Published in final edited form as:

Exp Aging Res. 2012 ; 38(1): 87–109. doi:10.1080/0361073X.2012.637008.

Aging and Random Task Switching: The Role of Endogenous Versus Exogenous Task Selection

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Abstract

Task switching experiments have emphasized two robust effects that arise when individuals are required to shift between competing tasks: *Mixing costs* (MCs), which indicate less efficient performance in mixed-task versus single-task conditions, and *switch costs* (SCs), which reflect differences between switch trials and repetition trials within mixed-task conditions. The current study examined how age-related differences in these effects were influenced by the method of task selection in two procedures. Results indicated that SCs were not disproportionately larger for older adults during an *exogenous* switching condition, but large age differences in MCs were present beyond the degree predicted by differences in baseline speed. In an *endogenous* switching condition, small age differences were present both for MCs and SCs, although further age differences were evident in older adults' reduced *switch rates*. These findings suggest that older adults are substantially slower at updating repeated task sets during exogenous switching, but partially counter these effects by adopting a more persistent within-set mode of processing during endogenous switching.

Keywords

cognitive aging; task switching; executive control

Daily life often demands mental flexibility. The capacity to select and shift between competing tasks – referred to as task switching – is thought to rely heavily on executive control processes (Logan, 2003; Monsell & Mizon, 2006; Rubinstein, Meyer, & Evans, 2001), critically engage certain regions of the frontal lobes (Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; MacDonald, Cohen, Stenger, & Carter, 2000; Sohn, Ursu, Anderson, Stenger, & Carter, 2000), and place similar demands on task coordination abilities as dual-task scenarios (Dreher & Grafman, 2003; Verhaeghen & Cerella, 2002). Normal aging is often associated with pronounced deficits both on tests of executive functioning that involve the frontal lobes (West, 1996) and dual-task procedures that require the execution of two overlapping tasks (Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). Recent studies of skill acquisition have also revealed significant delays in strategy shifting among older adults (e.g., Hertzog, Touron, & Hines, 2007; Touron & Hertzog, 2009), suggesting that the process of endogenously switching between tasks may also be associated with age-related changes in metacognitive processes.

However, findings regarding the effects of aging on task switching ability have suggested that only certain aspects of task switching may be sensitive to age-related declines in cognitive performance (Meiran, Gotler, & Perlman, 2001; Verhaeghen & Cerella, 2002). Individual differences studies of executive functioning have indicated that “set shifting” appears to represent a separate and distinct executive function as compared to operations such as inhibition and updating (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) or working memory operations that include storage, processing, and coordination (Oberauer, Süß, Wilhelm, & Wittman, 2003). In fact, as part of a latent variable analysis, Miyake and colleagues (2000) failed to find a significant relationship between a task switching factor and scores on several working memory capacity measures.

Furthermore, switch costs, as measured in most task switching procedures, are only sometimes interpreted as a direct index of executive control processes (Logan, 2003; Monsell & Mizon, 2006; Rubinstein, Meyer, & Evans, 2001). Logan and Bundesen (2003), for example, have presented data suggesting that cued task switching procedures may not require the activity of executive control processes, but merely reflect encoding benefits from the presentation of repeated task cues. Other researchers have argued that these procedures still involve an executive component, but that cue-encoding benefits account for the bulk of the difference between task-switch and task-repetition trials (Mayr & Kliegl, 2003). Consequently, both the method of task presentation and the metric used to measure task switching performance have become issues of debate in the literature on task switching, executive control, and aging.

Aging and Task Switching

The task switching literature has generally emphasized two effects that emerge when individuals are required to periodically switch between simple cognitive tasks that involve similar stimuli and responses: *Mixing costs* (MCs) and *switch costs* (SCs; Monsell, 2003). In mixed-task conditions, trials for which the same task is repeated tend to have slower response times (RTs) than trials within blocks of single-task performance (MC = mixed-task repetition RT – single-task RT), and trials for which the task is switched tend to be slower still (SC = mixed-task switch RT – mixed-task repetition RT).¹

Most studies examining the effects of aging on task switching performance have found larger age differences in MCs compared to SCs (e.g., Kray, Eber, & Lindenberger, 2004; Kray & Lindenberger, 2000; Mayr, 2001; Mayr & Liebscher, 2001; Van Asselen & Ridderinkhof, 2000). Furthermore, several investigations have demonstrated that once general slowing is taken into account, age differences in SCs become negligible, but age differences in MCs often remain significant (Kray & Lindenberger, 2000; Mayr, 2001; Van Asselen & Ridderinkhof, 2000). The bulk of evidence suggests that age differences in MCs are more pronounced, while age differences in SCs may only appear in certain situations (e.g., Kramer, Hahn, & Gopher, 1999).

