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Age Equivalence in Switch Costs for Prosaccade and Antisaccade Tasks

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This study examined age differences in task switching using prosaccade and antisaccade tasks. Significant specific and general switch costs were found for both young and old adults, suggesting the existence of 2 types of processes: those responsible for activation of the currently relevant task set and deactivation of the previously relevant task set and those responsible for maintaining more than 1 task active in working memory. Contrary to the findings of previous research, which used manual response tasks with arbitrary stimulus–response mappings to study task-switching performance, no age-related deficits in either type of switch costs were found. These data suggest age-related sparing of task-switching processes in situations in which memory load is low and stimulus–response mappings are well learned.

Executive control processes play an important role in the regulation and organization of our behavior. They include functions concerned with the selection, scheduling, and coordination of the computational processes responsible for perception, memory, and action (Baddeley, 1986; Norman & Shallice, 1986). We rely on these cognitive processes when we come across difficult or novel situations, when we engage in tasks that involve planning or decision making, and when we have to overcome strong habitual responses (Shallice, 1982). Deficits in frontal lobe patients, observed with psychometric tests that are assumed to require cognitive control, suggest that the neurobiological mechanisms associated with executive control processes are situated, in part, in the frontal lobes of the brain (Stuss, Eskes, & Foster, 1994; Tranel, Anderson, & Benton, 1994).

Ample empirical evidence demonstrates that age-related structural and functional changes in the frontal area of the brain differ from changes in other brain areas. Prefrontal and frontal regions show larger reductions in gray and white matter volume (Coffey et al., 1992; Colcombe et al., 2003; Pfefferbaum et al., 1992; Raz, 2000) and larger decreases in metabolic activity (Azari et al., 1992; Salmon et al., 1991) with aging than sensory and motor areas of cortex. As a result, performance on tasks that involve specific cognitive functions associated with the frontal and prefrontal cortical regions, such as inhibitory control, coordinative operations, or working memory processes, decline more rapidly in old age than performance on tasks that require use of functions supported by other regions of the brain (Ardila & Rosselli, 1989; Daigneault, Braun & Whitaker, 1992; Raz, 2000; Shimamura & Jurica, 1994).

A paradigm frequently used to study executive control is the task-switching paradigm, which involves rapid switching between two or more reaction time (RT) tasks (e.g., Allport, Styles, & Hsieh, 1994; Jersild, 1927; Rogers & Monsell, 1995). Comparisons between three different conditions in this paradigm (trials in task-homogeneous blocks, switch trials in task-heterogeneous blocks, and nonswitch trials in task-heterogeneous blocks) allow us to distinguish separate executive control components and to determine interactions among them. In task-homogeneous blocks participants perform the same task on every trial, whereas in task-heterogeneous blocks two (or more) tasks are intermixed. Task-heterogeneous blocks consist of two types of trials: switch trials, in which the task is different than the one in the preceding trial, and nonswitch trials, in which the task is the same as the task in the preceding trial.

The difference between performance on switch and nonswitch trials within task-heterogeneous blocks has been termed *specific switch costs* (Meiran, 1996; Rogers & Monsell, 1995). Specific switch costs reflect the effectiveness of executive control processes responsible for the activation of the currently relevant task set and the deactivation of the task set that was relevant on the previous trial. Another aspect of task switching, besides specific switch costs, is called *general switch costs* and is defined as the difference in performance between task-heterogeneous blocks and task-homogeneous blocks. General switch costs reflect the efficiency of maintaining multiple task sets in working memory as well as the selection of the task to be performed next (Kray & Lindenberger, 2000; but see Mayr, 2001; Mayr & Kliegl, 2000).

One of the goals of the current study was to determine the relationship between aging and the cognitive processes represented by specific and general switch costs. We were particularly interested in exploring age differences in each type of switch cost. Previous studies of task switching and aging have found significant general and specific switch costs for both young and old adults (e.g., Kray, Li, & Lindenberger, 2002) that were present even after extensive practice and when preparation time was substantially increased (Kray & Lindenberger, 2000, but see Kramer, Hahn, & Gopher, 1999). Research has also shown that age-related differences in specific switch costs are often moderate to absent when effects of general slowing are taken into account (Brinley, 1965; Hartley, Kieley, & Silbach, 1990; Kramer et al.,

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1999; Kray & Lindenberger, 2000; Mayr & Kliegl, 2000; Salthouse, Fristoe, McGuthry, & Hambrick, 1998). However, when age differences in specific switch costs are observed, the switch costs for old adults are larger than those for young adults (Kramer et al., 1999; Kray et al., 2002; Mayr, 2001).

Age effects in general switch costs are usually found to be larger than those in specific switch costs (Kray & Lindenberger, 2000; Mayr, 2001) and are often still observed after correction for general slowing. Kray and Lindenberger (2000) attributed this difference in the magnitude of age-related general and specific switch costs to the impairments of working memory associated with aging. In their study, task-heterogeneous blocks required the participants to keep track of the task sequence and remember twice as many stimulus–response (S-R) associations than task-homogeneous blocks did. Therefore, the demands on working memory in task-heterogeneous blocks were larger than those in task-homogeneous blocks. Kramer et al.'s (1999) findings support this explanation by showing that, when working memory load was low, older adults were capable of learning to switch between tasks as effectively as young adults. However, under high working memory load, older adults were unable to capitalize on practice to improve switch performance to levels exhibited by younger adults.

