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Aging and Cognitive Control: Discriminating Stimulus from Response Deficits of Attention

Kathryn A. Holt
College of William & Mary - Arts & Sciences

Aging and Cognitive Control:
Discriminating Stimulus from Response Deficits of Attention

Kathryn A. Holt

Lancaster, Ohio

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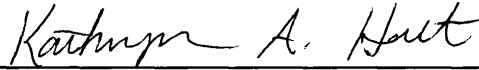
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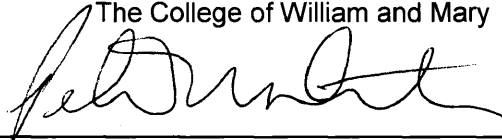
Kathryn A. Holt

Kathryn Ann Holt

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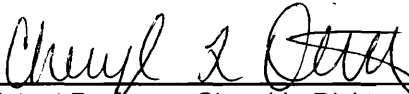
Committee Chair
Assistant Professor Paul D. Kieffaber, Psychology
The College of William and Mary

Associate Professor Peter M. Vishton, Psychology
The College of William and Mary

Assistant Professor Cheryl L. Dickter, Psychology
The College of William and Mary

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ABSTRACT PAGE

A novel paradigm was used to investigate age-related changes in the attentional- and response-selection components of task switching. While recording EEG, participants categorized pairs of figures according to one of three rules (shape, size, and color) and relayed their decisions by pressing one of two buttons. Because both the relevant dimension and response mapping changed per trial, both attentional and response processes were frequently updated. Behavioral and event-related brain potentials reveal significant differences in response components of task switching. Older participants were selectively vulnerable to response conflict as indexed by the N450 component of their ERP waveform. These results suggest that response conflict may be contributing to the task switching deficits observed in older populations.

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Aging and Cognitive Control:

Discriminating stimulus from response selection deficits of attention

Cognitive changes are well-documented in aging populations; however there is active debate regarding the trajectory of those changes and whether emerging cognitive deficits are precipitated by general or specific cognitive dysfunction (Band, Ridderinkhof, & Segalowitz, 2002). There is evidence that some cognitive functions such as contextual memory become impaired with age; however other processes, including content memory, remain intact (Simmons, Dodson, Bell, & Schacter, 2004). While this finding may suggest that cognitive change is specific to certain aspects of cognitive functions, it is also possible that elderly individuals may simply be better at compensating for the loss of certain types of cognitive abilities (Freidman, 2003; West, 2001). The primary aim of the current research is to more fully understand the specific cognitive mechanisms affected by aging. In order to accomplish this goal, this research introduces a novel task-switching paradigm that allows for more careful parsing of the underlying cognitive mechanisms in place. The following paragraphs will discuss the effects of aging on cognitive processes as well as introduce task-switching procedures and the accompanying conflict processing that is required to complete such tasks. The effects of aging on cognitive functions will be discussed throughout.

Converging evidence reveals a regional specificity for the effects of aging on the structural integrity of the prefrontal cortex, an area associated with higher order processing or executive functions (West, 1996). Synaptic atrophy, volume reduction, and neurotransmitter changes are most prevalent in the frontal lobe and are observed as early as the fifth decade (Band, 2002; West, 1996). These changes have prompted the Frontal

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Lobe Hypothesis in neurocognitive aging (West, 1996) linking deficits of executive function to age-related declines in neuropsychological test performance. Although it is unlikely that the prefrontal cortex is solely responsible for age-related changes in cognitive performance, there is an emphasis in the current literature on tasks that are thought to index the integrity of cognitive processing in the frontal cortex. For example, tasks such as the Wisconsin Card Sorting Test (WCST), Self-ordered Pointing Task, and task switching paradigms have all been used to assess executive functions and age-related deficits in older populations (Fristoe, Salthouse, & Woodard, 1997; West, 1996).

Although there is considerable agreement that age-related changes in cognitive functioning include domains such as attention and executive function, there remains debate regarding the specific mechanisms that may be involved. In part, this uncertainty is due to variance between the tasks used to index cognitive decline. For example, the Wisconsin Card Sorting Test requires participants to sort a set of cards based on one of three rules (Heaton, Chelune, Talley, Kay, & Curtiss, 1993). Rules governing behavior switch periodically and participants must keep track of the relevant rule based on the feedback they receive after making a sorting decision. With increasing age, participants exhibit more perseverative errors when completing the WCST (Axelrod & Henry, 1992). While perseverative errors are often linked to inhibition deficits (Chao & Knight, 1997), a proposed alternative interpretation to account for these results is declining processing speed and working memory, reducing older participants' ability to process and use feedback information necessary when evaluating the relevant rule (Fristoe et al., 1997).

The Stroop Task (Stroop, 1935) is another paradigm used to assess cognitive decline in the elderly. Participants view color words printed in either congruent or

incongruent ink color. Depending on the trial, participants report either the word itself or the ink color. Older participants exhibit longer reaction times and more errors when naming the ink color than younger participants (West, 1996). Poor performance on the Stroop is often interpreted as reduced inhibitory processes (West, 1996), similar to conclusions drawn from perseverative errors on the WCST. Although both the WCST and the Stroop Task evaluate executive function, clearly the two encompass different processes and cannot be explained solely by inhibition deficits. The WCST requires learning and applying rules that govern behavioral decisions whereas the Stroop task requires participants to override their natural response to read words. Both tasks are useful in revealing age-related differences in general performance; however, these tasks do not allow for a clear understanding of the underlying processes at work.

Cognitive or executive control is an example of a broad term used to describe mental flexibility associated with the selection and implementation of cognitive strategies that are appropriate for a current task (Band et al., 2002). For example, although unlimited sensory information is available, humans are adept at selectively paying attention only to information that is relevant to current goals while ignoring irrelevant information. Cognitive control is a necessary component of complex tasks such as the WCST and the Stroop task. In the context of a specific task, cognitive control is often called "mental set," referring to the ability to selectively bias information processing and has received a great deal of attention in the cognitive literature (Monsell, 2003; Rogers & Monsell, 1995). Although the specific components that comprise mental set are still in question (Hyafil, Summerfield, & Koechlin, 2009; Ruge, Braver, & Meiran, 2009), mental set has been shown to be affected in a broad range of clinical groups including

aging individuals (Band et al., 2002; Friedman, 2003) as well those with schizophrenia (Barch et al., 2001), bulimia (Álvarez-Moya et al., 2009), and autism (Shafritz, Dichter, Baranek, & Belger, 2008). Observing deficits of mental set in so many clinical groups suggests that there may be a number of critical cognitive subprocesses as it is highly unlikely that this diverse group suffers from the same neural impairment. As a result, there is increasing interest in delineating those subprocesses and understanding how each may precipitate deficits of mental set. One promising procedure used to discriminate underlying mechanisms involved in cognitive control is the task switching paradigm.

Task Switching

Task switching paradigms were developed to study the group of neurocognitive functions believed to underlie cognitive control and have been used to isolate preparatory from implementation sub-components related to reconfiguring mental set (Monsell, 2003). Although interest in task switching can be documented back to the 1800s, the original task switching paradigm is credited to Arthur Jersild (1927). Jersild timed students while they completed a variety of tasks. In some blocks students completed the same task repeatedly such as simple addition or color naming. Jersild refers to the required preparation for such tasks as mental "set" whereas a "shift" occurs when performing multiple tasks within the same block. Importantly, these "shift" blocks were associated with significant time-costs, suggesting that the process of shifting between tasks involves an additional, time-consuming cognitive process. Furthermore, Jersild concluded that not all mental shifts result in time costs. When the task requirements and accompanying stimuli were uniquely associated with each task, time costs were minimal. For example, when shifting between tasks like color naming and addition there were no

costs associated with the task switching. However, when switching between addition and subtraction wherein both tasks could be performed on the same set of number stimuli, significant switch costs occurred.

Contemporary task-switching procedures consist almost exclusively of polyvalent stimuli, affording multiple decisions for each stimulus. These decisions are typically associated with various dimensions (e.g., size, shape, color, etc.) of the stimuli (Monsell, 2003). Participants are instructed to switch their attention between these tasks/dimensions by a cue or signal. A common example requires participants to make either magnitude (greater than or less than 5) or odd/even decisions about a number (Friedman, Nessler, Johnson, Ritter, & Bersick, 2008). Countless variations of the task switching paradigm exist, with modifications on the cueing method, stimuli, decisions, and response mapping components (Monsell, 2003).

Task switching paradigms are often comprised of blocks of trials. The tasks or rules guiding decisions may vary between blocks (Monsell, 2003). Single-task blocks require participants to perform the same task on all trials, (e.g. decide if the number is greater/less than 5). A mixed block requires participants to switch between multiple tasks as directed by a cue or pattern (e.g. every third trial switch from the current rule to another). Importantly, these block types have been associated with corresponding costs of task-set switching. First "general switch costs" or "mixing" costs, refer to an increase in reaction time and decrease in accuracy when repeating two consecutive trials of the same task within a mixed block compared to repeating two consecutive trials of the same task within a single block (Kray & Lindenberger, 2000). The second cost, "specific switch cost," refers to the increase in reaction time and decrease in accuracy when switching

between two different tasks on consecutive trials in a mixed task block compared to

repeating the same task on consecutive trials within a mixed block (Kray &

Lindenberger, 2000). Whereas mixing costs are thought to measure the additional

resources recruited to prepare for multiple tasks, specific switch costs are thought to

measure the shifting of mental processes, or mental sets (Monsell, 2003).

Task switches encompass multiple processes and are not as simplistic as first

thought. When completing task switches, cognitive processes must refocus attention on

the now relevant dimension, filter irrelevant information regarding the previous task-set,

retrieve the current appropriate task-set from working memory, and implement the

current rule in order to make a correct decision (Friedman et al., 2008). The exact

mechanisms at work during this process and the relationship between these mechanisms

continue to be a topic of considerable debate. One commonly used method to explore the

mechanisms of cognitive control is to determine its psychophysiological correlates

(Hyafil et al., 2009; Kieffaber & Hetrick, 2005).

Event-related Potentials and Task Switching

Event-related potentials (ERPs) derived from electroencephalography (EEG) are

often used in addition to reaction times to measure cognitive components related to task

switching. As participants complete a cognitive task, electrodes affixed to the scalp

record electrical brain activity that is thought to be the result of the summation of

postsynaptic potentials (Luck, 2005). The raw data recorded from the electrodes can then

be segmented with respect to a time-locked event occurring within the task, such as the

presentation of a cue or target. The collection of data segments (or "epochs") can then be

averaged within each participant and across all participants in order to create grand

average waveforms. Since ERP waveforms are averages of multiple trials and multiple individuals, components of the resulting form are believed to reflect the cognitive processes that are unique to the processing of the time-locking event used to collect the data epochs. Irrelevant processes and noise from the environment are cancelled out through the averaging process (Luck, 2005).

Positive and negative deflections of this grand average waveform, labeled components, are named and analyzed with regard to their amplitude and latency (Luck, 2005). Component names usually begin with an "N" or "P" to reflect negative or positive amplitude followed by the peak's time course in milliseconds or the position within the waveform, (e.g. the first positive peak is labeled P1). Components can be divided into two categories, exogenous and endogenous (Luck, 2005). Exogenous components, N1, P1, P2, occur early within an epoch and are believed to index early visual processing dependent on the presentation of the stimulus (Luck, 2005). Endogenous components occur later within the epoch and represent internal cognitive processes relating to the processing of information represented within the stimuli.

Grand average ERP components must be interpreted with caution as they are averages of the latent or underlying components (Luck, 2005). When averaging components both timing and amplitude of the latent components are distorted. Therefore fixating on peak amplitudes and exact latencies should not be the focus of analysis. Proactive measures however can be taken in order to most reliably interpret waveforms. Choosing a few, large components of interest to test is best. Also, using a clean experimental design that introduces the least amount of noise and manipulates only the psychological processes of interest will likely lead to more reliable components.

One such EEG component often cited as an index of task switching is the P3 or

P300 (Kieffaber & Hetrick, 2005; Kray, Eppinger, & Mecklinger, 2005; West, & Travers,

2008). Due to variations of timing and location of this component, the P3 family is often

discussed (Luck, 2005). However, the P3 family shares common characteristics

suggesting the variations are indexing similar processes. The P3 is largest over parietal

sites occurring between 250 and 900ms after stimulus onset (Andreassi, 2007). Many

tasks elicit a P3 component and therefore it is often interpreted simply as an information

processing component (Andreassi, 2007).

In the task switching literature, a cue-locked P3 component has been linked to

preparation for upcoming trials with greater positivity for switch compared to stay trials

(Kieffaber & Hetrick, 2005). The component is commonly divided further into P3a and

P3b (Friedman et al., 2008). P3a is an earlier positive deflection occurring around 300-

400 ms after stimulus onset and is more frontally oriented. This component may represent

early attentional capture and orientation to the upcoming task (Friedman et al., 2008).

The P3b component occurring more posteriorly and between 400 and 800 ms post-

stimulus, has been proposed to reflect the updating of the mental set needed as

participants switch between tasks (Friedman et al., 2008).

Contingent negative variation (CNV) is also a component of interest in the task-

switching literature. This negative slow wave, typically observed following task cues and

before target presentation, is believed to index preparation or expectancy of the upcoming

target (Andreassi, 2007). Although the specific underlying processes are unclear, both

response and mental set preparation result in CNV-like waveforms and can be

conceptualized as aspects of updating or maintaining task set (Andreassi, 2007). In task

switching paradigms this component is found for both switch and stay trials and the amplitude may be greater with increased uncertainty of the upcoming stimulus (Forstmann, Ridderinkhoff, Kaiser, & Bledowski, 2007).

