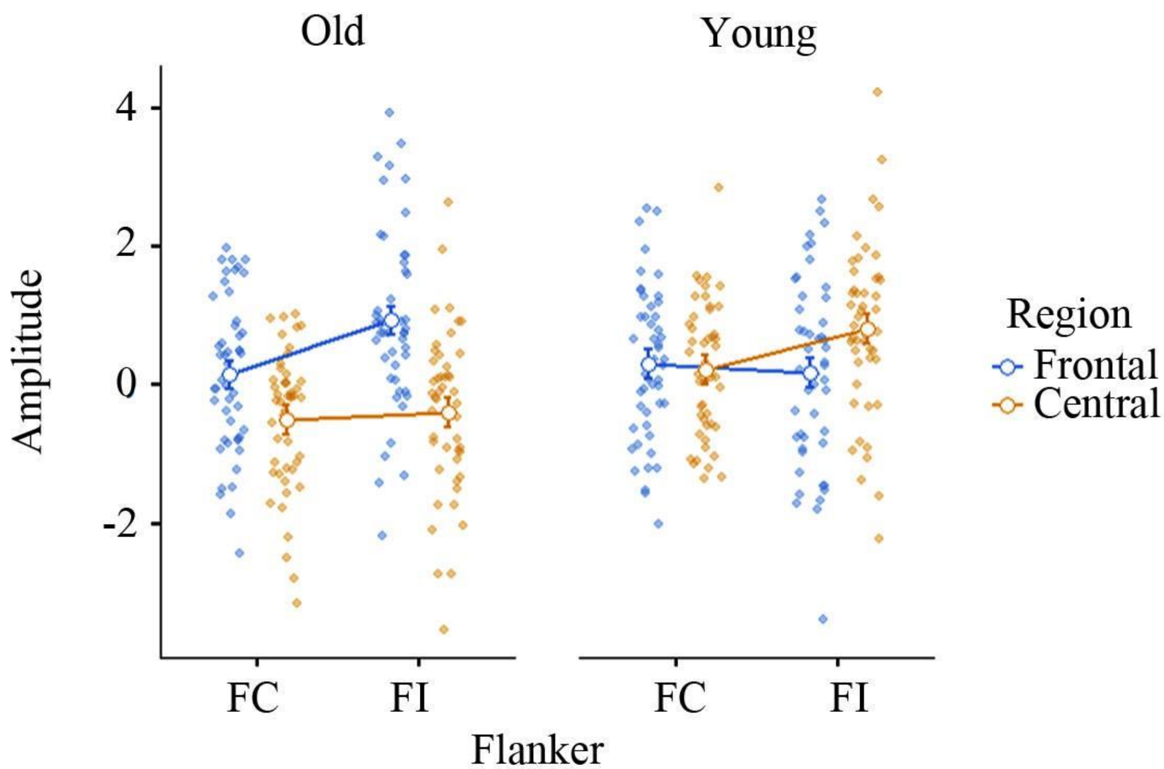


Figure 4. The significant interaction between Flanker, Region, and Age on the overall early P3 amplitude. Of importance, older adults experienced greater cognitive conflict in the frontal region as compared to younger adults who experienced greater cognitive conflict in the central region.

Figure 5. Age-related Differences in Later P3 Amplitude.