Mayr (2001) suggested that age-related differences in working memory capacity could not, in and of themselves, account for all of the age-related difference in switch costs. He examined this issue by minimizing the requirement to maintain the sequential structure of task switches in working memory through the use of cues and equal number of S-R rules used in task-homogeneous and task-heterogeneous blocks. Large age-related differences in general switch costs were found under conditions of reduced working memory but were present only when the stimulus was ambiguous and there was response overlap between tasks. The switch costs were interpreted in terms of an age-related impairment in the ability to internally differentiate among tasks sets. Keele and Rafal (2000), in a study that assessed switch costs in frontal lobe patients, also eliminated the difference in working memory demands between task-homogeneous and task-heterogeneous blocks by using cues and an equal number of S-R rules in blocks. Patients with lesions in the left frontal lobe showed larger general switch costs than the other groups, whereas specific switch costs did not differ among groups. Their results suggest that general switch costs, unlike specific switch costs, are related to frontal lobe functioning and, therefore, can be more affected by aging than specific switch costs.

However, Kray et al. (2002) demonstrated that age differences are not always larger for general than for specific switch costs. They used the same tasks as the Kray and Lindenberger (2000) study, but, in contrast to the previous study, the participants were provided with cues on a trial-by-trial basis. Age-related differences in general and specific switch costs were equal, mostly because of large age effects in specific switch costs. Thus, it is possible that the pattern of age differences found in the other studies holds only for certain situations that pose high demands on task control. Cues reduce those demands and, as a result, reduce the difference in age effects between general and specific switch costs. Interestingly, a similar study by Mayr (2001) also used external cues but found age-related differences to be larger for general than for specific switch costs.

Task Switching Between Prosaccade and Antisaccade Tasks

A common characteristic of previous studies on aging and task switching is the type of tasks participants were asked to perform. The tasks involved visual stimuli, such as words, digit strings, or geometrical figures, which appeared on a computer screen. The participants were asked to make decisions about the meaning of the words, number of letters or syllables in a word, value or number of the digits, or shape, size, or color of the figures. They indicated their responses manually by pressing a key on the keyboard. To perform those tasks, the participants had to remember which buttons were assigned to each possible response and then translate their answers to these arbitrary button presses.

To simplify the task-switching paradigm and minimize the response translation requirements and memory load, we decided to use saccadic eye movements as natural responses to visual stimuli. There are advantages of using saccades rather than manual responses. First, we know more about the neural circuits responsible for eye movements than we do about the neuronal circuits that support performance on tasks that have been previously used in task-switching paradigms. Second, saccades also provide us with additional measures of performance. For example, in addition to measures of saccade latency and direction errors, amplitudes of eye movements can be used as an index of performance. Thus, it is possible to provide a more fine-grained analysis of the spatiotemporal switch costs with eye-movement measures than with only manual reaction time and accuracy measures.

In our experiment, participants were asked to perform either a prosaccade or an antisaccade task, according to the cues provided. Both tasks require detecting a peripheral stimulus, which appears to the right or left of the fixation point. In the prosaccade task the participants are instructed to move their eyes to the stimulus, whereas in the antisaccade task (Hallett, 1978) they are instructed to look in the opposite direction, where no stimulus is presented.

Prosaccades and antisaccades differ in the way they are initiated. Prosaccades are based primarily on exogenous processes, especially when generated in response to a sudden-onset stimulus in the periphery (Mort et al., 2003; Trappenberg, Dorris, Munoz, & Klein, 2001), whereas antisaccades are based on endogenous processes. The term *exogenous* refers to marginally processed sensory inputs, and *endogenous* refers to processes that are dependent on voluntary inputs such as task-related instructions or expectancies (Klein, Kingstone, & Pontefract, 1994; Trappenberg et al., 2001). The antisaccade task requires not only the ability to initiate motor activity, like the prosaccade task does, but also additional processing, which includes inhibition of the exogenously based saccade toward the target and shifting attention away from the target (Olincy, Ross, Youngd, & Freedman, 1997). As a result of difficulties related to these additional processing requirements, the antisaccade task takes longer to perform and is more prone to direction errors than the prosaccade task (Butler, Zacks, & Henderson, 1999; Everling & Fischer, 1998; Olincy et al., 1997).