West and Travers (2008) used a novel task design to investigate the underlying components encompassed in task switches. After seeing a cue, these authors propose that participants engage in three processes to prepare for a switch; cue retrieval, task set configuration, and rule mapping. Using two different cues for each task, West and Travers included three trial types, cue repetitions (both cue and task repeat), task repetitions (cue changes but task remains the same), and task alternations (both cue and task change). The differences between cue repetition trials and task repetitions were used as an index of cue retrieval and the differences between task repetitions and task alternations were viewed as an index of task set configuration and rule mapping. In this study, a P3 component was elicited for switch trials, a slow wave parietal positivity for cue retrieval, and a parietal/frontal-parietal slow wave was observed for task set configuration or rule mapping. The distinct components support the hypothesis that separate processes occur during task switching paradigms.

Current research attempts to understand which ones of these processes are leading to the switch costs commonly observed (Monsell, 2003). One theory is that the mechanism that refocuses attention and prepares for the new task, what West and Travers (2008) labeled task set configuration, may be precipitating switch costs (Monsell, 2003). Another possible explanation proposes the previous task-set interferes with the current relevant set and a "task-set inertia" is experienced and must be overcome (Allport et al., 1994).

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Method of cuing is one design component that is often manipulated within a task in order to test the possible origin of switch costs. Past research has increased cue duration in an attempt to reduce switch costs with a longer preparatory period (Monsell, 2003). Although switch costs are often diminished, a residual cost remains after an initial cost decrease, suggesting that task-set preparation is not the only influenced component within a switch. Instead, the likelihood that many overlapping cognitive processes influence switch costs is gaining support (West, 2004).

Effects of Aging on Task Switching

The effects of aging on switch costs and their corresponding ERP components may provide insight into the underlying mechanisms and trajectory of cognitive decline in the elderly. Some studies have revealed that, after controlling for general slowing, older individuals show increased general switch costs but not specific/mixing costs (West & Travers, 2008). This finding has been interpreted by some to be a measure of working memory deficits in the elderly (West & Travers, 2008). West & Travers (2008) argue that the mixed task blocks require maintaining multiple task sets in working memory while implementing only the relevant set. Interestingly, the authors also observed increased activation over frontal regions during mixed blocks, suggesting that older adults recruit additional resources in this region in order to successfully complete task switches.

Although West and Travers (2008) support a theory of working memory decline evidenced by increases in general switching costs, other authors argue that specific costs, indexing unique cognitive processes, are also affected by aging and these costs are revealed when working memory load is reduced and switches are unpredictable (Friedman et al., 2008). In a task that was deigned to incorporate trials with increasing

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levels of executive processing, the authors observed specific or mixing costs, but not the general costs shown in other studies (West & Travers, 2008). For example, Friedman and colleagues (2008) designed a task in which four levels of attentional allocation were needed. "No switch trials" or "repeat trials" in a single task block were the least taxing, followed by "pre-switch trials" in a mixed block, "post-switch trials" in mixed blocks, and "switch trials" in mixed blocks. The results revealed that older adults show a more widely spread P3a component that was elicited for trials that did not demand such an attentional shift in younger participants (stay, pre-switch, post-switch). The P3b, indexing task set updating, was greater for all task types in the elderly, however this pattern was only shown for switch trials in younger participants. Again the authors interpret these findings to suggest that older participants recruit more or greater resources for trial types that are not as taxing in the younger group as more resources are needed for task updating.

In contrast, Kray and colleagues (2005) found general but not specific switch costs were greater for the elderly when performing a Stroop task. P3 latencies were delayed for the older participants, although no differences in amplitude were found, older participants' P3s did peak at more frontal locations. The authors also found greater CNV following task switches in elderly but not for young participants, believed to index task maintenance and response preparation. Kray and colleagues (2005) interpret these findings as evidence the recruitment of more frontal regions for updating task context and suggest that elderly also engage in motor preparation during trials that do not elicit such preparation in younger participants.

Importantly, switches in the Kray et al. study (2005) were strictly between attentional components of the tasks, shifting attention from either the word or ink color of the Stroop stimulus. Other tasks incorporate response-oriented switches. One such study investigated the effects of aging when both attention and response switches were incorporated into the design (Hahn, Anderson, & Kramer, 2004). Contrary to predictions, switches on both dimensions did not result in the longest reaction time trials. Task switches were longest for both age groups, however older participants exhibited greater reaction time costs for response switches compared to younger participants (Hahn et al., 2004).

The varied results associated with task switching and the accompanying costs are potentially caused by differences in procedural design. The multitude of varying factors within designs likely changes the cognitive operations in question and leads to difficulty when comparing behavioral and physiological results. Method and duration of cuing, feedback, valencey of stimuli, task type, response method, and response mapping all vary from study to study. Although these design inconsistencies are often the result of attempts to increase our understanding about the specific mechanisms of task-switching, they make it difficult to integrate results across studies.

Conflict Processing

Task switching procedures offer another avenue for investigating cognitive functions. Because task stimuli are polyvalent, they engender both relevant and irrelevant information. When a given stimulus contains features that are associated with incompatible responses (e.g., the word RED written in green ink) that stimulus is said to recruit specialized "conflict processing" in order to negotiate the response alternatives. Conflict processing is generally thought to be a top-down mechanism that is directed by

environmental cues and includes the selection of relevant stimuli and responses while inhibiting or filtering irrelevant dimensions (MacDonald, Cohen, Stenger, & Carter, 2000). The Stroop Task (Stroop, 1935) is the classic example of conflict processing. Participants must either report the color of the ink in which the word is printed, or the lexical identity of the word itself and these two dimensions may be congruent or incongruent. Effects of conflict are evidenced in the behavioral components of task switching studies. Target stimuli with high conflict (i.e., "incongruent") are associated with longer reaction times and lower accuracy rates (Kray et al., 2005; West, 2004; West & Bell, 1997). These reaction time costs likely represent the inhibitory or filtering process whereas the higher error rates reveal the limited capacity of the cognitive control processes at work (MacDonald et al., 2000).

Within the task switching literature most tasks include bivalent stimuli to reveal not only the behavioral effects, but also the neural mechanisms recruited for conflict processing. There is evidence that the dorsolateral prefrontal cortex (DLPF) and the anterior cingulate cortex (ACC) serve to detect and monitor conflict in information processing (MacDonald et al., 2000). Whereas the DLPFC may function as a top-down process, filtering out irrelevant information (MacDonald et al., 2000) the ACC may act as a feedback loop, monitoring conflict and exhibiting greater activation when more conflict is embedded within a stimulus (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999).

Event-related potentials and conflict processing

Electroencephalography is one method used for researching the components of conflict processing. A variety of ERP components are proposed as indexes of conflict detection and monitoring. These components are generally target- or stimulus- locked and

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occur throughout the epoch. The N2 and N400 are negative deflections appearing between 200-600 ms after stimulus onset (West, 2004; West, Bowry, & McConville 2004). These components are generally thought to relay conflict detection as they become more negative with increased conflict. Finally, a sustained positivity (SP) has also been proposed as a measure of conflict resolution and is observed as a parietal positive deflection (West, 2004).

Although conflict within the stimulus is often the focus of task switching studies, conflict may also exist in the task responses (Monsell, 2003). Another form of response conflict exists when multiple decisions are mapped onto the same response (button press); therefore each button represents different decisions depending on the relevant dimension. Although many tasks include bivalent response mappings (Friedman et al., 2008; Ruge et al., 2009), rarely is the bivalent mapping factored into analyses.

More recently researchers have investigated the cognitive components associated with processing response conflict (Nessler, Friedman, Johnson, & Bersick, 2007; Wendt, Heldman, Münte, & Kluwe, 2007; West et al., 2004). Response conflict is sometimes used to reference conflict that exists within the stimulus that activates an incorrect response (Aarts, Roelofs, & van Turennout, 2009; West et al., 2004). For example, if the word "right" is embedded in a left facing arrow the appropriate response for the trial is conflicting (Aarts et al., 2009). Stimulus conflict, on the other hand, is elicited by incorporating a dimension that is irrelevant to current responses, for example if the word "right" was embedded in an arrow that pointed upward, however no upward button press was part of the task design.

Findings regarding this form of response conflict are in disagreement. While some researchers suggest that ACC activation is sensitive to response conflict (Milham et al., 2001) others find that both task and response conflict reflect similar neural components (West et al., 2004). West and colleagues (2004) used a digit counting design in which participants had to identify the number of elements on the screen. In neutral conditions the elements were x's however the elements could also be numbers (e.g. 1's). Element length could range from 1-4 and sometimes the elements used were the numbers 1-4 (incongruent eligible) while other times the elements were 5-7 (incongruent ineligible). To respond, participants had to press one of four keys, each key representing a different number (1-4). The results suggest that a N450, conflict detection component, was present for both incongruent eligible and incongruent ineligible trials. The authors interpretation of this finding is a neural generator, likely the ACC, is activated for both stimulus and response conflict. Similar findings are reported by Wendt and colleagues (2007) using a different paradigm. In their study Wendt et al. used a flanker task with four stimuli responses mapped onto two buttons. The N2 component showed greater negativity for both stimulus and response conflict (Wendt et al., 2007).

Other authors have attempted to separate neural processes related to the attentional- and response-set components of task-set, addressing these types of conflict as different processes (Ruge et al., 2009). In order to tease conflict types apart, authors reverse the order of cue and target so that preparatory motor planning can be engaged before one knows which cognitive operation to perform. Ruge and colleagues (2009) showed participants letter/number pairs and asked participants to categorize the targets as either odd/even or consonant/vowel depending on the relevant stimulus. On some trials

participants would view the target before they saw the cue indicating which target letter or number was relevant. On other trials the cue indicating the relevant target appeared first. Four decision options (odd/even, consonant/vowel) were mapped onto two buttons. The authors state that distinct patterns of control emerged within this experimental design. Differential activation for attentional and response activation was revealed with fMRI.

However, confounds in the experimental design such as those used by Aarts and colleagues (2009) and Braver and colleagues (2009) make it difficult to accurately parse the different cognitive functions. Because responses mappings were bivalent but the stimuli were univalent, task cues (e.g. let or num) indicated multiple aspects of task-set. For example, a 'let' cue would not only inform the participant of the relevant stimulus, but also what judgment to make and what response mapping to follow. This overlap in given information makes it difficult to assess exactly what cognitive functions take place. Although this study begins to address the question of separate attention processes, it also reveals a need for more precisely designed experimental procedures.

Aarts and colleagues (2009) also used a design that focused on task conflict. Participants has to respond to either an arrow (pointing left or right) or the words "left" and "right" with a left or right button press. The relevant dimension, arrow or word, varied between trials. The authors' fMRI imaging results indicate that response and stimulus conflict are both represented with ACC activation; however, in the lateral prefrontal cortex (LPFC) activation for response conflict occurred ventrally whereas activation for task conflict was both ventral and dorsal. This research suggests distinct cognitive processing for handling differing types of conflict. However, again confounds

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within the design make such claims questionable. Both the arrow and the word tasks required participants to push a left or right button. Response mapping in this study never changed and therefore a complete measure of response conflict could not be assessed as participants never had to switch their response set.

Rushworth, Passingham, and Nobre (2002) designed a task that specifically targeted response mapping switches. Within this task participants responded to rectangles with left button presses and triangles with right presses. Stay cues indicated to continue responding with the same mapping while switch cues indicated to reverse the response mapping; rectangles would now require a right button press. Reaction time data revealed a significant switch costs as participants were slower after switching response mappings. After seeing a switch cue, ERPs revealed an early, central-frontal positivity (360-520 ms) and a later central-left, parietal positivity (520-1040 ms). The early positive components were localized to the dorsomedial frontal cortex and anterior medial frontal cortex. The later component was localized to a left ventromedial occipito-temporal location. Once participants implemented the task on individual shapes two distinct ERP forms were observed, one parietal-central negative component (240-280 ms) and a frontal positive component (400-920 ms).

Rushworth and colleagues (2002) discuss components related specifically to response switching and propose that before a task set is initiated, distinct components emerge for switching or maintaining task set as early as 300 ms after cue presentation. This early frontal component suggests that prefrontal cortex is involved in changing the task set before attention needs to be shifted. ERPs linked to task implementation as the

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authors refer to task completion after a cue, were shown to exhibit a N2-like component that is likely linked to response inhibition for previously mapped stimuli/response pairs.

Effects of Aging on Conflict Processing

Vallesi, Stuss, McIntosh, and Picton (2009) found that elder participants had difficulty ignoring irrelevant information as indexed by the P3 component of their ERPs. The P3 was larger for older adults when asked to respond to conflicting stimuli. In this task, participants were asked only to respond to certain stimuli (red x's and blue o's) while ignoring irrelevant distractor-targets (blue o's and red x's). The conflicting information in this task is attentional, as participants must focus on the physical dimensions of each target and evaluate their relevance.

West (2004) investigated other ERP components shown to index conflict processing in the elderly. Attenuated N450 components and greater sustained potentials over parietal sites were revealed in older participants completing a Stroop task. Although younger participants exhibited reliable N450s for all incongruent stimuli, older adults exhibited this deflection only when conflict was greatest. The, sustained positive potential, a positive parietal wave, was observed to be greater in older participants when they named the ink color of the Stroop stimulus. West (2004) interprets these findings as evidence for decline in the conflict detection abilities of older participants.

Multiple studies have also investigated age-related changes in response conflict. While older participants show patterns similar to younger groups when response conflict is minimal, greater conflict leads to age differences in the medial frontal negativity (MFN) associated with correct responses (Nessler et al., 2007).

Although the literature of task switching has grown to incorporate numerous designs and countless combinations of bivalent and univalent stimuli, there is still a need for a task design that allows for control over the proposed cognitive subprocesses within task switching. The present study addresses this limitation by introducing a novel task switching procedure that is able to control for attention and response switches and conflict with an aim to more accurately identify the components affected by cognitive aging.