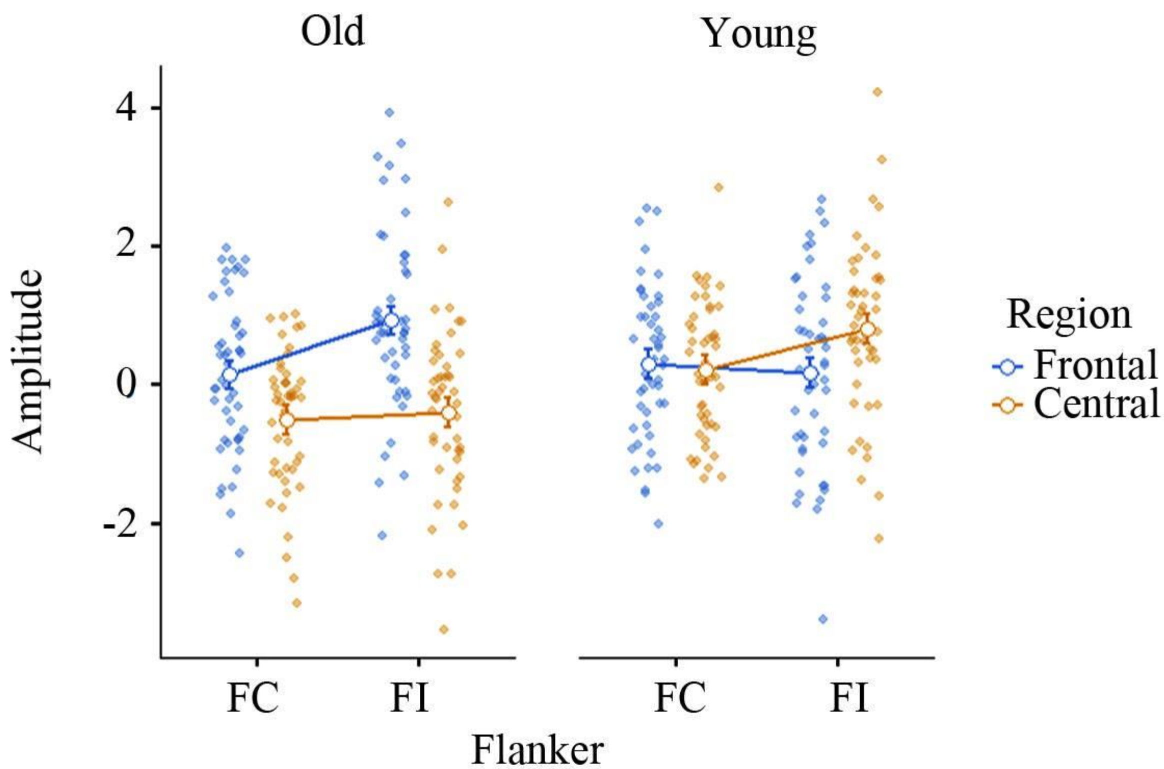


Figure 5. The significant three-way interaction between Simon, Flanker, and Age on the later P3 component. Older adults experienced greater cognitive conflict in the frontal region as compared to younger adults who experienced greater cognitive conflict in the central region.

Figure 6.