Previous research on aging and performance in pro- and antisaccade tasks has yielded inconsistent results. A study by Olincy et al. (1997), in which young and old adults performed prosaccade and antisaccade tasks, reported a disproportional age-related increase in latencies on the correct antisaccade trials relative to the correct prosaccade trials and a decrease in accuracy for both tasks. Nieuwenhuis, Ridderinkhof, De Jong, Kok, and Van der Molen

(2000) also found an age-related decline in the suppression of reflexive eye movements, which was indicated by an increased number of saccadic direction errors and a longer time needed to initiate correct antisaccades. Although an extensive discussion of the neuronal circuits that underlie the control of pro- and antisaccades is beyond the scope of this article (see reviews by Becker, 1991; Gaymard, Ploner, Rivaud, Vermersch, & Pierrot-Deselligny, 1998; Pierrot-Deseilligny, Rivaud, Gaymard, Muri, & Vermersch, 1995; Tehovnik, Sommer, Chou, Slocum, & Schiller, 2000, for additional details), the aging data discussed previously are consistent with the larger role for frontal and prefrontal regions such as the frontal eye fields, supplementary motor areas, and dorsolateral prefrontal cortex in the control of antisaccades than prosaccades (Gaymard et al., 1998; O'Driscoll et al., 1995; Mort et al., 2003; Schlag-Rey, Amador, Sanchez, & Schlag, 1997; Tehovnik et al., 2000). As previously discussed, older adults have been shown to have difficulty with tasks that rely heavily on frontal and prefrontal regions of the brain (Ardila & Rosselli, 1989; Daigneault et al., 1992; Raz, 2000; Shimamura & Jurica, 1994).

However, studies in which participants received more extensive practice (Fischer, Biscaldi, Gezeck, 1997; Munoz, Broughton, Goldring, & Armstrong, 1998) failed to replicate Olincy et al.'s (1997) and Nieuwenhuis et al.'s (2000) results. The number of direction errors in the antisaccade task and the extra time needed to initiate correct antisaccades compared with prosaccades were similar for both old and young adults. These results indicate that the ability to inhibit reflexive eye movements in relatively unfamiliar situations declines with age but can be substantially improved with practice.

On the basis of the findings of previous research, we expected general performance to be better on the prosaccade task than on the antisaccade task. Because our experiment consisted of two short sessions only, we predicted that older adults' performance on the antisaccade task compared with the prosaccade task would be significantly inferior to that of young adults. We did not expect to observe large practice effects.

To our knowledge, no studies have examined age differences in switch costs using anti- and prosaccades. As mentioned, studies that used manual tasks found that specific switch costs were either comparable for both age groups or slightly higher for old adults than for young adults. Age differences in general switch costs were found to be quite large, with old adults showing higher costs than young adults. We hypothesized, however, that because the tasks we used, especially prosaccades, were so natural and well practiced and placed small working memory demands on participants, there would be no differences in either kind of switch costs between young and old adults.

Another goal of the current study was to determine the effects of task preparation on specific and general switch costs by varying the length of the interval between the cue and the onset of the imperative stimulus or target. Two important findings were obtained in other task-switching studies that manipulated the cue–target interval. First, Rogers and Monsell (1995) showed that the duration of the preparation period affects the switch costs only when it is constant within a block. Second, the magnitude of both general and specific switch costs decreases with increasing stimulus onset asynchrony (SOA) (Kramer et al., 1999; Kray & Lindenberger, 2000; Meiran, Gotler, & Perlman, 2001; Rogers & Monsell, 1995). However, switch costs do not entirely disappear even with the longest SOAs. An exception to this general finding was provided by Hunt and Klein (2002), who used saccades (i.e., pro- and antisaccade tasks) to study task-switching performance (see also Weber, 1995). Contrary to previous studies that have used manual responses with arbitrary S-R mapping, Hunt and Klein (2002) observed that switch costs were eliminated at modest cue–task SOAs. We replicated the Hunt and Klein study with some methodological and analytical changes. First, tasks switched randomly in our study, as compared with predictably in Hunt and Klein, in an effort to provide a strong test of the hypothesis that age-related differences in switch costs could be eliminated with nonarbitrary S-R relations and low memory load. Random or unpredictable switches have previously been shown to produce larger switch costs and larger age differences than predictable switches (Kramer et al., 1999) and, therefore, should be more difficult to eliminate, even with long cue–task SOAs. Second, we separately examined age-related differences in specific and general task-switching costs. This contrast is important because of both the differences in the processes that underlie these two types of switch costs as well as the difference in the magnitudes of the age-related effects that have previously been observed for specific and general switch costs.

In the current experiment, we compared the effects of preparation time (0, 200, and 600 ms) on performance of young and old adults, using a cuing paradigm and prosaccade and antisaccade tasks grouped in task-homogeneous and task-heterogeneous blocks. Our dependent variables were saccade direction accuracy, saccadic latency, amplitude, and specific and general switch costs. The main goals of the current study were to determine the presence of specific and general switch costs in performance on a task involving eye movements, to examine the effect of the length of the preparatory interval on both types of costs, and to explore age differences in switch costs.