Current Procedure

In the present study while recording their electroencephalography (EEG), participants categorized pairs of figures according to one of three rules: shape, size, or color. Two of the rules (shape and size) required a judgment about whether the two figures were the "same" or "different" according to the relevant rule. The third rule (color) required a decision about the color of the figure-pair (red or blue). The rules were conveyed with cues that appeared before the target figure-pair. Participants responded by moving a mouse pointer over one of two "buttons." One button represented same and blue decisions and the other represented different and red decisions. Because both the stimuli and response buttons were bivalent, the meanings of these buttons changed depending upon the current rule, requiring participants to frequently update their attentional-selection (i.e., to shape, size, or color) and/or their response-selection (i.e., same/different or red/blue) processes.

This experimental design allowed us to measure differences in response times and brain activity between switch types and congruencies. For switches, three trial types are of interest: trials when (1) the rule *and* response-meanings switch (switch attention/response), (2) only the rule switches (switch attention), and (3) when both rule

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and response-meanings repeat (stay). There are also four types of conflict: trials when (1) the relevant attentional dimension (size) and the irrelevant dimensions (shape and color) of the targets are congruent resulting in no conflicting information (e.g. both shapes were small, blue, circles: all suggesting a "same/blue" button press: no conflict), (2) the relevant same/different dimension of the stimului (size) was congruent with the irrelevant same/different dimension (shape) (e.g. both shapes were small circles: suggesting a button press of "same"), however the third dimension (color) for the two figures was incongruent or in conflict (e.g. figures were red: suggesting a "red" button press: response conflict), (3) the relevant attentional dimension (size) was congruent with the color dimension, however the other same/different dimension (shape) was incongruent (e.g. the figures were both small and blue suggesting a "same/blue" button pres, but the shapes were different suggesting a "red" button press: stimulus conflict), (4) both the irrelevant same/different dimension and the color dimension were incongruent (e.g. although the figures were the same size suggesting a button press "same," they were different shapes and red, suggesting a "different/red" button press: all conflict). See Figure 1 for a diagram of the task and examples of the four conflict types.

Hypotheses for the current procedure predict contrasting patterns for behavioral and physiological data that may differentiate older from younger participants. For switch type data, the overarching predicting pattern would suggest that with each additional switch there is an additive cost, with two switches being more detrimental (longer reaction times) than one. If this pattern results, attention switch and attention and response switch trials will show increasing behavioral switch costs. This differentiation is also predicted to exhibit different P3 component activation. Additional patterns may

emerge that will differentiate the age groups. Based on previous work (Hahn et al., 2004) older participants are expected to show a significantly larger behavioral cost for response switches compared to attentional switches. Younger participants in contrast are expected to exhibit a larger switch cost for attentional switch trials.

Conflict types are also predicted to reveal different patterns for the two age groups. In general no conflict trials are predicted to be fastest and all conflict trials the slowest, however, age differences are expected for the behavioral and physiological results for response and stimulus conflict trials. Older participants, once again are predicted to have proportionally more difficulty with response conflict and therefore we would expect response conflict trials to be significantly longer than no conflict trials. Younger participants are not expected to exhibit costs for response conflict, and instead their response conflict trials will resemble those with no conflict. Instead, the stimulus conflict trials will show the behavioral costs and take longer than no conflict and response conflict trials. The N2 or N450 ERP component would reveal processing differences for the conflict types. For the elderly, more negative components are expected for the response conflict, stimulus conflict, and all conflict trials compared to no conflict trials. Younger participants are predicted to exhibit more negative components for the stimulus and all conflict trials compared to the response and no conflict trials.

Method

Participants

Written informed consent was obtained prior to testing in accordance with the Institutional Review Board at the College of William and Mary. Twenty-two younger (16 females, age 20.2, range 18-34) and 21 older (11 females, mean age 74.6, range 64-86)

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healthy adults participated in this study. Two elderly and three younger participants were excluded due to low signal to noise ratio in the electrophysiological data. Younger participants were undergraduate students recruited from a public university; they received course credit for participation. Older participants were recruited from retirement communities and continuing education classes at the same public university and were paid for their time. Forty-one participants had right hand preference according to the Edinburgh Handedness Inventory (Oldfield, 1971). Both younger and older participants had normal or corrected to normal vision and no history of neurological of psychological disorders. Older participants differed from younger participants on three demographic measures. Older participants had obtained significantly more years of formal education (M=17.14, SD=2.15) than younger students (M=13.95, SD=.90), t(41)=6.29, p<.001. Older participants also reported more weekly activities or hobbies (M=3.80, SD=1.24) than younger participants (M=2.59, SD=1.14), t(40)=3.29, p=.002. Older participants also had slower simple reaction times (M=337.33, SD=56.89) than younger participants (M=286.79, SD=49.82), t(40)=3.07, p=.004. Specific demographic data is presented in Table 1.

Materials

Neuropsychological measures. All participants were screened for dementia and psychological well-being using the Mini Mental Status Examination (MMS) (Mini Mental LLC, Boston, MA) and the short form of the Geriatric Depression Scale (Yesavage et al., 1982). The MMS was scored according to the manual with 30 points possible. The 15 item Geriatric Depression Scale was scored according to the manual with number of negative items endorsed as the dependent variable. Scores above five are suggestive of depression and scores above 10 are considered almost always depressive.

The Digits Forward and Backwards tasks (adapted from Wechsler, 1981) were administered as a measure of working memory and a simple reaction time task was also performed.

Stimuli and task. All stimuli were generated and presented by E-Prime software (Psychology Software Tools, Inc., Pittsburg, PA) on an LCD computer monitor with a grey background. Participants sat approximately 100 cm from the monitor. Participants first read a set of instructions and completed a block of 10 practice trials to learn the rules and response mappings for the current task. During the practice block and for the remainder of the task, participants categorized pairs of figures according to one of the three rules: shape, size, or color. The rules switched or repeated randomly across trials with a switch or stay being equiprobable. Rules were conveyed with cues ("size," "shape," or "color") that appeared centrally on the screen for 800 ms and then disappeared for 700 ms before the target figure-pair appeared. Targets remained on the screen until a response. Participants were asked to respond as quickly and as accurately as possible by moving a mouse pointer over one of two "buttons" on the screen. The response buttons were centered vertically on the left and right side of the monitor. One button represented different and red decisions and the other represented same and blue decisions. Feedback appeared following a response. To begin the next trial, participants were required to move the mouse pointer back to the center of the screen for a neutral starting position for the next trial. An interval of 1500 ms occurred before the next cue. After the practice block, participants completed three blocks of 120 trials. Participants were given an opportunity to take a rest between each block. Shape, size, and color judgments were divided evenly across blocks. Figure 2 depicts the task schematic. Words

were presented in Courier New font with a visual angle of 2.5° for cues, 6.5° for large targets and 3.5° for small targets.

Procedure

Upon arrival at the laboratory, participants were oriented to the testing facilities and told the experiment timeline. After filling out informed consent, participants completed the demographic session and psychometric tests in the following order: demographic questionnaire, GDS, MMS, DF, DB, simple reaction time task. Researchers then prepared participants for EEG recording and began the task-switching paradigm, which lasted between 30-50 minutes depending upon decision time and length of breaks. After completing the computerized task, participants were debriefed and reimbursed for their time.

Data Recording and Analysis

Behavioral data. E-Prime recorded the behavioral data, both reaction times and accuracy. Reaction time was divided into two components, action delay (AD) and action time (AT). Action delay was defined as the elapsed time between the presentation of the target figures and the initiation of mouse movement. Action time was defined as the elapsed time between the initial mouse movement and the time that the pointer reached the decisional button. For each participant the highest and lowest 10% of trials for both action delay and action time were trimmed.

Electrophysiological recording and analysis. Electrophysiological data were recorded continuously at 2000 samples per second using a DBPA-1 Sensorium bio-amplifier (Sensorium Inc., Charlotte, VT) with an analog high-pass filter of 0.01 Hz and a low-pass filter of 500 Hz (four-pole Bessel). Recordings were made using an extended

10-20 cap system with 74 Ag-AgCl sintered electrodes while participants were seated in an electrically shielded booth. EEG recordings were made using a forehead ground electrode and a reference at the tip of the nose. EOG was recorded from peri-occular electrodes placed on the superior and inferior orbits (centered with the pupil) and from electrodes placed at the lateral canthi. All impedances were adjusted to within 0-20 kilohms at the start of the recording session.

EEG data were undersampled at 500 Hz and analyzed off-line using EMSE (Source Signal Imaging, San Diego, CA). Psychophysiological data were visually inspected for trials containing extreme muscular artifact and/or out-of-range values. Trials in which more than 20 (28%) of the channels were contaminated by such artifact were removed from the analysis. The EEG data were corrected for ocular artifact using independent components analysis (Jung et al., 2000). Individual channels were then analyzed in one-second sweeps over the entire recording epoch. Channels containing extreme values (+/- 300 μV) in more than 40% of the sweeps were replaced by interpolation (spherical spline). Data were then low-pass filtered at 20 Hz and re-referenced to the common average.

Data were segmented between -200ms and 1500ms with respect to stimulus onset and baseline corrected over the pre-stimulus interval. Segmented data were then averaged for each subject within each condition. ERPs were identified by inspection of the grand-averaged waveforms.

Results

Recognizing the discrepancy between the "shape" & "size" judgments, which required a comparison of the two figures, and the "color" task, which required only the

identification of the color, the primary hypotheses outlined above are based on trials that required a comparison judgment ("shape" and "size"). All data analysis includes only trials where shape or size was the relevant dimension. In order to validate the distinction between comparison and identity judgments, mean response times for these two tasks-types were submit to a paired-samples t-test. Color trials were faster (M=785.10, SD=365.97) than shape/size trials (M=1031.48, SD=397.09) t(42)=12.32, p<.001.

For purposes of brevity, for the analysis section, switch and conflict types will be abbreviated. For switch types the following abbreviations will be used: stay (ST), switch attention (SW$_a$), switch attention and response (SW$_{ar}$). For conflict types the following abbreviations will be used: no conflict (NOCON), response conflict (RCON), stimulus conflict (SCON) and all conflict (ALLCON).

Behavioral Data

Response times and accuracy rates for the 12 trial types created by the factorial combination of the Switch (ST, SW$_a$, SW$_{ar}$) and Conflict (NOCON, RCON, SCON, ALLCON) factors with a between subjects factor of Age (younger and older) were submitted individually to a Switch (3) X Conflict (4) X Age (2) repeated mixed-measures ANOVA. Greenhouse-Geisser corrected p-values are provided where appropriate.

Accuracy. Mean accuracy rates were high for both the older (M=.96, SE=.01) and younger (M=.96, SE=.01) participants with no significant difference between the groups, F(1, 41)=.02, n.s. There was not a main effect for switch type, F(2, 82)=2.13, n.s. There were also no interactions with age and switch type F(2, 82)=.62, n.s, nor age and congruency F(3, 123)=1.03, n.s. There was a main effect for congruency F(3, 123)=26.84, p<.001, see Figure 3. Pairwise comparisons reveal that both NOCON (M=.99, SE=.002) and RCON (M=.97, SE=.01) trials were significantly more accurate

than SCON (*M*=.95, *SE*=.01), *p*<.001, p=.03, and ALLCON trials (*M*=.93, *SE*=.01), *p*<.001 for both respectively. Stimulus conflict (SCON) trials were significantly more accurate than ALLCON trials, *p*=.01.

Reaction Times. Reaction time data was submitted to a Switch type X Conflict X Age X (2) Reaction time type (RT), (AD and AT), repeated mixed measures ANOVA. A main effect for age revealed that older participants were generally slower (*M*=888.24 ms, *SE*=41.10) than younger participants (*M*=545.97 ms, *SE*=40.16), $F(1, 41)=35.48$, *p*<.001. There were also main effects for switch type, $F(2, 82)=21.46$, *p*<.001 and congruency $F(3, 123)=10.05$, *p*<.001 and RT, $F(1, 41)=205.02$, *p*<.001. All main effects were moderated by other variables.

A significant three-way interaction for switch type, reaction time type, and age was significant, $F(2, 82)=3.72$, *p*=.03. To further understand this interaction separate Age X Switch Type ANOVAs was run for both AD and AT data. An interaction between Switch Type and Age was significant $F(2, 82)=8.50$, *p*<.001 for the AD component of RT but not for the AT component, $F(2, 82)=.98$, n.s. This interaction was observed to result from smaller switch costs in the SW_a and SW_{ar} types for the younger compared to the older participants. For younger participants action delays were not significantly longer on SW_a (M=775.49, SD=174.63) than on ST trials (*M*=767.75, *SD*=159.46), $t(21)=.85$, n.s. and were only marginally longer on SW_{ar} trials (*M*=793.24, *SD*=170.65) than ST trials $t(21)=2.00$, *p*=.06. For older participants however, switch costs were marginally significant for SW_a trials (*M*=1279.46, *SD*=411.90) compared with ST trials (*M*=1226.51, *SD*=358.54), $t(20)=1.83$, *p*=.08. Switch costs were significantly longer for

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SW$_{ar}$ trials (*M*=1382.56, *SD*=444.22), than both ST, *t(20)*=4.91, *p*<.001; and SW$_a$

t(20)=3.53, *p*=.002 respectively. Figure 4 illustrates this three-way interaction.