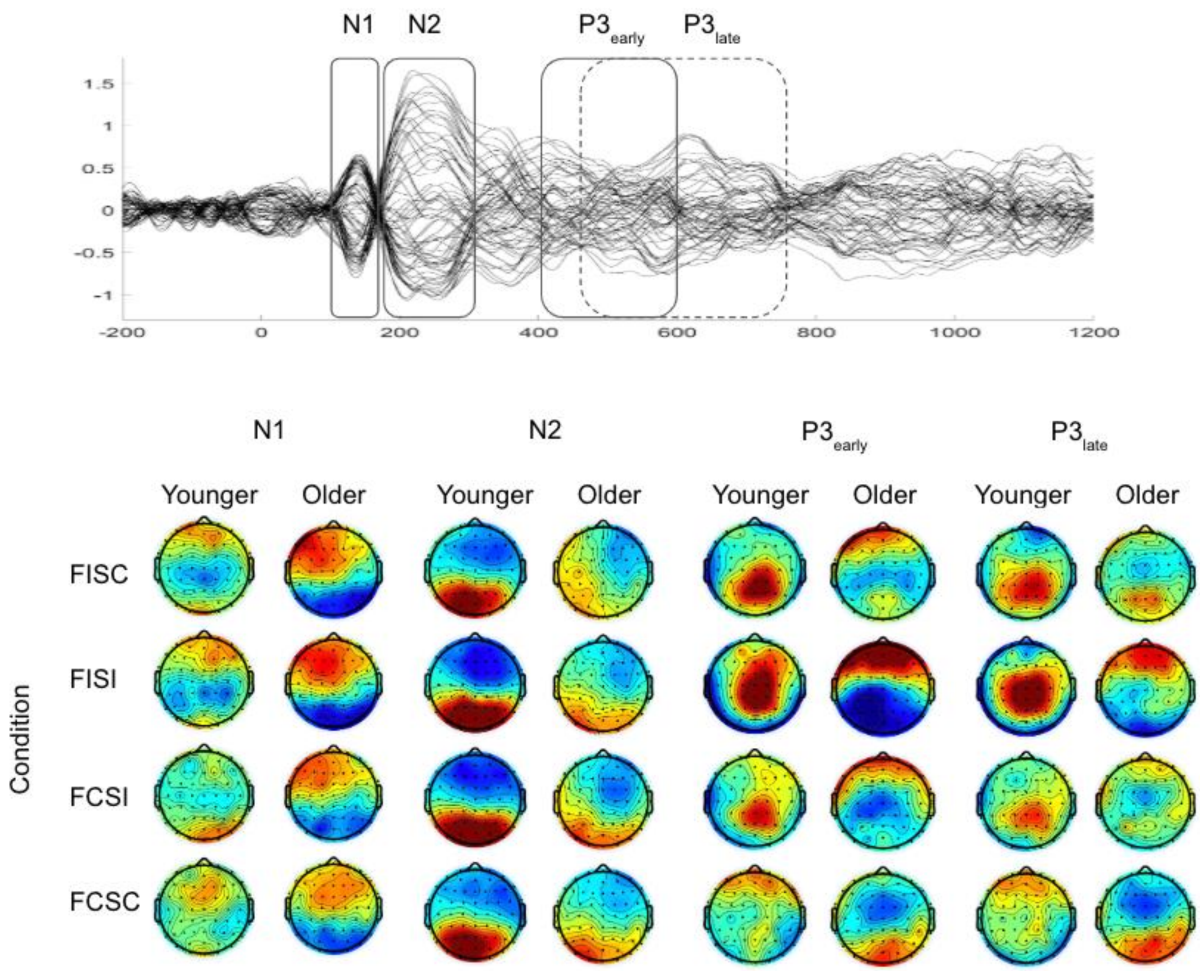


Figure 6. (Top) Butterfly plot of ERP difference waveforms averaged over FCSI, FISC, FCSC, and FISI conditions. Epochs of interest are highlighted. (Bottom) Topographical maps of mean ERP difference amplitude for each epoch of interest, experimental condition, and participant group.

Figure 7.