Method

Participants

Fifteen young adults (age range = 19–29 years, *M* = 22.4 years) and 16 old adults (age range = 63–79, *M* = 70.7) participated in the study.[1] Eight

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[1] Twenty-five old and 14 young adults completed the experiment. However, an initial examination of the data indicated that a subset of the older adults had high error rates (9 of 25 participants), particularly on the antisaccade trials (for both the homogeneous and heterogeneous trial blocks). These high error rates render it difficult to interpret switch costs for participants who are, in essence, performing with chance accuracy on the antisaccade trials. Thus, it was possible that age-related switch costs may have been masked as a result of chance performance on antisaccade trials for a subset of the older participants. To examine this issue, we removed all trials that followed incorrect or inconclusive responses from our data before conducting analyses. In this way, we could be assured that participants were switching from a correctly performed task to the task to be performed next. The inconclusive responses were all responses that were initially excluded because of participants' blinking or their inability to keep their eyes focused on the fixation cross or saccadic latencies shorter than 80 ms or longer than 1,000 ms. After excluding participants with fewer than 10 trials per cell, we were left with the data for 16 old and 15 young participants. The set of analyses reported here is from this reduced set of older adults. However, it is important to point out that the switch cost effects were statistically equivalent in the full and reduced data set, as were the demographic characteristics of the older adult participants.

of the young participants and 9 of the old participants were women. The young adults were students at the University of Illinois at Urbana–Champaign, and the older adults were recruited from the local community. Both groups were paid for their participation in the study.

All of the participants, both young and old, had near-visual acuities of at least 20/40 corrected as measured by a Snellen acuity chart. Young and old participants also possessed statistically equivalent years of formal education (14.5 and 14.9 for the young and old, respectively) and rated their health as excellent (4.7/5.0 and 4.5/5.0 for the young and old, respectively).

Apparatus

The tasks in the computerized part of the experiment (Sessions 2 and 3) were presented on a 21-in. monitor interfaced with a Gateway Pentium 150-mHz computer. Each participant was seated in a dimly lit room with the head stabilized by means of a chin rest, which was located 71 cm from the monitor. Eye movements were recorded with an Eyelink eye tracker with 250-Hz temporal resolution and a 0.2-degree spatial resolution.

Stimuli

A fixation cross, 0.4 × 0.4 degrees of visual angle, was presented in the center of the display. A letter cue, either *A* or *T*, which appeared in place of the fixation cross, measured approximately 0.32 degrees in width and 0.36 degrees in height. The stimulus to which participants responded was a dot, 0.5 degrees in diameter, which was shown 4.7 degrees either to the left or to the right of fixation (measured from the center of the dot). The fixation cross, cues, and dot were presented in white on a black background.

Procedure

The experiment consisted of three sessions. In the first session, which took place on a different day than the other two, demographic information such as age, ratings of health, years of education, and visual acuity were collected. The participants were also familiarized with the laboratory and eye-movement-recording equipment during this session.

The second and third sessions were identical and consisted of a computerized task-switching paradigm. A short rest period separated the two sessions. Each session consisted of 15 practice trials followed by 200 experimental trials. Figure 1 presents the series of events that made up a trial. At the beginning of each trial, a fixation cross was presented in the center of the display. After 1,000 ms, the cross was replaced with a letter cue, either *A* or *T*, which remained on the screen for the rest of the trial. The letter *A* indicated that the participant should look away from the stimulus (antisaccade), and the letter *T* indicated that he or she should look toward the stimulus (prosaccade). The stimulus appeared on either the left or right side of fixation. The trial ended once the eyes returned to fixation after having made a saccade toward or away from the dot. The trials were paced at 2,500 ms. If the eyes did not move and return to fixation within 1,500 ms from the onset of the cue, a warning message accompanied by a beep appeared on the screen, and the next trial was initiated after the participant pressed a key on the keyboard. Any blinks and eye movements before the onset of the peripheral stimulus also resulted in a warning beep.

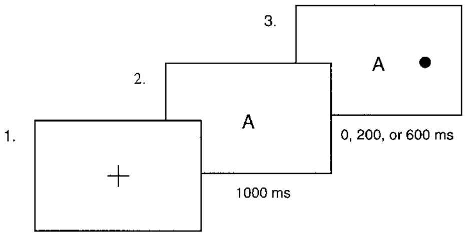

Figure 1. A graphic illustration of the temporal sequence of an experimental trial. The fixation cross (+) was replaced after 1,000 ms by a letter cue (A in the antisaccade task). The imperative stimulus (solid circle) appeared 0, 200, or 600 ms after the onset of the letter cue.

In each of the two sessions, the experimental trials were grouped in seven blocks. The first two and the last two blocks were task-homogeneous blocks, which required making either a prosaccade (Blocks 2 and 6) or an antisaccade (Blocks 1 and 7) on every trial in the block. Each task-homogeneous block consisted of 20 trials and was preceded by appropriate instructions. Even though the task was clearly specified and did not change throughout the block, the letter cue (*A* or *T*) was provided on each trial. The stimulus onset was simultaneous with the cue onset. That is, the SOA between the central informative cue and the peripheral stimulus was 0 ms. The stimulus was presented randomly either on the right or on the left from the cue, with equal numbers of appearances on each side.