There was also a three way interaction between switch type, congruency, and

reaction time type, *F*(6, 246)=3.22, *p*=.01, which was also interpreted using separate

ANOVAs for AD and AT reaction time data. For AD, the Switch Type X Congruency

interaction was significant, *F*(6, 246)=2.80, *p*=.04. This interaction was not significant for

AT data, *F*(3, 246)=.82, n.s. For AT data, ST trials (*M*=373.93, SE=21.63) were faster

than SW$_a$ (*M*=403.28, *SE*=25.21) and SW$_{ar}$ (*M*=412.92, *SE*=24.78), *p*=.04, *p*=.002

respectively. One way ANOVAs for each switch type were run with four levels of

conflict for AD data. Pairwise comparisons for ST trials reveal NOCON (*M*=900.78,

SE=47.60) trials were faster than SCON (*M*=1027.03, *SE*=54.31) and ALLCON trials

(*M*=1084, *SE*=62.24), p<.001 for both. NOCON and RCON (M=954.51, SE=60.64) were

not different from one another, n.s. RCON trials were faster than SCON trials, *p*=.03. For

SW$_a$ trials, NOCON (*M*=950.43, *SE*=52.31) trials were faster than both RCON

(*M*=1047.44, *SE*=62.20), *p*=.04 and SCON (*M*=1032.25, *SE*=56.56), *p*=.04, but

surprisingly not ALLCON trials (*M*=1056.33, *SD*=93.66) n.s. For SW$_{ar}$ trials, no

significant differences were revealed with the ANOVA. NOCON (*M*=1065.06,

SE=69.14), RCON (*M*=1067.41, *SE*=79.14), SCON (*M*=1088.70, *SE*=63.56), and

ALLCON (*M*=1103.04, *SE*=72.72) were not different from one another. Figure 5

represents this three way interaction.

Although a significant interaction was not observed between congruency and age

in the omnibus *F*-test, paired-samples t-tests were used to test the apriori prediction that

different behavioral patterns would emerge for older and younger participants. For

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younger participants NOCON (M=749.23, SD=160.65) and RCON trials (M=755.92, SD=171.92) were not significantly different, $t(21)$=.45, n.s. NOCON and RCON trials were faster than SCON trials (M=803.30, SD=174.88), $t(20)$=2.79, p=.01, $t(20)$=2.21, p=.04 and faster than ALLCON (M=806.84, SD=181.16), $t(21)$=3.45, p=.002, $t(21)$=2.81, p=.01. SCON and ALLCON were not different from one another, $t(21)$=.25, n.s. A different pattern emerged for older participants, NOCON trials (M=1205.55, SD=360.67) were faster than RCON trials (M=1303.04, SD=445.61), although this was only a trend, $t(20)$=1.92, p=.07. NOCON trials were significantly faster than SCON (M=1307.06, SD=339.09) and ALLCON (M=1369.06, SD=530.94). Figure 6 illustrates these patterns.

Electrophysiological Data

  Cues. Three exogenous and two endogenous ERP components were identified in the cue-locked grand-average waveforms. The exogenous P1, N1, and P2 components were maximal bilaterally over occipital and parietal occipital recording sites. The P1 was measured between 50 and 120 ms, the N1 between 120 and 210, and the P2 between 210 and 310 ms, all at electrodes OZ, O1, and O2. The endogenous components of interest were the P3, measured between 275 and 375 ms, and slow wave component, measured between 500 and 1500ms. Both components were maximal at parietal and central parietal sites and measured at PZ, P1, P2, CZ, CP1, and CP2.

  Exogenous. The exogenous components of the cue-locked data were submitted to a repeated mixed measures ANOVA, Switch Type X Electrode (O1, O2, OZ) X Age.

  P1. No main effects or interactions were found for the P1 amplitude or latency.

  N1. A main effect of Switch Type, $F(2, 82)$=3.92, p=.03, in the mean amplitude of the N1 component revealed that amplitudes were more negative for SW_{ar} trials (M=.18

µV, *SE*= .30) than ST trials (*M*=.66, *SE*=.30), *p*=.01, but were not different from SW_a

trials (*M*=.48, *SE*=.30), n.s. Moreover, a main effect of electrode, $F(2, 82)=19.54$, $p<.001$

indicated that for N1 mean amplitudes were more negative over the left hemisphere with

site O1 (*M*=-.14, *SE*=.29) differing from O2 (*M*=.66, *SE*=.30) and OZ (*M*=.79, *SE*=.30),

$p<.001$ for both.

P2. For the P2 amplitude, a main effect of Switch Type, $F(2, 82)=5.04$ $p=.01$,

revealed that the mean amplitude for SW_{ar} trials (*M*=2.22 µV, *SE*=.41) was lower than

both ST (*M*=2.73, *SE*=.41) and SW_a trials (*M*=2.76, *SE*=.43), $p=.06$, $p=.02$, which were

not different from each other, n.s.

Endogenous. *P3*. The endogenous P3 component amplitude was submitted to a

Switch Type X Row (CP, P) X Side (left, right, center) X Age ANOVA. The analysis

revealed a main effect for age, $F(1, 41)=6.48$, $p=.02$. Younger participants had more

positive P3 components (*M*=2.51, *SE*=.32) than older participants (*M*=1.34, *SE*=.33). A

main effect for row was also revealed, $F(1, 41)=68.21$, $p<.001$. The P3 amplitude was

greater at parietal sites (*M*=2.62, *SE*=.28) than central parietal sites (*M*=1.22, *SE*=.20).

See Figure 7 for an illustration of cue-locked EEG components. Figure 8 illustrates the

amplitudes for the P3 component.

Slow wave. The slow wave component was submitted to a Switch Type X Age

X Row (CP, P) X Side (left, right, center) X Time (early: 500-1000 ms, late:1000-1500

ms) ANOVA. A main effect for switch type was revealed, $F(2, 82)=18.00$, $p<.001$, as

well as a main effect for age, $F(1, 41)=7.80$, $p=.008$. There was also a switch type by age

interaction, $F(2, 82)=4.69$, $p=.01$. For older participants there were no differences in

amplitude for switch type, ST trials (*M*=.70, *SD*=1.22)= SW_a trials (*M*=.50, *SD*=1.33)=

SW$_{ar}$ trials (M=.50, SD=.99), n.s. However for younger participants the SW$_{ar}$ amplitude (M=1.82, SD=.91) was greater than the ST amplitude (M=1.05, SD=1.00), t(21)=3.43, p=.003 and the SW$_a$ amplitude (M=1.34, SD=.97), t(21)=2.47, p=.02. ST and SW$_a$ trials were marginally different, t(21)=1.87, p=.08, with SW$_a$ trials more positive than ST trials. See Figure 9 for the amplitudes of the slow wave component.

A row main effect was also significant, F(1, 41)=36.82, p<.001. The parietal electrode sites exhibited greater slow wave positivity (M=1.59, SE=.18) than the central parietal sites (M=.77, SE=.14). A time main effect was also present, F(1, 41)=33.24, p<.001. The positivity was greater in the early slow wave (M=1.46, SE=.17) than the later slow wave (M=.90, SE=.15).

Multiple three-way interactions were significant. Switch type by row by time F(2, 82)=6.22, p=.004 was significant. However, the switch type by row interaction was not significant for either early F(2, 82)=.64, n.s or late F(2, 82)=1.79, n.s. period. The switch type by side by time interaction was also significant, F(4, 164)=3.43, p=.03. However once again the switch type by side interaction was not significant for either time period, F(4, 164)=.47, n.s., F(4, 164)=.92, n.s. The side by age by time interaction was also significant. The side by age interaction was not significant in the early slow wave, F(2, 82)=1.10, n.s., nor was the interaction significant at the later time, F(2, 82)=1.36, n.s.

Targets. Three exogenous and four endogenous ERP components were identified in the target-locked grand-average waveforms. The exogenous P1, N1, and P2 components were maximal bilaterally over occipital and were measured during the same time periods and from the same sites as the cue-locked components. Endogenous components of interest included the N2, measured between 240 and 350 ms, and N450,

measured between 375 and 525 ms. Both components were maximal at frontal sites and measured at FZ, F1, F2. The P3b and sustained positivity (SP) were also measured. The P3b component was defined between 450-750 ms and maximal over parietal, central parietal, and central sites, PZ, P1, P2, CPZ, CP1, CP2, CZ, C1, C2. The sustained positivity was measured between 800-1400 ms. The amplitudes were maximal over the central and parietal regions and were therefore defined by regions, parietal (P3, P4, P5, P6, P7, P8), central (C3, C4, C5, C6, T7, T8) and frontal (F3, F4, F5, F6, F7, F8).

Exogenous. The mean amplitudes of the exogenous components elicited by the target were analyzed with a Conflict X Electrode (O1, O2, OZ) x Age mixed measures ANOVA. Electrode sites were chosen based on the maximal amplitude as revealed by grand average headplots and the standards for such components. See Figure 10 and 11 for the exogenous cue-locked components.

P1. For the P1 component a main effect for conflict F (3, 123) =3.86, p=.01, and electrode, F (2, 82) =10.55, $p<.001$ were present. The main effect for conflict was mediated by an age interaction, F (3, 123)=2.96, p=.04. Paired-samples t-tests illustrate a different pattern for congruency amplitudes for younger and older participants. For younger participants, NOCON trials (M=-.82 μV, SD=2.41) have a more negative amplitude than RCON trials (M=-.16, SD= 2.36), p=.01, however NOCON trials have a more positive amplitude than SCON trials (M=-1.49, SD=2.43), p=.01. SCON amplitudes were also more negative than RCON, $p<.001$ and ALLCON (M=-.64, SD=2.67), p=.001. No significant differences were found between conflict trials with older participants.

N1. The N1 component showed no main effects for age, F(1, 41)=.02, n.s., nor for electrode F(2, 82)=.80, n.s. However there was a main effect for conflict, F(3, 123)=3.21,

p=.03. Pairwise comparisons reveal the average amplitude for RCON trials (M=-3.37 µV, SE=.50) was less negative than the N1 amplitude for SCON trials (M=-3.83, SE=.53), p=.02. No other congruency level differences were significant.

P2. The mean amplitude of the P2 component illustrated a main effect for conflict, F(3, 123)=3.15, p=.03, and electrode F(2, 82)=3.54, p=.04. Pairwise comparisons reveal more positive amplitudes for RCON trials (M=-.44 µV, SE=.54) than SCON trials (M=-.88, SE=.54), p=.03. For electrodes, site O1 had more positive amplitude (M=-.26. SE=.57) than site OZ (M=-1.01, SE=.57).

Endogenous. The endogenous components N2 and N450 were submitted to a Conflict X Electrode (F1, F2, FZ) X Age mixed measures ANOVA. See Figure 12 for the endogenous cue-locked components at site FZ.

N2. For the N2 component main effects for age F(1, 41)=2.35, n.s., and conflict F(3, 123)=.93, n.s were not significant. There was a main effect for electrode, F(2, 82)=21.87, p<.001, with more negative amplitudes toward the center and left of center sites. The N2 amplitude at site F1 (M=-1.24, SE=.30) and site FZ (M=-1.15, SE=.32) were more negative than the amplitude at site F2 (M=-.40 µV, SE=.33), p<.001 for both comparisons.

N450. N450 analyses revealed a main effect of conflict that was mediated by a conflict by age interaction, F(3, 123)=3.68, p=.02. Paired-samples t-tests were used to better understand the interaction. For younger participants, NOCON trials (M=-2.15, SD=2.79) were similar to RCON trials (M=-1.85, SD=2.67), t(21)=1.09, n.s. SCON trials (M=-.79, SD=2.92) were also similar to ALLCON trials (M=-.83, SD=3.34), t(21)=.11, n.s. However the two groups were significantly different from one another with greater

negativity found for NOCON and RCON trials. NOCON trials were significantly

different from SCON and ALLCON trials, $t(21)=5.06$, $p<.001$, $t(21)=3.99$, $p=.001$.

Similarly, RCON trials were significantly different from SCON and ALLCON,

$t(21)=3.93$, $p=.001$, $t(21)=2.76$, $p=.01$. For older participants there were no significant

differences between conflict types. NOCON trials did however have the least positive

amplitude ($M=.40$, $SD=1.96$) and ICON trials were the most positive ($M=.88$, $SD=1.97$).

Figure 13 illustrates the 450 conflict X age interaction. Figure 14 illustrates the difference

scalp topographies for older and younger participants for the N450.

There was also a main effect for electrode, $F(2, 82)=44.18$, $p<.001$. The

amplitudes at all three electrode sites were different from one another with greater

negativity on the left side. Site F1 ($M=-1.05$, $SE=.33$) had a more negative amplitude that

site F2 ($M=.43$, $SE=.41$), $p<.001$ and site FZ ($M=-.63$, $SE=.39$), $p=.01$. Site FZ was more

negative than F2, $p<.001$.

P3b. The mean amplitude for the P3b component was submitted to Conflict X

Row (C, CP, P) X Side (left, right, center) X Age repeated mixed measures ANOVA. A

main effect of row was revealed, $F(2, 82)=4.24$, $p=.04$. Also a main effect for side, $F(2,$

$82)=37.67$, $p<.001$ and a row by side interaction $F(4, 164)=14.81$, $p<.001$. For the central

and central parietal row the same pattern was observed for the electrode side's amplitude.

The right electrode in both the central and central parietal row had the greatest positivity

($M=1.62$, $SD=1.92$), ($M=2.12$, $SD=1.91$) respectively. The right electrode was

significantly different from both the left ($M=-.28$, $SD=1.67$), ($M=.76$, $SD=1.93$),

$t(42)=7.88$, 6.73, $p<.001$ and the middle sites ($M=.96$, $SD=2.26$), ($M=1.53$, $SD=2.21$),

$t(42)=4.02$, 3.80, $p<.001$. However for the parietal row, the middle and right sites did not

differ from each other, (M=1.71, SD=2.49), (M=1.69, SD=2.55), $t(42)$=.10, n.s. The parietal left electrode (M=1.13, SD=2.21) did differ from the right, $t(42)$=3.22, p=.002 and the center, $t(42)$=3.77, p=.001.