Interestingly, most studies of task switching have relied on *exogenous* task selection by requiring participants to follow external task cues presented randomly before each trial (Meiran, 1996). These types of procedures have been used to demonstrate age-related deficits in various aspects of performance (e.g., Kray, Li, & Lindenberger, 2002; Mayr, 2001; Meiran, Gotler, & Perlman, 2001). However, fewer studies have emphasized *endogenous* task selection by allowing participants to choose which task to perform on each new stimulus (Arrington & Logan, 2004; Arrington & Logan, 2005; Mayr & Bell, 2006; Terry, 2005). This distinction may be of critical importance for studying executive control in

¹These costs are also sometimes referred to as *global/general* and *local/specific* costs, respectively.

task switching (Arrington & Logan, 2005; Logan & Bundesen, 2003; Logan, Schneider, & Bundesen, 2007), yet to our knowledge this type of endogenous task switching procedure has not yet been examined in older adults.

In a review of meta-analyses, Verhaeghen and Cerella (2002) found evidence that age deficits beyond those predicted by general slowing were present in MCs and *divided attention* paradigms, but not in SCs or *selective attention* paradigms. The authors concluded that, beyond the effects of general slowing, aging exerts its influence on one's ability to manage multiple task sets, but is less likely to affect one's ability to implement immediate switches between tasks within a mixed-task setting. Similarly, other researchers have suggested that age differences in MCs may be more pronounced because blocks of mixed-task performance actually represent a "special case" of more general, dual-task scenarios (Kray, Li, & Lindenberger, 2002).

Although the notion of a general, age-related overhead in MCs has received some support, this finding may also be subject to certain constraints. In a series of experiments, Mayr (2001) found that pronounced age differences in MCs only emerged in conditions involving bivalent stimuli and full response-set overlap (i.e., where the same stimuli and responses are used for both tasks). Furthermore, changes in working memory demands or inhibitory processes alone did not produce substantial age differences in MCs. The author proposed that MCs reflect the activity of an updating process that adjusts internal control settings in the face of potential task set interference, and that age-related increases in MCs indicate a deficit in this task set updating process.

However, these results were derived from a task switching procedure that emphasized exogenous task selection by requiring participants to process unpredictable task cues on a trial-to-trial basis. More research is needed in order to determine whether updating task sets under more endogenous conditions would increase executive set switching demands and lead to greater age-related performance costs. Therefore, the goals of the current investigation were twofold: 1) compare exogenous versus endogenous methods of task selection in two procedures that emphasize random task switching, and 2) determine whether age-related deficits in task switching performance are more pronounced during an endogenously directed procedure in which participants control the selection of each new task.

Voluntary Task Switching

The most widely used task switching protocol is the explicitly-cued switching procedure (Meiran, 1996), which requires subjects to randomly shift between tasks by processing an unpredictable task cue on each trial. This procedure is often described as a form of exogenous random switching because the task is randomly selected by the programming software on each trial. Conversely, Arrington and Logan (2004) recently introduced a voluntary task switching procedure that also relies on a random task sequence, but places the trial-by-trial burden of task selection on the participant. By instructing participants to randomly select one of two possible tasks to perform on each trial, this protocol serves as a counter to cued switching in that it represents a form of endogenous random switching.