Blocks 3, 4, and 5 were task-heterogeneous blocks, in which the participant was to make either a prosaccade or an antisaccade within the same block according to the letter cue. There were zero, one, two, three, or four possible repetitions of a task before a switch occurred. The number of repetitions was random. The SOA (0, 200, or 600 ms after the onset of the letter cue) was manipulated between blocks, and the order of the blocks was counterbalanced across participants. Each task-heterogeneous block consisted of 40 trials. Participants pressed the space bar when they were ready to start the next block. Appropriate instructions were provided before the first task-heterogeneous block.

Analyses

Responses were considered correct if the first fixation was on the correct side of the fixation point (i.e., on the same side as the dot for the prosaccade task and on the opposite side from the dot for the antisaccade task). Saccade latencies were measured from target onset to the onset of the first saccade. Because the visual system requires at least 80 ms to initiate a saccade in response to a visual stimulus (Becker, 1985), saccades with latencies shorter than 80 ms (0.2% of all responses) were classified as anticipatory and were excluded from the analysis. Saccades with latencies longer than 1,000 ms (0.3% of all responses) were also discarded from the analysis as were saccade latencies obtained when participants moved their eyes to the wrong location.

Results

We first performed analyses on absolute performance measures, such as error rate, log-transformed first-saccade latencies for correct responses, and first-saccade amplitudes for correct responses. We then focused on specific and general switch costs for both error rates and log-transformed latencies, following the predictions laid out early in this article. Logarithm-transformed saccadic reaction times were used for our analyses because their mean differences are equivalent to ratio scores and, therefore, less sensitive to differences in baseline performance, especially between the young and old adult groups (Ratcliff, 1993).

Analyses of Absolute Performance Measures

For error rates, log-transformed latencies, and saccade amplitudes, we computed a 2 (age group: young and old) × 2 (task: antisaccades and prosaccades) mixed analysis of variance (ANOVA), with age group as a between-subjects variable and task as a within-subject variable. Error rates, log-transformed latencies, and saccade amplitudes are displayed as a function of age group, task, and block in Figure 2.

In the analyses of error rates and latencies in the homogeneous trial blocks, all main effects were significant. We found substantial

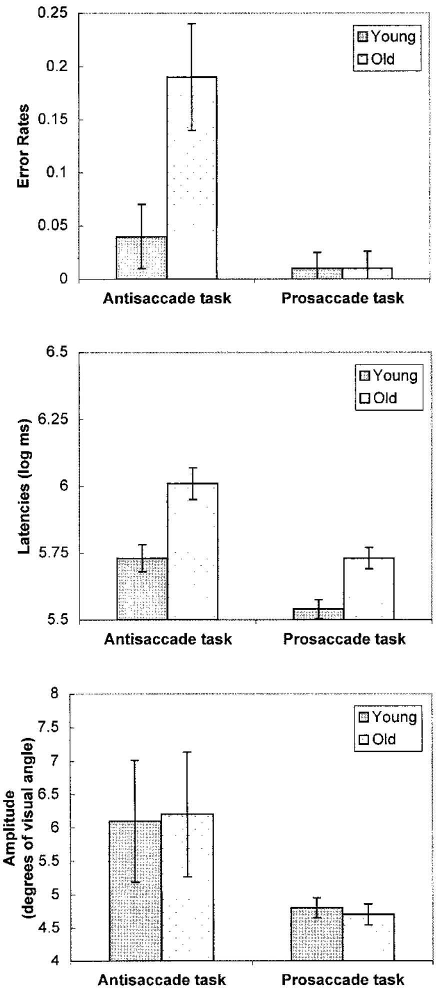

Figure 2. Error rates, log-transformed saccade latencies, and saccade amplitudes as a function of age group and task for the homogeneous trial blocks.

age differences—errors, $F(1, 29) = 11.7$, $d = 1.3$,[2] $p < .01$; latencies, $F(1, 29) = 14.4$, $d = 1.4$, $p < .01$—indicating that young adults responded faster and more accurately (5.64 mean log ms and .025 error rate) than old adults (5.87 mean log ms and .10 error rate). The main effect for task was also observed: errors, $F(1, 29) = 24.6$, $d = 1.8$, $p < .01$; latencies, $F(1, 29) = 13.3$, $d = 1.4$, $p < .01$. Performance on the prosaccade task was more accurate and faster (5.64 mean log ms and .01 error rate) than on the antisaccade task (5.87 mean log ms and .115 error rate). A significant two-way interaction between age group and task was obtained for error rates, $F(1, 29) = 8.5$, $d = 1.1$, $p < .01$. As can be seen in Figure 2, old adults' accuracy in the prosaccade task was similar to that of young adults' performance in both the prosaccade and antisaccade tasks. In the antisaccade task, however, old adults were significantly less accurate than young adults.

The saccade amplitude analysis revealed a main effect for task, $F(1, 29) = 10.8$, $d = 1.2$, $p < .01$; amplitudes of correct antisaccades were larger (6.15 degrees of visual angle) than those of correct prosaccades (4.75 degrees of visual angle). The amplitude of the prosaccades was similar to the distance between the fixation cross and the dot (4.7 degrees), whereas the amplitude of the antisaccades was much greater than 4.7 degrees. This was likely a result of the lack of a target on the opposite side of the dot in the antisaccade task.