Analyses also revealed a congruency by row interaction, $F(6, 246)$=6.52, p<.001. ALLCON trials had a more positive amplitude (M=1.21, SD=2.02) than SCON (M=.82, SD=1.78), $t(42)$=2.10, p=.04, RCON (M=.60, SD=1.80), $t(42)$=3.27, p<=.002, and NOCON (M=.45, SD=2.12), $t(42)$4.62, p<.001. SCON trials were marginally greater than NOCON trials, $t(42)$=1.96, p=.06. For the central parietal row, the ALLCON trials (M=1.67, SD=2.05) were marginally more positive than the NOCON (M=1.32, SD=2.21), $t(42)$=1,89, p=.07. For the parietal row, no differences were significant.

Sustained Positivity (SP). The sustained positivity was submitted to a Conflict X Region (parietal, central, frontal) X Hemisphere (left, right) X Age mixed measures ANOVA. A marginal main effect of conflict was revealed, $F(3, 123)$=2.63, p=.05. Although none of the pairwise comparisons were significant, SCON trials had the greatest amplitude (M=.27, SE=.09), followed by ALLCON (M=.18, SE=.09), RCON (M=.13, SE=.09) and lastly NOCON (M=.10, SE=.07).

There was a significant main effect for hemisphere, $F(1, 41)$=43.17, p<.001 that was mediated by a region interaction, $F(2, 82)$=5.52, p=.01. Amplitudes were more positive in the right hemisphere (M=1.35, SE=.19) than the left hemisphere (M=-1.01, SE=.20). For the right hemisphere the frontal (M=1.63, SD=2.00) and central regions (M=1.76, SD=1.59) had greater amplitudes than the parietal (M=.68, SD=1.87), $t(42)$=2.17, 3.09; p=.04, p=.004. For the left hemisphere the frontal region (M=-.67,

SD=1.90) had a less negative amplitude than the central region (*M*=-1.23, *SD*=1.51),

t(42)=2.23, *p*=.03.

Discussion

Previous studies suggest age related differences in cognitive control, including

deficits in task switching paradigms; however the specific mechanisms of that deficit

remain unclear. The primary aim of the present study was to determine whether deficits

of cognitive control in the elderly could be attributed to attentional- or response-relevant

cognitive processes. The current findings support claims of distinct attentional and

response related cognitive processes, and offer evidence for selective cognitive deficits in

older participants.

The behavioral data reveal increases in processing time related to task switches

and increasing levels of conflict. By separating action delay and action time, two

measures were available to more fully understand when the increased task difficulty

affected responses. Overall, action delay, the time before initiation of mouse movement,

was more sensitive to the increasing levels of switches and conflict than action time, the

time to move the mouse pointer to the response button. Action time differences were only

revealed between attention and response switch and stay trials for both age groups, with

attention and response switch trials having longer action times. Action delay patterns

revealed more differences between conditions. Although the specific switch costs

between stay and attentional switch trials were not significant for younger participants,

older participants did show a specific switch cost trend. Longer action delays resulted for

attention and response switch trials compared to stay trials for both younger and older

participants. Action delay was also sensitive to conflict type. As number of switches

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increased ($ST<SW_a<SW_{ar}$) conflict differentiation decreased for both age groups. For stay trials no conflict and response conflict were faster than stimulus conflict and all conflict. This pattern is in accordance with the second prediction as both the no conflict and response conflict trials would be considered least difficult if response conflict is less disruptive of cognitive processes, whereas stimulus conflict and all conflict trials would be more difficult. This pattern may result for stay trials as this is the least difficult of the switch types, allowing for conflict patterns to more clearly emerge. For attention switch trials although the significant differences suggest that no conflict and all conflict trials were not different from one another, looking at the mean action delay times, a steady increase in time occurred with increasing levels of conflict. Response conflict and stimulus conflict trials did result in significantly longer reaction times than no conflict. For attention and response switch trials, no differences were found for conflict type suggesting that when incorporating multiple switches, all conflict was challenging. The action delay for congruency alone was not mediated by age; however, different behavioral patterns did emerge in the two age groups. Younger participants exhibited the second predicted pattern. Action delays for no conflict trials were similar for delays with response conflict trials and this set was significantly faster than action delays for stimulus conflict and all conflict trials. For older participants, the first predicted pattern occurred. Action delays for no conflict trials were shorter than delays for response conflict, stimulus conflict, and all conflict trials.

Although reaction time data offers one perspective on the cognitive mechanisms involved with task switching, electrophysiological data can reveal more precise evidence for differences in cognitive processing. The endogenous components of interest were

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both cue and target-locked and reveal differences in processing. The cue-locked parietal P3 component has been found to index task encoding and updating mental set (Friedman et al., 2008). In the current study older participants exhibited an attenuated P3 component suggesting deficits in preparing for the upcoming trial. The later parietal slow wave was also reduced for older participants with no differences between trial switch types. However, for younger participants the attention and response switch trials had the greatest slow wave amplitude. This differentiation for trial type found only in younger participants may reveal that older participants manage all trials similarly, regardless of level of difficulty.

For target locked data the N2 and N450 are components believed to index conflict detection and monitoring (West, 2004; West et al., 2004). These were components of interest proposed to shower greater negativity for stimulus conflict and all conflict trials. The results revealed that both young and old participants had an N2 component however no differences existed between age groups, switch types, or conflict types. The N450 was more sensitive to this task. The older participants did not have a negative deflection as did the younger participants. Younger participants' N450 components also exhibited a parsing for the levels of conflict. No conflict and response conflict trials had similar amplitudes that were more negative than the amplitudes for the stimulus conflict and all conflict trials. Although this separation is not in the predicted direction, it does suggest separate processes or activation for stimulus and response conflict. A possible generator for the N450 is the anterior cingulate cortex (Nessler et al., 2007). The lack of a N450-like component may suggest ACC deterioration in the older participants and therefore different conflict processing mechanisms. The behavioral patterns found in the action

delay data suggest different behavioral costs for the older and younger participants. The older participants showed increased action delays for both types of conflict. This behavioral pattern may be represented in the lack of differentiation within the N450. Although not significant, the amplitude for the no conflict trials was least positive.

Limitations of the current research must be considered when synthesizing results. First, the age range for the older population was larger than many of the other papers addressing the effects of aging on task switching abilities. The current study includes five participants over the age of 80 whereas other literature describes populations in their late 60's and early 70's. Because of this difference, current findings may be less informative as to the initial changes in cognition. The variability introduced by this much older population may limit the significant findings. Recruiting enough participants to form multiple levels of aging may greatly add to the research as the effects of aging likely change with increasing age.

Considering the older population recruited for this study, the task procedure may also be viewed as a limitation. The current procedure presented participants with buttons with both same/different and red/blue labels present regardless of the relevant task. The older participants struggled with this mapping and had difficulty ignoring the irrelevant labels. Although this age specific difficulty is itself interesting to the current research, the confusion regarding button labels may have prevented the older participants from fully understanding and therefore engaging in the same cognitive processes completed by the undergraduate participants.

Despite these concerns, the specificity afforded by this procedure offers a unique contribution to the field of age-related changes in task-switching. The ability to separate

stimulus from response switching components may lead to an improved understanding of pathological changes in cognitive functioning associated with aging. Whereas younger participants showed longer action delays and differential amplitudes for trials with the greatest number of switches or levels of conflict, older participants appeared to have more difficulty with attentional switches and response conflict trials. Both older and younger participants were able to accurately complete the task, however, perhaps the neural mechanisms in place varied for the groups as suggested by the ERP waveforms.

This research contributes to the accumulating knowledge about the neural effects of aging. Through the study of the specific cognitive processes used for attention, we hope to gain a more thorough understanding of what specifically is contributing to the deterioration of attention in aging individuals. With more precise knowledge, clinicians will be better able to understand the differences between normal and pathological processes that occur with aging and may thus lead to the development of new diagnoses and treatment approaches.

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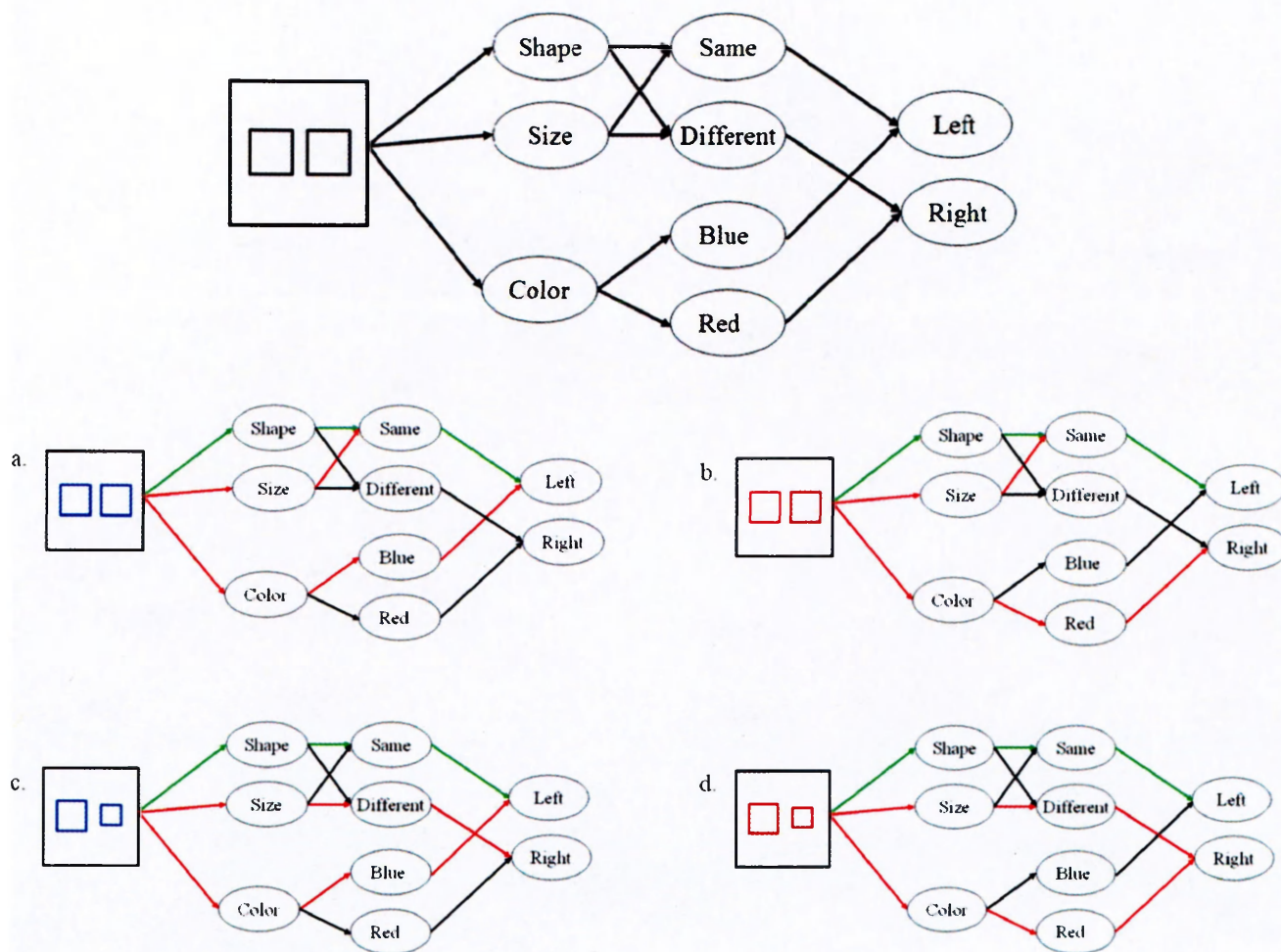
Figure 1. Diagram of task. If shape is the relevant dimension/rule: a. NOCON trial, b. RCON trial, c. SCON trial, d. ALLCON trial.