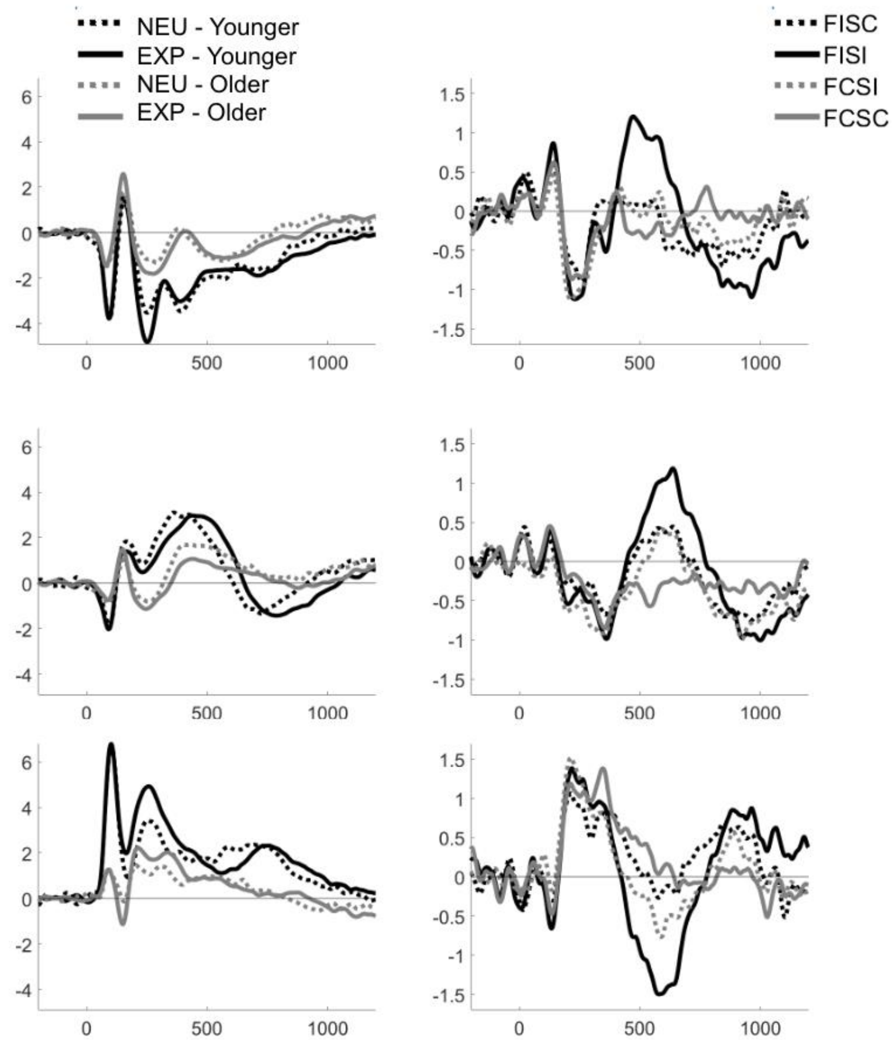


Figure 7. (Left) Grand average ERPs from a subset of midline electrode sites, time-locked to stimulus onset and averaged over experimental (EXP) conditions for Younger and Older adults. Dotted lines represent the grand averages of the conflict-neutral FNSN (NEU) used as a baseline for data analysis. (Right) Difference waveforms (e.g., EXP-NEU) averaged over all participants for each of the four experimental conditions separately. (Right) These averages were measured at Fz, Pz, and Cz respectively.