The explicitly-cued switching procedure has been studied quite extensively in young adults (Monsell, 2003), and substantial age-related increases in MCs have been previously demonstrated using this exogenously directed procedure (e.g., Kray, Li, & Lindenberger, 2002; Mayr, 2001; Meiran, Gotler, & Perlman, 2001). However, only a few studies have examined how the "voluntary" method of task selection introduced by Arrington and Logan (2004) affects task switching performance in young adults (Arrington & Logan, 2005; Mayr

& Bell, 2006; Terry, 2005), and to our knowledge this procedure has not yet been tested with older adults.² Additionally, the voluntary switching paradigm has been argued to place stronger demands on executive control processes than externally driven task switching procedures (Arrington & Logan, 2005). Because the frequency and timing with which individuals change tasks is not directly controlled by the experimenter, voluntary switching allows each individual to produce a unique *switch rate*. Therefore, beyond differences in MCs and SCs, age-related differences in one's ability to flexibly shift between competing tasks may also be evidenced by reduced switch rates.

A number of unique findings regarding age-related changes in various dimensions of executive functioning suggest that this paradigm should be particularly sensitive to the effects of aging (Braver & West, 2008). For example, research indicating that older adults demonstrate deficits in their ability to suppress habitual or prepotent response tendencies (e.g., Treitz, Heyder, & Daum, 2007) implies that age-differences are likely to appear with respect to switch rates, which are thought to reflect one's ability to frequently (but non-stereotypically) initiate task changes within a context where the task might otherwise remain constant. A large body of research demonstrating persistent age-related declines in performance on the Wisconsin Card Sorting Test, including a tendency to produce more perseverative errors (see Rhodes, 2004 for a review), also supports this notion, as does evidence that older adults are less proficient at generating random sequences (e.g., Van der Linden, Beerten, & Pesenti, 1998). Furthermore, age-related decrements in context processing have been clearly demonstrated to affect performance beyond differences in processing speed during continuous performance tasks in which the nature of the previous trial may directly affect the context of the current stimulus (e.g., Rush, Barch, & Braver, 2006).

Still, literature regarding aging and dual-task performance suggests that the voluntary task switching procedure may comprise similar components as many dual-task paradigms that are particularly sensitive to the effects of aging (e.g., Verhaeghen & Cerella, 2002; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). For instance, the voluntary switching paradigm imposes two competing sets of instructions upon participants. As a primary task, participants are expected to execute either of two competing choice-reaction-time tasks as quickly and accurately as possible on each trial and in equal proportion throughout a block of trials. As a secondary task, participants are instructed to switch between the two tasks in a random fashion, such that a) 50-percent of trials will involve a task switch, and b) the series of task switches will not resemble a stereotyped sequence. This unusual combination of instructions suggests that additional age differences beyond those associated with task set updating processes in working memory (e.g., Fisk & Sharp, 2004) should result from the unique demands on executive functioning associated with voluntary task selection.

Current Study

The current study examined whether MCs or SCs resulting from bivalent stimuli were larger for older adults in two procedures that differed based on the method of task selection. Specifically, when tasks are selected at random on a trial-by-trial basis, do age differences in MCs or SCs differ when tasks are selected in an exogenous or endogenous fashion? We addressed this question by comparing younger and older adults' performance on cued and

²Another commonly studied task switching paradigm is the alternating-runs procedure (Rogers & Monsell, 1995), which requires subjects to follow a fixed task sequence throughout a block of trials. This procedure generates uncertainty regarding the relative exogenous versus endogenous processes underlying task performance, and embedded task cues (e.g., stimulus location) can affect the level of monitoring and memory retrieval required to execute the proper task sequence (Koch, 2003). For these reasons, the alternating-runs paradigm was not examined in the present study, although it has been used in some aging studies of task switching (e.g., Kray & Lindenberger, 2000).

voluntary task switching, both of which require a random sequence of task changes, but place different demands on externally versus internally directed processes. Furthermore, including the voluntary task switching procedure also made it possible to examine whether potential age differences in endogenous task switching were reflected in participants' switch rates. A separate binary random selection task was also included in order to determine whether younger and older adults' conceptions of randomness differed when tested in a different context from the voluntary task switching procedure.

