



Differential effects of aging on processes underlying task switching

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ABSTRACT

In this study, we used event-related brain potentials (ERPs) to examine the effects of aging on processes underlying task switching. The response time data revealed an age-related increase in mixing costs before controlling for general slowing and no effect of aging on switching costs. In the cue-locked epoch, the ERP data revealed little effect of age on the parietal P3 related to cue encoding, an age-related decrease in parietal activity related to cue retrieval, and an age-related increase in the amplitude of the parietal and frontal activity related to task set configuration and rule mapping. In the target-locked epoch, there was differential neural recruitment in younger and older adults in response to task mixing. These data are consistent with the idea that older adults may not fully implement task set before onset of the target stimulus.

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1. Introduction

The idea that later adulthood is associated with a decline in the efficiency of executive or cognitive control processes has a long history in the cognitive aging and neuropsychological literatures (Albert & Kaplin, 1980; Braver et al., 2001; Hasher & Zacks, 1979; Moscovitch & Winocur, 1992; West, 1996). Support for this position has been garnered from behavioral studies demonstrating significant age-related declines in performance on neuropsychological tests that are considered general indices of executive functions (e.g., the Wisconsin Card Sorting Test (Rhodes, 2004) and the self-ordered pointing test (Daigneault & Braun, 1993)) and from experimental tasks that are designed to target-specific control processes such as goal maintenance (Braver et al., 2001) and focus switching (Verhaeghen & Basak, 2005; Verhaeghen & Hoyer, 2007). This behavioral work is complimented by studies incorporating electrophysiological and functional neuroimaging techniques that reveal effects of aging on the neural correlates of specific control processes underlying action monitoring (Falkenstein, Hoorman, & Hohnbein, 2001), task preparation (DiGirolamo et al., 2001; Kray, Eppinger, & Mecklinger, 2005), and interference control (Jonides et al., 2000). The current study used event-related brain potentials (ERPs) to extend the findings of recent work examining the effects of aging on processes underlying task switching (Kray et al., 2005; West, 2004; West & Moore, 2005). Specifically, we considered the effects of aging on the neural correlates of processes associated with task mixing, cue retrieval, task

set configuration, and rule mapping in an explicit cue task switching paradigm.

The task switching paradigm has been used increasingly often to examine the effects of aging on the ability to manage the sequential processing demands of alternating between two or more tasks, and the ability to implement an appropriate task set in anticipation of an upcoming event (Kramer, Hahn, & Gopher, 1999; Mayr, 2001; Verhaeghen, Cerella, Bopp, & Basak, 2005). The first of these abilities is typically operationalized as *task mixing costs* that represent an increase in response time or decrease in response accuracy when performance of two tasks is mixed within a block of trials relative to when a single task is performed in a block of trials. The second ability is typically operationalized as *task switching costs* that represent an increase in response time or decrease in response accuracy that occurs when one alternates between tasks in a mixed block relative to when the same task is performed on consecutive trials in a mixed block. Behavioral and electrophysiological evidence reveals that switching costs may arise from the recruitment of diverse processes associated with cue retrieval (Logan & Bundesen, 2003), rule mapping (Logan & Bundesen, 2004; Mayr & Kliegel, 2003; Travers & West, in press), and task set configuration (Monsell & Mizon, 2006; Nicholson, Karayanidis, Bumak, Poboka, & Michie, 2006; Travers & West, in press).

The extant literature often reveals differential effects of aging on behavioral indices of mixing and switching costs. The magnitude of mixing costs is typically larger for older adults than for younger adults (Mayr, 2001; Verhaeghen et al., 2005). The age-related increase in mixing costs is generally larger than expected by general slowing (Verhaeghen et al., 2005), remains significant

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after several practice sessions (Kray & Lindenberger, 2000), and is observed in memory-based and cue-based task switching paradigms (Kray, 2006; Kray & Lindenberger, 2000). The source of the age-related increase in mixing costs is not fully understood, although De Jong (2001) has provided some evidence indicating that older adults may not fully engage the relevant task set before onset of the target stimulus (Nieuwenhuis, Ridderinkhof, de Jong, Kok, & van der Molen, 2000). In contrast to the effects of aging on mixing costs, age-related differences in switching costs are typically minimal and non-significant (Verhaeghen et al., 2005). However, work modeling the effects of aging on specific components of task switching has revealed moderate to large age-related differences in some aspects of switching costs (Meiran & Gotler, 2001; Meiran, Gotler, & Perlman, 2001). This later finding is consistent with evidence from a study using ERPs that revealed an age-related reduction in the amplitude of a parietal slow wave elicited during task switching (West & Moore, 2005). Variation in the effect of aging across these studies indicates that more work is needed in order to gain a more complete understanding of the influence of aging on the processes underlying task switching costs.