Figure 8. Conflict Adaptation Effects in Older Adults on $N2_D$**.**

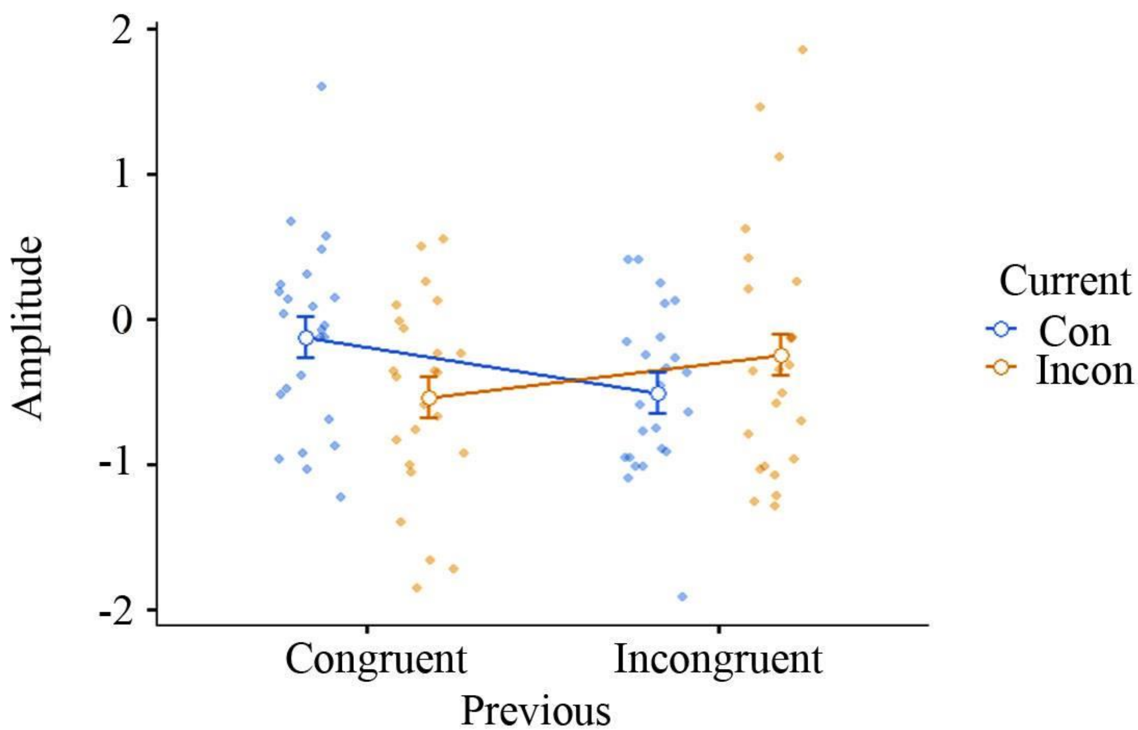


Figure 8. The significant interaction between Previous and Current congruency trial types in older adults measured with the $N2_D$, demonstrating significant conflict adaptation effects in the Simon task.

APPENDIX A

Filtered 2x2x2 Mixed Measures ANOVA Results

To ensure that older adults who scored lower than the threshold of 25 points on the MoCA assessment (Nasreddine et al., 2005) did not influence the significant Simon and flanker effect findings, two separate 2 (Simon: congruent/incongruent) x 2 (Flanker: congruent/incongruent) mixed measures ANOVAs were run where all older adults were included in analyses and then only those who scored over the threshold of 25 points. For all older adults, it was found that there was a significant main effect of Simon, $F(1,47) = 124.10$, $p < .0001$, $\eta^2 = 0.381$, flanker, $F(1,47) = 96.10$, $p < .001$, $\eta^2 = 0.247$, and a significant interaction between Simon and Flanker, $F(1,47) = 10.6$, $p = 0.003$, $\eta^2 = 0.012$. After filtering out older adults who scored lower than 25 points, there was still a significant main effect of Simon, $F(1,47) = 110.10$, $p < .001$, $\eta^2 = 0.347$, Flanker, $F(1,47) = 75.00$, $p < .001$, $\eta^2 = 0.282$, and a significant interaction between Simon and Flanker, $F(1,47) = 15.90$, $p < .001$, $\eta^2 = 0.016$. Therefore, the inclusion of older adults with cognitive impairment does not significantly impact the present study's results.

APPENDIX B

Demographic questions

1. What is your age?
2. What is your gender?
3. What is your ethnicity?
4. What is the highest diploma/degree you obtained?
5. Please select your handedness.
6. Do you require corrective eyewear?
7. What kind of corrective eyewear do you currently wear?
8. Which best describes your vision?
9. Do you have astigmatism?
10. Are you colorblind?
11. Do you wear a hearing aid?
12. Are you currently taking any prescription medication?
13. Please list any medications you are currently taking.
14. Have you or any members of your immediate family been diagnosed with a psychiatric condition such as depression, bipolar disorder, obsessive-compulsive disorder etc.?
15. Please list any psychiatric conditions you have had.
16. Please list any psychiatric conditions in your immediate family.
17. Have you ever had a seizure?
18. Have you had a seizure in the last (year, two years, three years, more than three years)?
19. Have you ever had a stroke?
20. How many strokes have you had in your lifetime?

21. Have you had a stroke in the last twelve months?

22. Have you ever had a concussion?

23. How many concussions have you had in your lifetime?

24. Have you had a concussion in the last year?

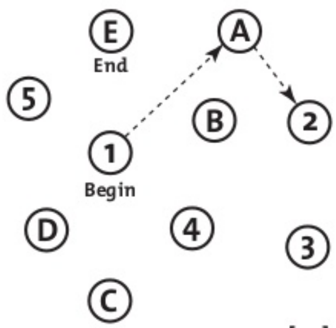
APPENDIX C

The MoCA assessment (Nasreddine et al., 2005)

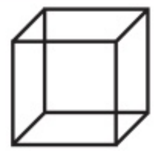
MONTREAL COGNITIVE ASSESSMENT (MOCA)

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE



[ ]