Table 1

Mean (±SD) demographic data for both participant groups

	Young adults (*N*=22)	Older adults (*N*=21)
Age (years)	20.23 (3.35)	74.62 (6.70)
Age range (years)	18-34	64-86
Years of Education *	13.95 (.90)	17.14 (2.15)
Laterality quotient (EHI)[1]	78.18 (38.50)	88.57 (27.26)
MMS[2]	29.23 (1.07)	29.62 (.74)
Digits Forward[3]	7.45 (1.26)	6.95 (1.20)
Digits Backward[4]	5.45 (1.30)	5.50 (1.61)
GDS[5]	1.18 (1.14)	1.0 (1.58)
Weekly activities[6]*	2.59 (1.14)	3.8 (1.24)
Simple reaction time (ms)[7]*	286.79 (49.82)	337.33 (56.89)

* $p<.01$
[1] Edinburgh Handedness Inventory, 100 is completely right handed
[2] Mini Mental Status Examination, highest score is 30
[3] Number of corrects digits repeated, highest score is 9
[4] Number of correct digits repeated backwards, highest score is 9
[5] Geriatric Depression Scale short form, scores over 10 are strongly suggestive of depression
[6] Number of hobbies or weekly activities reported
[7] Score on simple reaction time test

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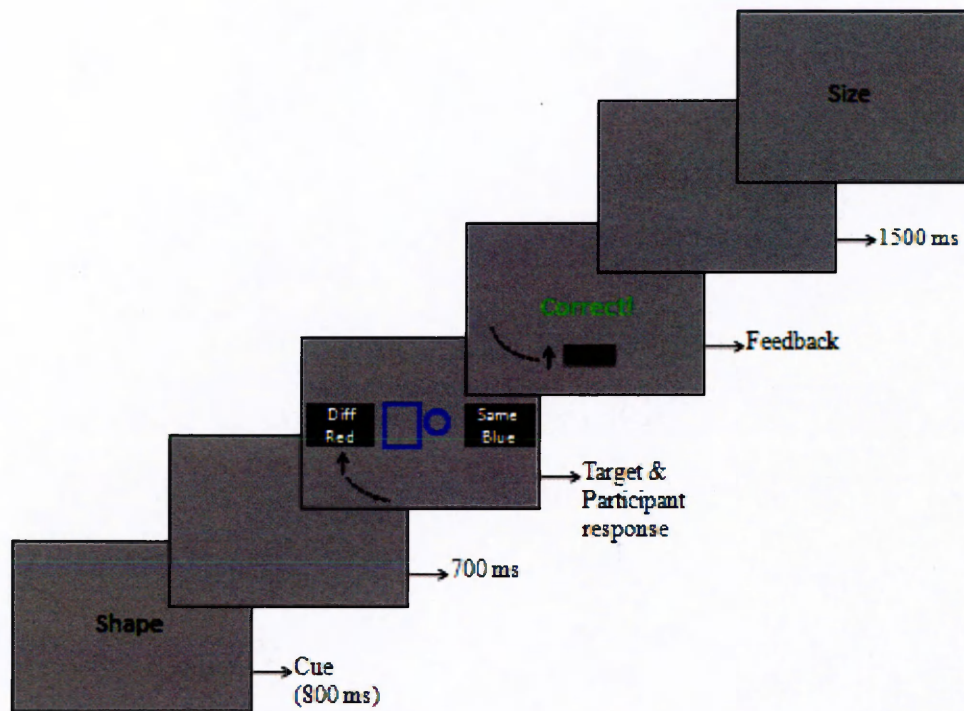
Figure 2. Task schematic: This schematic represents an RCON trial, the same/different dimensions (shape and size) are both different; however the color dimension, blue, suggests an incorrect response.
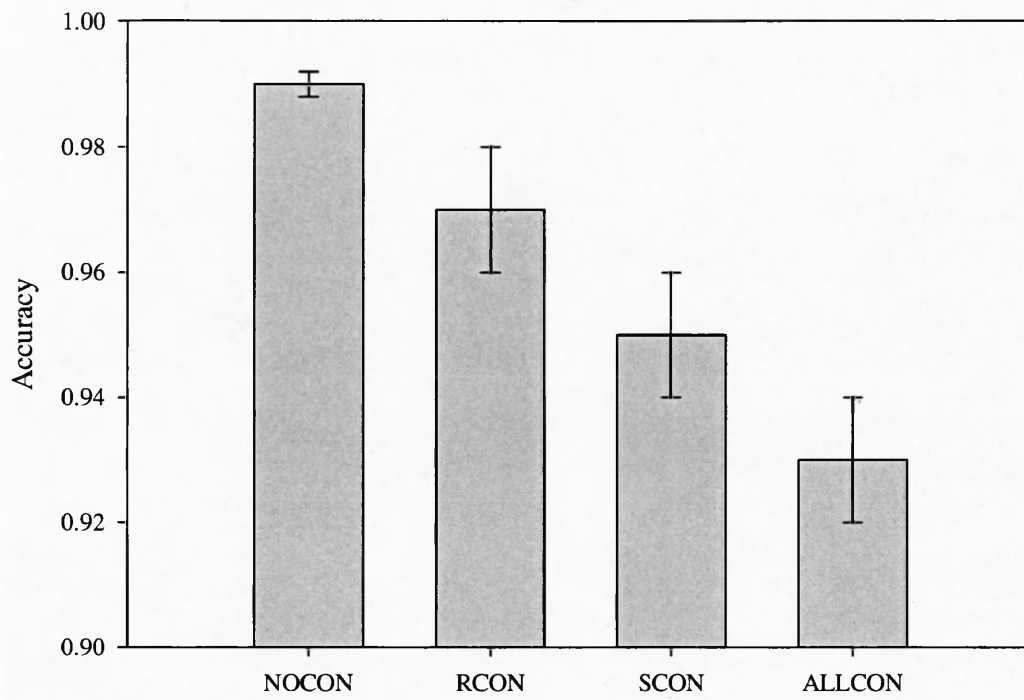
Figure 3. Accuracy rates for each conflict type.
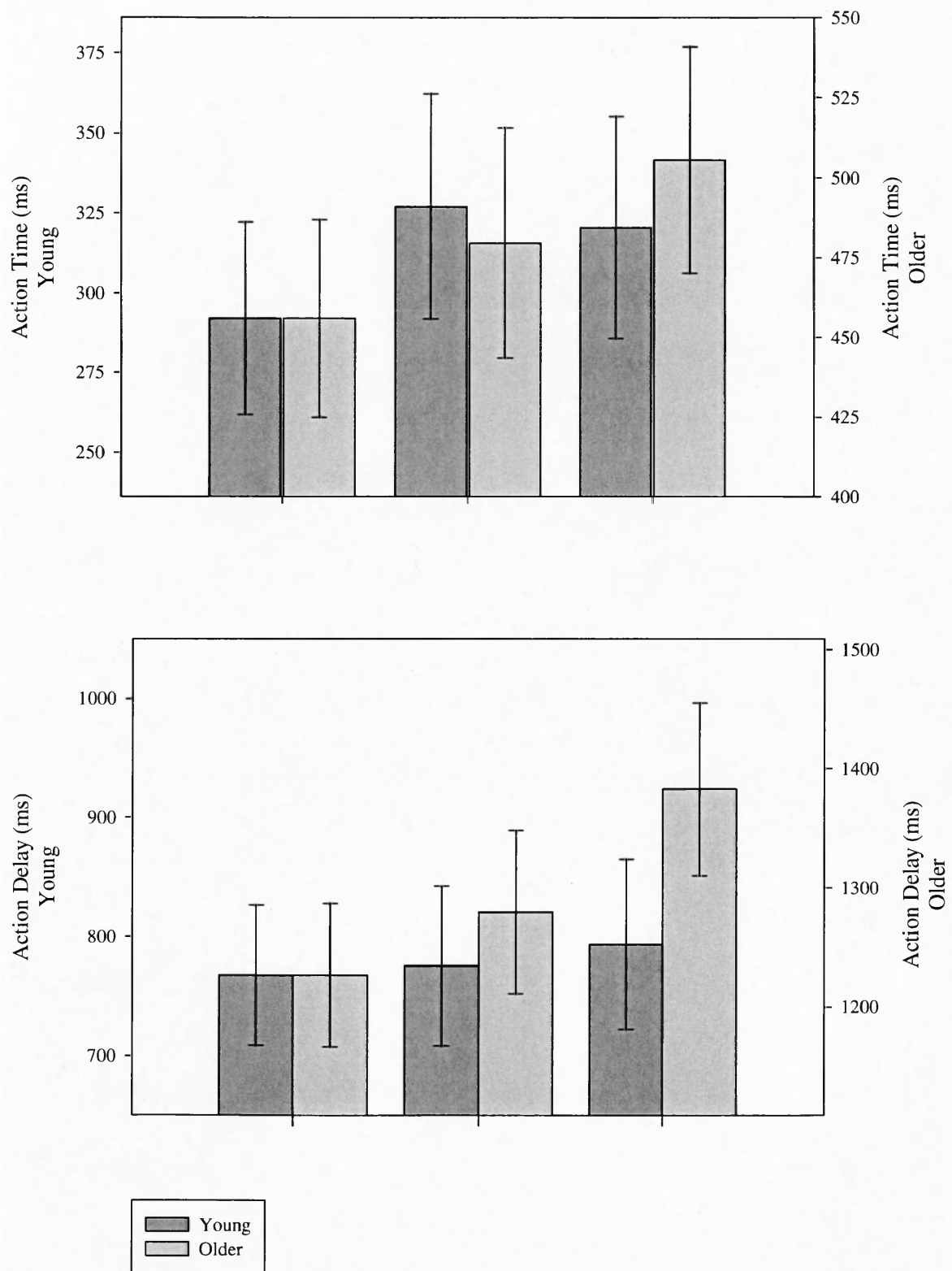
Figure 4. Switch Type X Age X RT interaction.
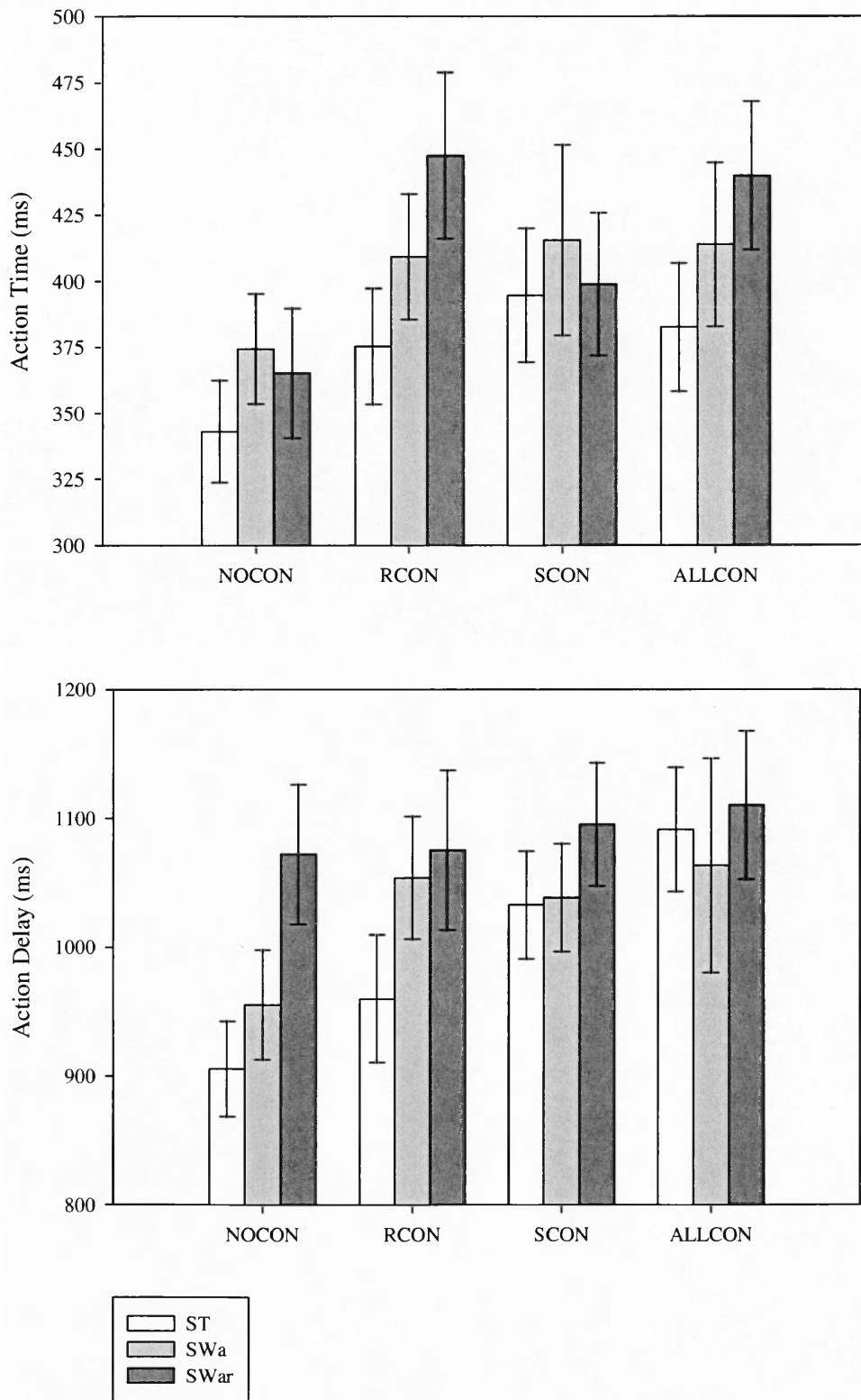
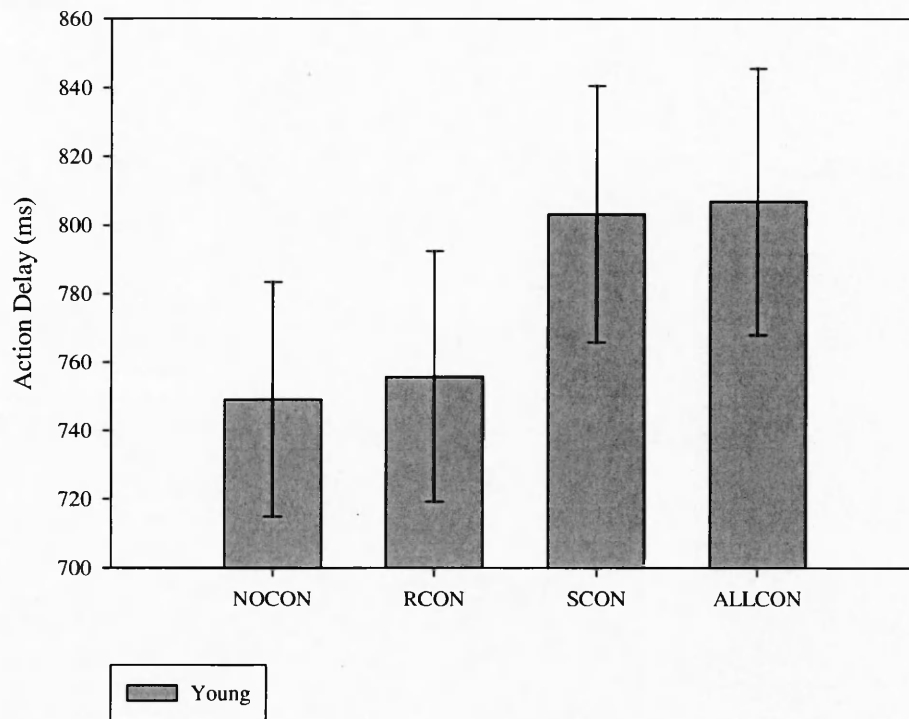*Figure 5.* Switch Type X Conflict X RT interaction.
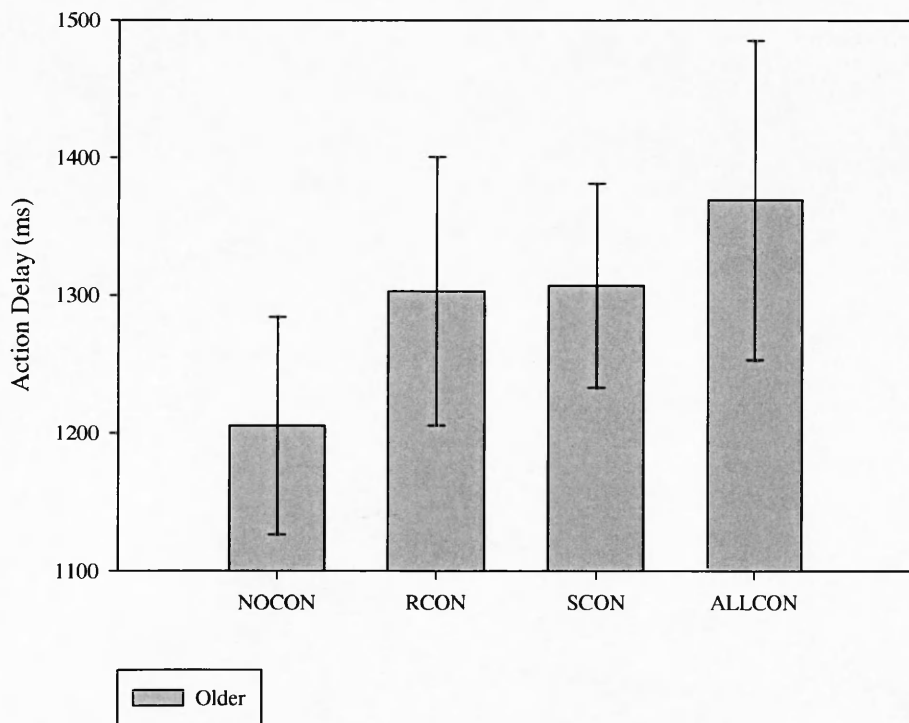
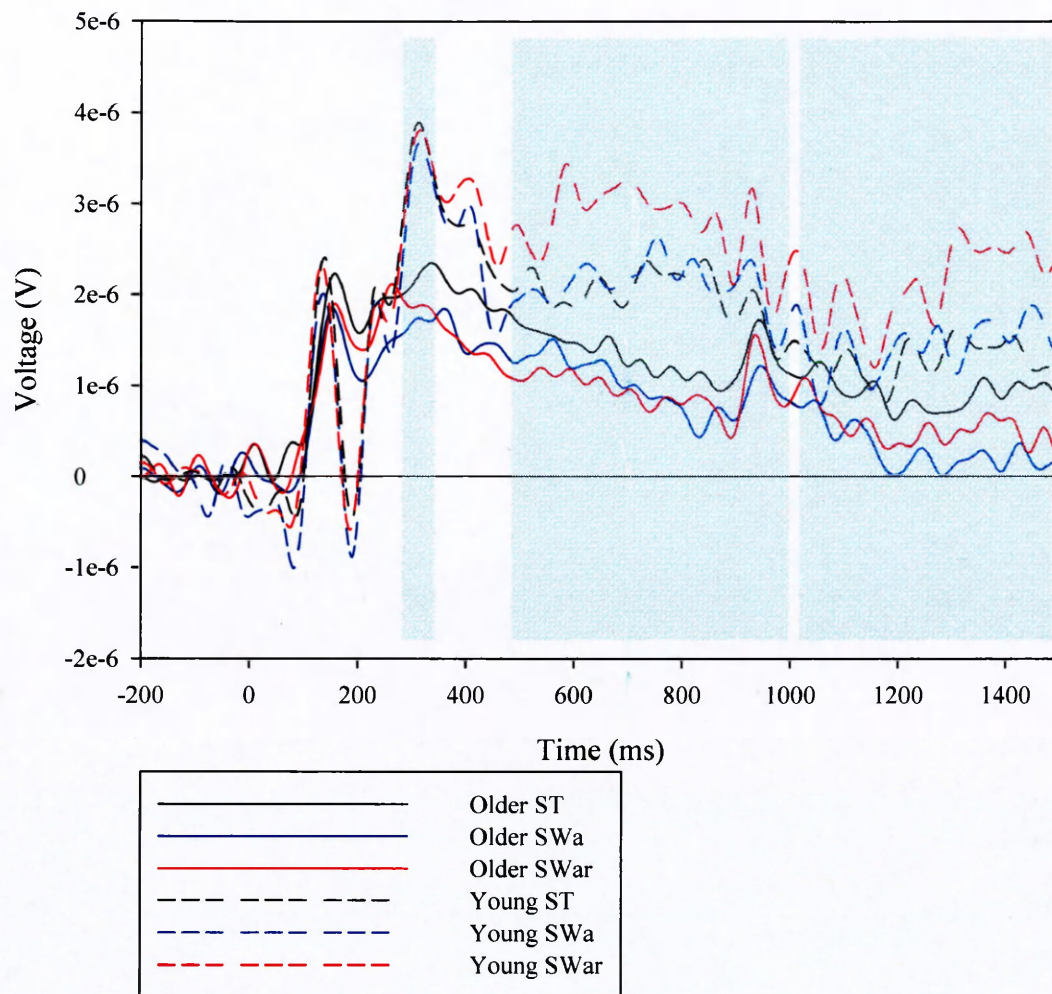*Figure 6.* Action Delay behavioral patterns for older and younger participants.
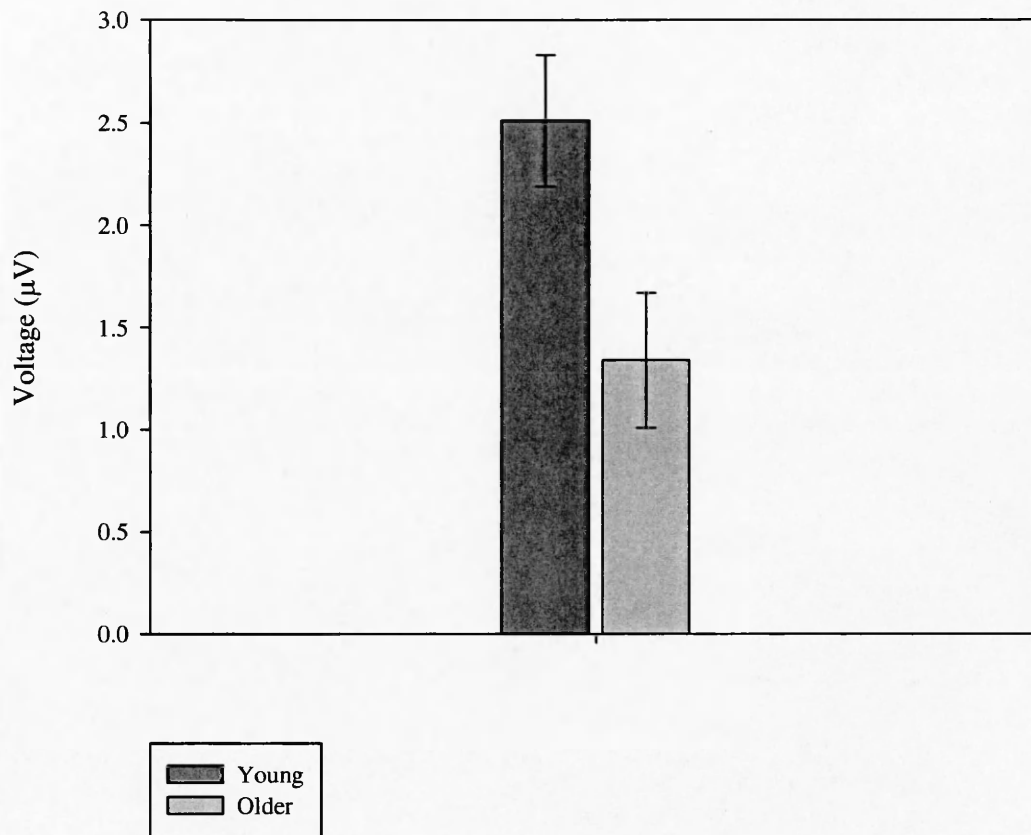
Figure 7. Cue-locked, exogenous components, P3 and Slow Wave, at site PZ.