In the next set of analyses, task-heterogeneous blocks were analyzed separately. Error rates, log-transformed latencies, and saccade amplitudes were submitted to a repeated measures ANOVA with age group (young and old) as a between-subjects variable and trial type (switch and nonswitch), task (antisaccades and prosaccades), and SOA (0, 200, and 600 ms) as within-subject variables. Figure 3 shows error rates, log-transformed latencies, and saccade amplitudes as a function of age group, trial type, task, and SOA.

For errors and saccadic latencies, all main effects were significant. We found considerable age differences—errors, $F(1, 29) = 10.0$, $d = 1.2$, $p < .01$; latencies, $F(1, 26) = 39.5$, $d = 2.3$, $p < .01$—with old adults responding slower and less accurately (6.02 mean log RT and .20 error rate) than young adults (5.76 mean log RT and .12 error rate). We also observed the main effect for task—errors, $F(1, 29) = 63.5$, $d = 2.9$, $p < .01$; latencies, $F(1, 26) = 6.2$, $d = 1.4$, $p < .05$—with the prosaccade task being performed faster and more accurately (5.83 mean log RT and .07 error rate) than the antisaccade task (5.95 mean log RT and .25 error rate). A significant effect for SOA was also obtained—errors, $F(2, 58) = 11.9$, $d = .91$, $p < .01$; latencies, $F(2, 52) = 27.3$, $d = 1.4$, $p < .01$—which indicates that response speed increased (6.01, 5.88, and 5.79 mean log RTs for 0, 200, and 600 ms, respectively) and the number of errors decreased (.22, .15, and .11 error rates for 0, 200, and 600 ms, respectively) as SOA became longer. Finally, we found significant differences in error rates and latencies between switch and nonswitch trials—errors, $F(1, 29) = 32.6$, $d = 2.1$, $p < .01$; latencies, $F(1, 26) = 5.7$, $d = .94$, $p < .05$—with switch trials being less accurate and slower (.21 error rate and 5.93 mean log RT) than nonswitch trials (.11 error rate and 5.85 mean log RT). Two significant interactions were also observed. A significant interaction between task and age was found for error rates only, $F(1, 29) = 11.2$, $d = 1.2$, $p < .01$. Young and old adults' accuracies were similar in the prosaccade task, but old adults' accuracy in the antisaccade task was lower than that of young adults. Another interaction, between task and trial type, was found only for saccadic latencies, $F(1, 26) = 32.4$, $d = 2.2$, $p < .01$. The interaction indicated that the difference in latencies between switch and nonswitch trials was larger for prosaccades than for antisaccades. The amplitude analysis revealed only a main effect of task, $F(1, 26) = 10.7$, $d = 1.3$, $p < .01$, with antisaccades' amplitudes being greater than prosaccades' amplitudes (6.04 and 4.70 mean degrees of visual angle for antisaccades and prosaccades, respectively).

Analyses of Switch Costs

With the use of a one-sample t test, we obtained significant specific switch costs for both error rates, $t(30) = 5.81$, $d = 2.1$, $p < .01$, and latencies, $t(30) = 2.11$, $d = .77$, $p < .05$, and

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[2] Cohen's d was used to estimate effect size for the analyses reported here. Cohen (1988) provided a heuristic for interpreting measures of d, in which a small effect size would have a value of less than .20, a medium effect size would have a value of .50, and a larger effect size would have a value greater than .80.