Based on previous studies of task switching, we expected that within the cued switching paradigm age differences beyond those predicted by general slowing would be apparent for MCs, but not necessarily for SCs (Verhaeghen & Cerella, 2002). Furthermore, because it has been argued that voluntary task switching places strong demands on executive control processes (Arrington & Logan, 2005), we expected that pronounced age-related performance decrements would also emerge in this procedure. Mayr (2001) has shown that during conditions involving exogenous task selection older adults incur large MCs due to their apparent reliance on a costly task set updating process. Therefore, we hypothesized that if older adults maintained this task set updating mode of processing while performing voluntary task switching, then this would result in disproportionately large increases in MCs, while age differences in SCs and switch rates would be minimal. However, previous research with the voluntary task switching procedure has indicated that even younger adults struggle to establish switch rates as high as 50-percent (Arrington & Logan, 2004; 2005; Mayr & Bell, 2006; Terry, 2005). In this case, we hypothesized that if older adults adopted a more dominant within-set mode of processing during voluntary task switching, as suggested by Mayr & Bell (2006), age-related differences in performance would be reflected by increased SCs and/or decreased switch rates.

Method

Participants

Twenty-six young adults, 18 to 21 years of age ($M = 18.4$, $SD = 1.1$), were recruited from the Syracuse University undergraduate subject pool and received course credit for their participation. Twenty-five older adults, 74 to 87 years of age ($M = 80.3$, $SD = 5.4$), were recruited from the community and participated as part of a larger study called the Cognition, Health, and Aging Project (CHAP). Older adults who volunteered for the current experiment were remunerated separately for their total participation in CHAP. All participants enrolled in CHAP demonstrated intact mental status by making fewer than eight errors on the Blessed mental status exam (Blessed, Tomlinson, & Roth, 1968). As a group, the twenty-five older adults who participated in this portion of the experiment scored just above the national average based on their scaled scores both for the Digit Symbol ($M = 10.9$, $SD = 2.3$) and Vocabulary ($M = 11.7$, $SD = 2.5$) subtests of the WAIS-III (Wechsler, 1997).

Stimuli and Tasks

Stimuli were presented on Dell monitors using a Dell computer and E-Prime software. All stimuli were presented in large, white font (42 pt.) against a black background. The stimuli for the task switching procedures included digits from the sets 1-4 and 6-9, and were presented in the center of the screen. For each trial, subjects were required to perform one of two choice-reaction-time tasks, which included a parity judgment (even vs. odd) and a magnitude judgment (higher or lower than five). In the voluntary switching condition, all trials contained a fixed response-stimulus interval (RSI) of 100ms and only the target stimulus appeared on the screen (modeled after the short RSI condition in Arrington & Logan, 2004). In the cued switching condition, all trials contained a fixed response-cue interval (RCI) of 100ms and each two-word task cue ("Odd-Even" or "Low-High")

appeared directly above the target stimulus, which appeared following a consistent 100ms cue-target interval (CTI). These RCI and CTI durations are commonly used in the task switching experiments.

Subjects responded manually on a standard QWERTY keyboard and employed a univalent response mapping that incorporated four keys: “B” and “N” with the left hand, and “1” and “2” on the number pad with the right hand. One task was mapped to each hand and the four response keys were labeled to match each of the possible responses: “O” for odd, “E” for even, “L” for low, and “H” for high. Subjects were instructed to use their index and middle fingers on each hand to press the keys, which stood-out prominently on the keyboard due to yellow and blue labels.

Subjects also performed a binary random selection task (“coin flipping”) in which they were instructed to reproduce the outcome of a series of hypothetical coin flips by pressing one of two response keys on the keyboard in order to indicate the outcome of each imaginary coin flip. For this task, the “Z” and “/” keys were labeled “H” and “T” in green, representing *heads* and *tails*, and subjects were instructed to press each key using their index finger on each hand. Participants were told to simply imagine that they were flipping a coin and to indicate the outcome of each imaginary flip by pressing either the key for heads or for tails. Participants were given several trials of practice before beginning the task.

Procedure

For all subjects, the experiment was divided into three segments lasting approximately 15-20 minutes each. Before each new condition, the subject reviewed the instructions with the experimenter and then performed 16 practice trials, which could be repeated if necessary. In the first segment, subjects established a baseline level of task performance by performing each task separately in single-task conditions and completing the coin flipping task. This segment included four blocks of single-task performance for each task, followed by four blocks of the coin flipping task (1 block = 48 trials). For half of the single-task blocks a cue indicating which task to perform remained on the screen, while for the other blocks the screen was blank except for the trial stimulus.