Figure 8. Mean amplitude for P3 cue-locked component. Error bars represent standard error.
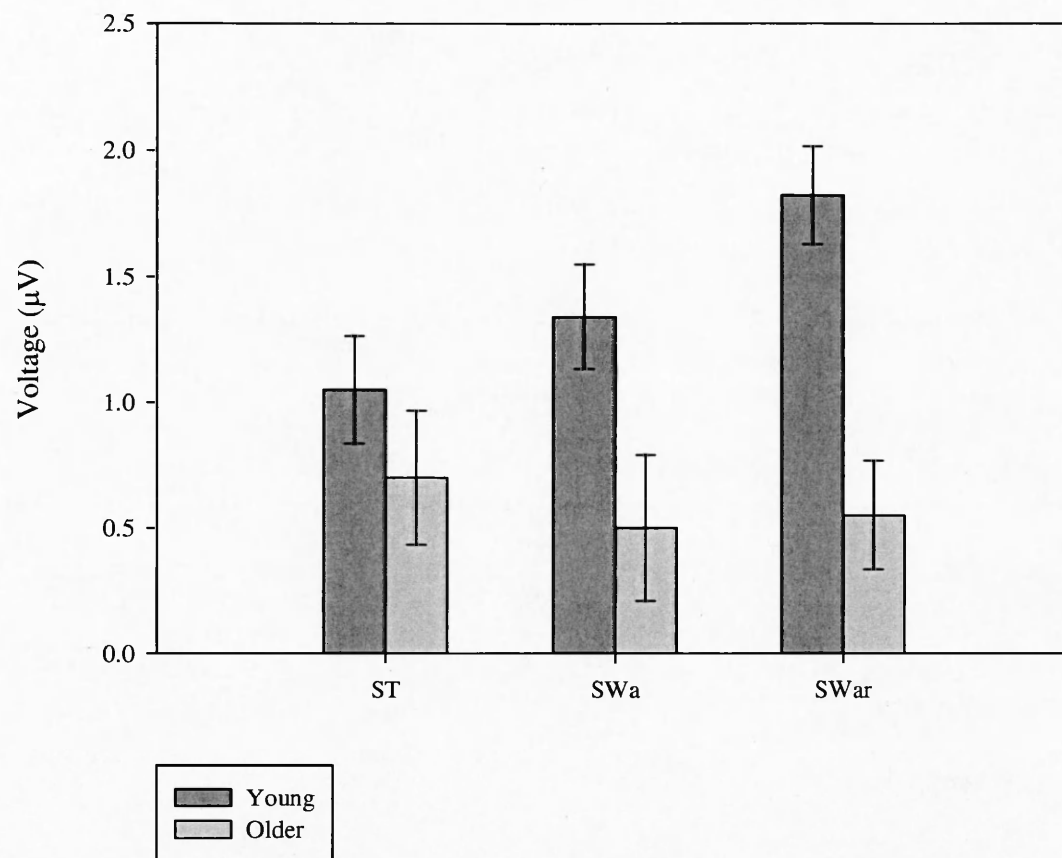
Figure 9. Slow wave mean amplitudes for young and older participants, illustrating the Conflict X Age interaction. Error bars represent standard error.
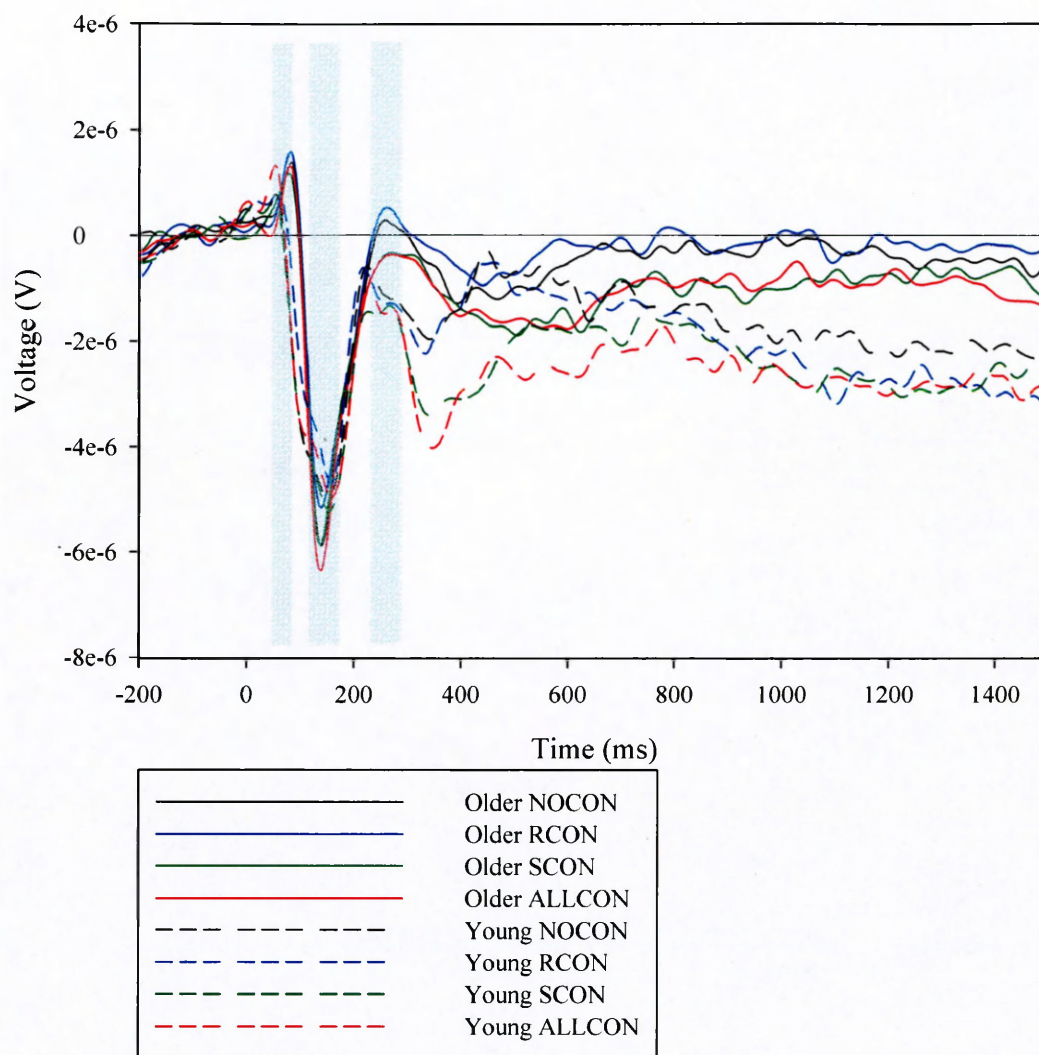
Figure 10. Target-locked exogenous components, P1, N1, P2, at site OZ.
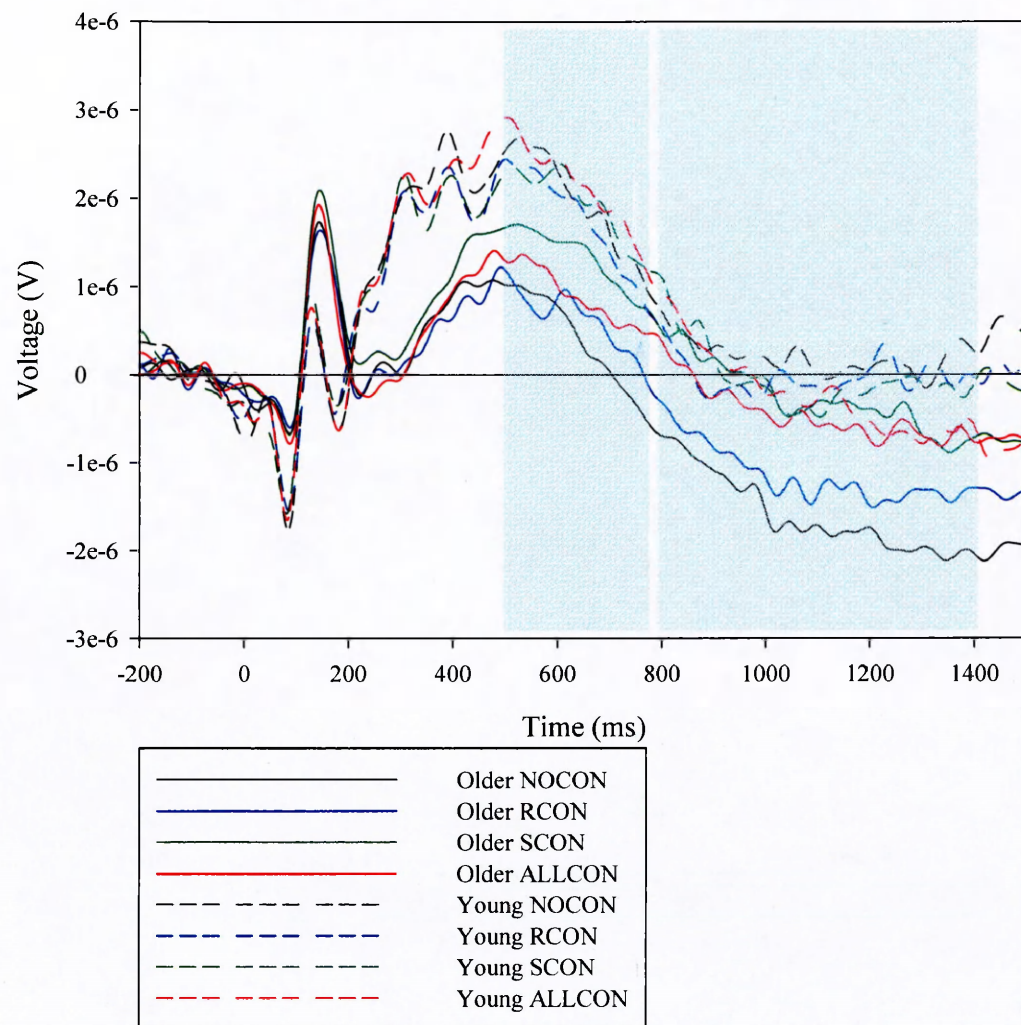
Figure 11. Target-locked, exogenous components, P3b and SP, at site CPZ.
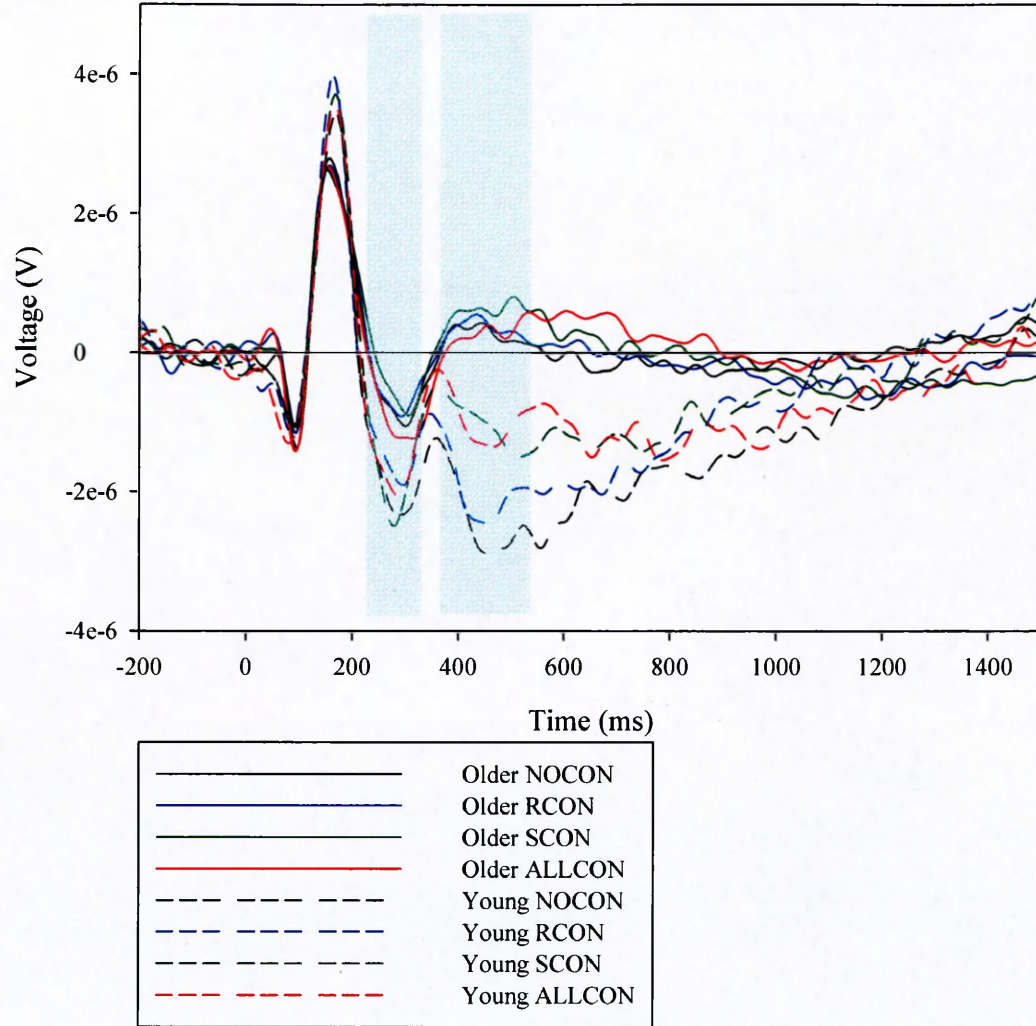
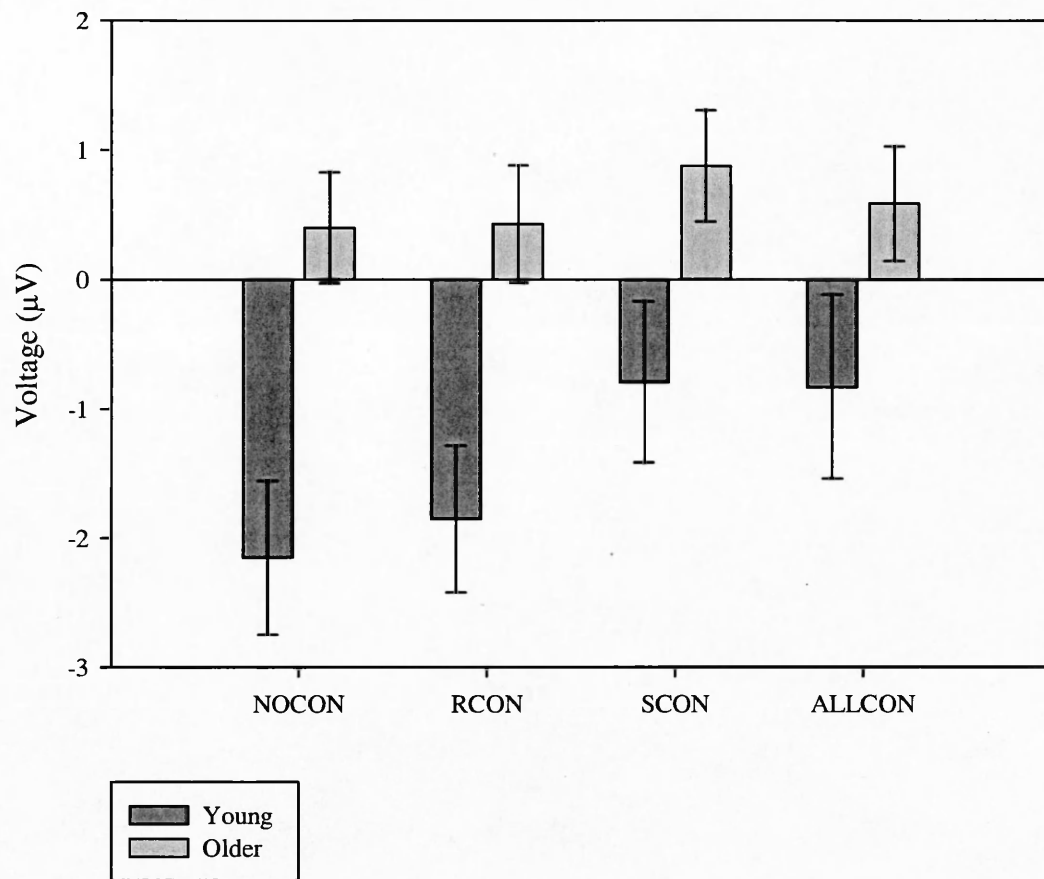*Figure 12*. Target-locked endogenous components, N2 and N450, at site FZ.