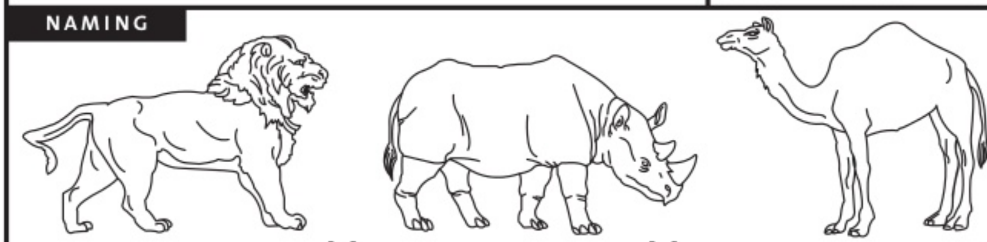
Copy cube [ ]

Draw CLOCK (Ten past eleven) (3 points)

[ ] Contour [ ] Numbers [ ] Hands

POINTS __/5

NAMING



[ ] [ ] [ ] __/3

MEMORY

Read list of words, subject must repeat them. Do 2 trials. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION

Read list of digits (1 digit/ sec.). Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2 __/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B __/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt** __/3

LANGUAGE

Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ] __/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] ____ (N ≥ 11 words) __/1

ABSTRACTION

Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler __/2

DELAYED RECALL

Has to recall words WITH NO CUE	FACE	VELVET	CHURCH	DAISY	RED	Points for UNCUED recall only
	[ ]	[ ]	[ ]	[ ]	[ ]	__/5
Optional: Category cue						
Optional: Multiple choice cue						

ORIENTATION

[ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City __/6

© Z.Nasreddine MD Version November 7, 2004
www.mocatest.org

Normal ≥ 26 / 30 TOTAL __/30
Add 1 point if ≤ 12 yr edu

APPENDIX D

Cognitive Functioning Self-Assessment Scale (CFSS)

(Annunziata, Muzzatti, Giovannini, & Lucchini, 2012)

1. Lack of concentration
2. Absent-mindedness
3. Difficulty in performing two tasks simultaneously
4. Difficulty in performing mental calculation
5. Tip of the tongue phenomenon
6. Absent-mindedness during intellectual/cognitive activities
7. Difficulty in organizing extra-routine activities
8. Difficulty in recalling recent information
9. Difficulty in recalling old information
10. Difficulty in recalling autobiographical events
11. Forgetfulness
12. Lack of concentration while reading
13. Lack of motor coordination
14. Slowness in the execution in movements
15. Difficulty in finding the appropriate words
16. Use of periphrases or generic terms instead of specific words
17. Difficulty in spatial orientation
18. Difficulty in temporal orientation

APPENDIX E

3x3x2 Mixed ANOVA Results

Despite the fact that the present study was interested in effects related to the calculated differences between trials containing conflict and baseline, a complete factorial was run. This allowed the researchers to determine whether the present study exhibited the Simon and flanker effects in RT for both younger and older adults. The repeated measures ANOVA revealed a significant main effect of Simon ($F(2,46) = 261.79$, $p < .001$, $\eta^2 = 0.081$), where SI trials (M = 669, SE = 11.6) were significantly longer than SC trials (M = 603, SE = 11.6), $t(92) = -17.14$, $p < .001$ and SN trials (M = 586, SE = 11.6), $t(92) = 21.70$, $p < .001$. It was also found that SC trials were significantly longer than SN trials, $t(92) = 4.56$, $p < .001$. A significant main effect was also found for flanker ($F(2,46) = 264.50$, $p < .001$, $\eta^2 = 0.004$), where FI trials (M = 656, SE = 11.6) were significantly longer than FC trials (M = 607, SE = 11.6), $t(92) = -17.19$, $p < .001$ and FN trials (M = 594, SE = 11.6), $t(92) = 21.83$, $p < .001$. Additionally, FC trials were significantly longer than FN trials, $t(92) = 4.64$, $p < .001$. Lastly, a significant main effect was found between older (M = 703, SE = 16.2) and younger adults (M = 535, SE = 16.2), $F(1,47) = 54.0$, $p < .001$, $\eta^2 = 0.450$, where older adults had significantly longer RTs as compared to younger adults $t(46) = 7.35$, $p < .001$. Thus, these results demonstrate that the present study replicated the Simon and flanker effects for both age groups and that older adults have significantly slower reaction times overall.