1.1. ERPs, task switching, and aging

ERPs have been used in studies of task switching to examine the neural correlates of mixing and switching costs that are associated with presentation of the task cues and onset of the target stimuli. Task mixing is associated with an increase in the amplitude of the parietal P3 (Kieffaber & Hetrick, 2005; Kray et al., 2005; Nicholson et al., 2006). The effect of task mixing on the parietal P3 probably results from the need to encode the task cues in mixed blocks (Kieffaber & Hetrick, 2005). This idea is consistent with the classic interpretation of the parietal P3 as an index of context updating related to working memory (Donchin & Coles, 1988). The enhancement of the parietal P3 associated with mixing costs appears to be delayed in older adults relative to younger adults, while the amplitude of this effect may be immune to the effects of aging (Kray et al., 2005; West, 2004). This finding could indicate that cue encoding is slowed, but otherwise intact, in later adulthood. In addition to the increased latency of the parietal P3 in older adults, mixing costs are also associated with an age-related increase in the amplitude of the P3 over the frontal region of the scalp (West, 2004). This anterior shift in the P3 is a common observation in studies examining the effects of aging on the P3 component in the oddball paradigm (Fabiani, Friedman, & Cheng, 1998). Fabiani et al. (1998) found that in older adults the frontal P3 was correlated with performance on the Wisconsin Card Sorting Test leading to the suggestion that the effect of aging on the amplitude of the frontal P3 may reflect a decline in the integrity of executive control processes.

Task mixing can also be associated with slow wave activity that is broadly distributed over the scalp. Slow wave activity associated with mixing costs appears to covary with task difficulty, being prominent when difficult response selection tasks are used (e.g., Stroop stimuli; Kray et al., 2005; West, 2004) and less pronounced or absent when less demanding tasks requiring perceptual or numeric judgments are used (Kieffaber & Hetrick, 2005). West (2004) observed that slow wave activity elicited by task mixing was attenuated in older adults relative to younger adults before stimulus onset, while Kray et al. (2005) found that slow wave activity elicited by task mixing was present in older, but not younger, adults. The reason for the difference in the effects of aging in these two studies is unclear. Although it may be related to variation in the groups of older adults that were tested or differences in the cue-to-stimulus (CSI) interval that was 1000 ms longer in the study by Kray et al. than in that by West.

In cue-locked ERP data, task switching has been associated with enhanced slow wave activity over the parietal (Kieffaber & Hetrick, 2005; Nicholson et al., 2006) and frontal-polar regions of the scalp (Travers & West, *in press*). Aging appears to result in a reduction in the amplitude of the parietal slow wave (West & Moore, 2005). The effect of aging on the parietal slow wave is interesting when considered within the context of behavioral studies that tend to reveal little effect of aging on switching costs (Verhaeghen et al., 2005), and highlights the need to supplement measures of response time and accuracy with physiological indices of the processes underlying task switching (West & Moore, 2005). The possible effects of aging on the frontal-polar slow wave have not been examined in prior research.

The neural correlates of task mixing and task switching elicited by presentation of the target stimulus are not as well understood as modulations of the ERPs elicited by presentation of the task cue. Some evidence indicates that mixing costs are associated with broadly distributed slow wave activity that begins shortly after stimulus onset and persists over much of the analyzed epoch (Kieffaber & Hetrick, 2005). Given the rather non-specific nature of this effect, it may reflect neural activity associated with an increase in attentional demands when two tasks are mixed over trials. The effects of aging on modulations of the ERPs related to task mixing and task switching elicited by presentation of the target stimulus have not been examined in the existing literature.

1.2. The information reduction paradigm

The nature of the processes giving rise to cue-locked parietal and frontal-polar slow wave activity has been investigated in studies using the information reduction task switching paradigm developed by Logan and Bundesen (2003) and Mayr and Kliegel (2003). This paradigm allows one to differentiate the influence of three types of processes (i.e., those associated with cue retrieval, task set configuration, and rule mapping) that are confounded in the comparison of task repetitions—where the cue and task repeat on consecutive trials—and task alternations—where both the cue and task change on consecutive trials—in the typical task switching paradigm (Mayr & Kliegel, 2003). Cue retrieval reflects those processes that support the ability to retrieve the cue-task associations from long-term memory (Logan & Bundesen, 2003); task set configuration reflects those processes that support the ability to prepare for the upcoming task (Monsell & Mizon, 2006) that may vary with the ease of switching from one task to the other (Allport, Styles, & Hsieh, 1994; West & Travers, *in press*); and rule mapping reflects those processes that support the ability to represent novel cue-task associations that result from the arbitrary pairing of cues and tasks (Logan & Bundesen, 2004; Mayr & Kliegel, 2003).

In the information reduction paradigm each task is associated with two cues, allowing one to consider three types of trials: cue repetitions, task repetitions, and task alternations. For cue repetitions, the cue and task are the same on consecutive trials; for task repetitions, the cue changes from one trial to the next and the task remains the same; and for task alternations, both the cue and task change on consecutive trials (Logan & Bundesen, 2003; Mayr & Kliegel, 2003). The difference between task repetitions and cue repetitions provides an index of processes associated with cue retrieval, as a cue-task association must be retrieved from memory for task, but not cue, repetitions (Logan & Bundesen, 2003). The difference between task alternations and task repetitions provides an index of processes associated with task set configuration and/or rule mapping, as for task alternations a cue-task association must be retrieved from memory and a new task set instantiated from one trial to the next (Logan & Bundesen, 2004; Mayr & Kliegel, 2003; Monsell & Mizon, 2006).

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