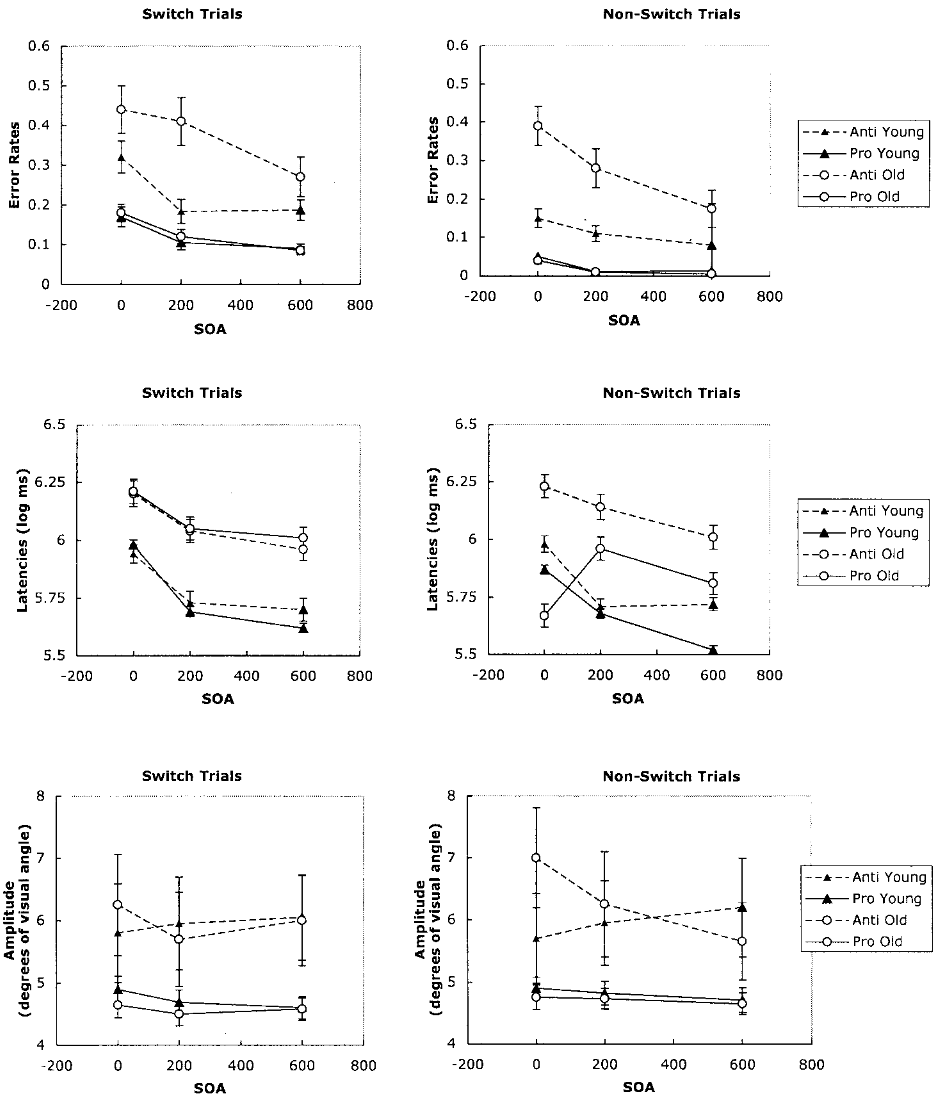

Figure 3. Error rates, log-transformed latencies, and saccade amplitudes as a function of trial type, age group, task, and stimulus onset asynchrony (SOA). These data are from the heterogeneous trial blocks. Anti = antisaccades; Pro = prosaccades.

significant general switch costs[3] for both error rates, $t(30) = 10.83$, $d = 1.2$, $p < .01$, and latencies, $t(30) = 5.80$, $d = .88$, $p < .01$.

Specific and general switch costs for both error rates and log-transformed latencies were submitted to a 2 (age group: young and old) × 2 (task: antisaccades and prosaccades) × 3 (SOA: 0, 200, and 600 ms) ANOVA, with age group as a between-subjects variable and task and SOA as within-subject variables. Figure 4 shows specific and general switch costs for accuracy and latencies as a function of age, task, and SOA. Although there is an apparent increase in age differences with SOA for the specific switch cost latency measures for prosaccade trials, this increase was not significant. Indeed, one of the most notable results is the lack of a main effect for age group for specific and general switch costs for both error rates and latencies (ds $< .30$, ps $> .1$). We also did not find a main effect of SOA for specific switch costs, which indicated that specific switch costs do not systematically decrease as SOA increases. However, a main effect for SOA was observed for general switch costs—errors, $F(2, 58) = 15.6$, $d = 1.0$, $p < .01$;

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[3] General switch costs were calculated by subtracting the 0-ms homogeneous condition from each of the different SOA (i.e., 0, 200, and 600 ms) conditions for the heterogeneous blocks. The use of the 0-ms homogeneous condition to calculate the general switch cost for each of the three SOAs (i.e., with the 0, 200, and 600 ms SOAs in the heterogeneous blocks) presupposes that significant cuing effects will not accrue in the homogeneous blocks (because participants perform the same task repeatedly and they are aware that they perform only a single task in these trial blocks). To test this assumption, we conducted a pilot study in which 4 young and 4 older adults performed in homogeneous trial blocks with 0-, 200-, and 600-ms cue–stimulus SOAs. Consistent with our assumption, we failed to find any evidence of an SOA effect for either the younger or the older adults (ps $> .50$).