Figure 13. N450 mean amplitudes for young and older participants, illustrating the Conflict X Age interaction. Error bars represent standard error.
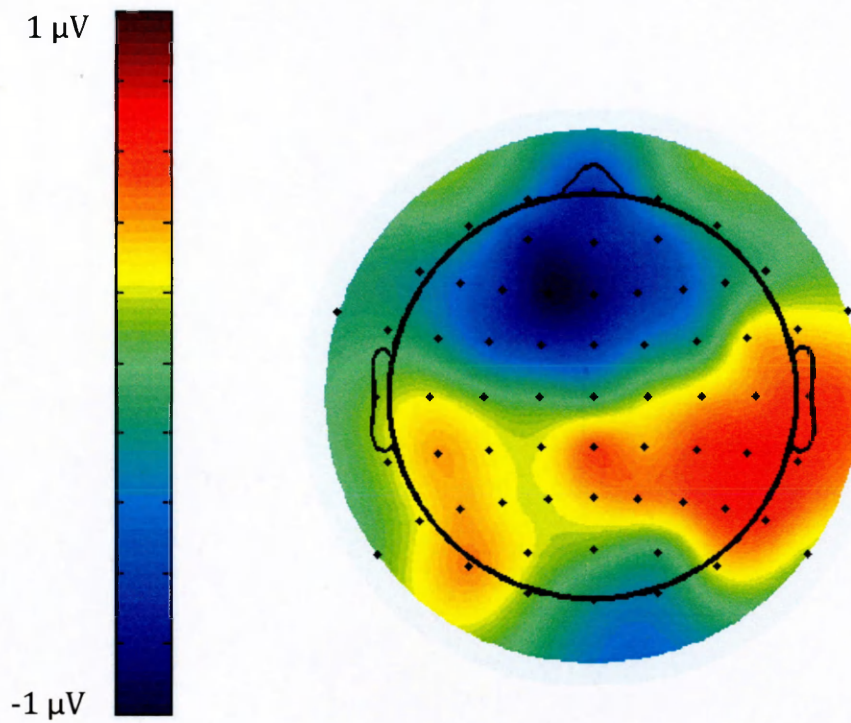
Figure 14. Scalp topography of amplitude differences between elderly and young over the N450 component (375-525 ms).