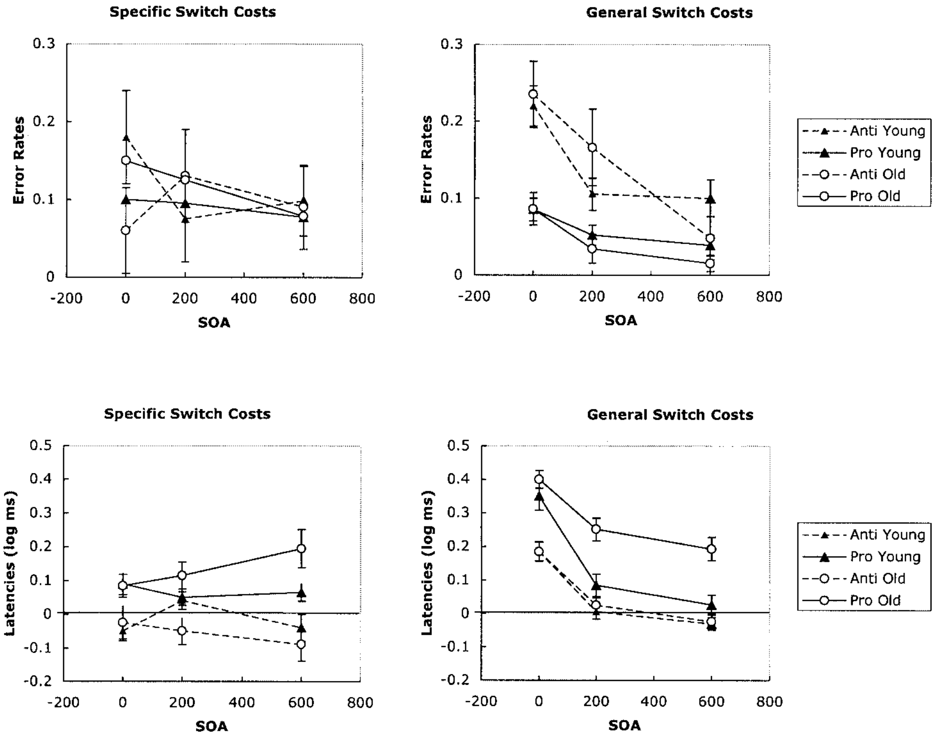

Figure 4. Specific and general switch costs for error rates and log-transformed latencies as a function of age group, task, and stimulus onset asynchrony (SOA). Anti = antisaccades; Pro = prosaccades.

latencies, $F(2, 58) = 28.6$, $d = 1.4$, $p < .01$—suggesting that general switch costs decrease as the preparatory interval becomes longer (.16, .09, and .05 error rates and .26, .09, and .04 mean log RT switch costs for 0, 200, and 600 ms, respectively).

Discussion

The main goal of the current study was to examine the relationship between aging and the executive control processes that underlie the ability to switch between different tasks. Specifically, we focused on two types of processes: those measured by specific switch costs and responsible for the activation of the currently relevant task set and the deactivation of the previously relevant set and those measured by general switch costs and responsible for keeping more than one task-set instruction active and selecting the task set to be performed next. We were also interested in determining how task preparation affects these processes.

With regard to the first goal, we found no differences, in any of our measures or analyses, in general or specific switch costs between young and old adults. These findings are contrary to most of previous research, which indicates the existence of small to moderate age-related differences in specific switch costs (e.g., Kramer et al., 1999; Kray et al., 2002) and large age differences in general switch costs (e.g., Kray & Lindenberger, 2000; Mayr, 2001), with old adults exhibiting higher switch costs than young adults.

The main difference between previous studies and the current work is the nature of the tasks between which the participants were asked to switch. In our experiment, we used saccades as responses to stimuli instead of previously used manual responses (button presses). By using eye movements, which are natural and well-learned responses to visual stimuli, we eliminated the need to remember arbitrary S-R mappings. Thus, the tasks in the current study required minimum working memory. Our data suggest age-related sparing of executive processes responsible for task-switching performance in situations in which memory load is low and S-R assignments are well learned (see also Mayr, 2001).

Another important goal of our study was to determine the effect of task preparation on switch costs by examining three different durations (0, 200, and 600 ms) of the interval between the cue and the onset of the imperative stimulus. As expected, switch costs were not entirely eliminated at long SOAs, likely as a result of the unpredictable occurrence of switches from one task to the other.

Contrary to our initial predictions, we found no effect of SOA on specific switch costs for either age group. That is, specific switch costs did not decrease as the length of the preparatory interval increased. This lack of an SOA or preparation effect resulted from the fact that, in our experiment, switch trials and nonswitch trials in the task-heterogeneous blocks benefited equally from the increase in preparation time. In previous studies, which found that specific switch costs decreased as SOA increased (Kramer et al., 1999; Kray & Lindenberger, 2000; Meiran et al., 2001; Rogers & Monsell, 1995), switch trials tended to benefit from an SOA increase more than nonswitch trials did. This discrepancy in the findings of the current study compared with previous studies could have been the result of the reduced difficulty of determining S-R relations in the current study.

We also wanted to determine whether saccadic latency and error rates in heterogeneous blocks could be reduced to those observed in 0-ms SOA homogeneous blocks as the length of the preparatory interval in the heterogeneous blocks increased. Our data suggest that this is, in fact, the case for saccadic latency when SOA in the heterogeneous blocks is equal to 600 ms ($p > .55$). However, error rates were still significantly higher in the heterogeneous block than in the homogeneous block, $F(1, 29) = 11.4$, $d = 1.2$, $p < .01$. Thus, these data suggest that participants can prepare, at least in part, for task switches (see also De Jong, 2001) given sufficient time with tasks with nonarbitrary S-R mappings.

In summary, an important conclusion of the current study, when viewed in the context of previous studies of aging and task switching, is that the magnitude of age-related differences in switch costs can be influenced by the nature of the tasks. When manual tasks with arbitrary S-R mappings are used, old adults show poorer task-switching abilities than young adults. However, in the case of saccades, which rely less on working memory than manual responses, the ability to switch between tasks is comparable between the two age groups. Future research is needed to examine task-switching performance with other well-learned tasks that require little memory load to determine the generalizability of our findings.

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