In the second segment, subjects completed the exogenous random switching protocol. After two blocks of additional single-task practice (with cues present), subjects performed four blocks of cued task switching at a 50-percent switch rate (as programmed by the experimenter). In the third segment, subjects completed the endogenous random switching protocol. After another two blocks of single-task practice (with cues absent), subjects performed four blocks of voluntary task switching and were instructed to a) establish a 50-percent switch rate, and b) do so in a random fashion so that the trial-by-trial selection of tasks resembles the outcome of a series of coin flips. For more specific instructions regarding voluntary task switching see Arrington and Logan (2004).

Results

Mean RTs and accuracy rates for younger and older adults performing cued and voluntary switching in single-task and mixed-task conditions are shown by trial type in Table 1 (RTs are plotted in Figure 1). Error trials and trials shorter than 200ms or longer than 5000ms were eliminated from the analyses (this equaled less than 10% of trials for all participants). Log-transforming the RT data in order to account for the influence of generalized age-related slowing did not alter the pattern of effects produced by the primary analyses. Furthermore, all results for accuracy were either non-significant or in the same direction as the RT results. Therefore, the following analyses focus solely on the RT results for the untransformed data.

Response Times

Mean RTs were analyzed in a 2 (Age: Young vs. Old) $\times$ 2 (Procedure: Cued vs. Voluntary) $\times$ 3 (Trial Type: Single-task vs. Repetition vs. Switch) mixed ANOVA. There was a main effect of age, $F(1, 49) = 43.57$, $p < .0001$, $\eta_p^2 = .58$, such that older adults were slower than younger adults, a main effect of procedure, $F(1, 245) = 13.61$, $p < .001$, $\eta_p^2 = .05$, such that cued switching took longer than voluntary switching, and a main effect of trial type, $F(2, 245) = 529.03$, $p < .0001$, $\eta_p^2 = .81$, such that single-task trials were fastest, followed by mixed-task repetition trials, and then mixed-task switch trials.

These results were qualified by several interactions. An age by procedure interaction, $F(1, 245) = 11.11$, $p < .001$, $\eta_p^2 = .04$, indicated that although younger adults had nearly equivalent average RTs across the two procedures, older adults had slower average RTs in cued switching compared to voluntary switching. An age by trial type interaction, $F(2, 245) = 23.51$, $p < .0001$, $\eta_p^2 = .16$, also indicated that differences across trial types were larger for older adults than for younger adults. Whereas, a procedure by trial type interaction, $F(2, 245) = 12.30$, $p < .0001$, $\eta_p^2 = .09$, suggested that although RTs in the cued and voluntary procedures were similar for single-task trials and mixed-task switch trials, mixed-task repetitions were notably slower in the cued switching procedure compared to voluntary switching. However, the three-way interaction between age, procedure, and trial type did not quite reach significance, $F(2, 245) = 2.40$, $p = .09$, $\eta_p^2 = .16$. Therefore, further analyses were conducted by calculating MCs and SCs for each procedure.

Mixing Costs and Switch Costs

MCs and SCs were calculated for each subject and the mean group data (see Figure 2) were analyzed in a 2 (Age: Young vs. Old) $\times$ 2 (Procedure: Cued vs. Voluntary) $\times$ 2 (Cost: MC vs. SC) mixed ANOVA. There was a main effect of age, $F(1, 49) = 21.28$, $p < .0001$, $\eta_p^2 = .21$, such that older adults incurred larger costs than younger adults, and a main effect of cost, $F(1, 147) = 34.07$, $p < .0001$, $\eta_p^2 = .19$, such that MCs were larger than SCs; however, there was no main effect of procedure, $F(1, 147) = 1.22$, $p = .27$, $\eta_p^2 = .01$.

These results were also qualified by several interactions. An age by cost interaction, $F(1, 147) = 5.46$, $p < .03$, $\eta_p^2 = .04$, suggested that age differences were larger for MCs than for SCs. Furthermore, a procedure by cost interaction, $F(1, 147) = 61.49$, $p < .0001$, $\eta_p^2 = .29$, indicated that although MCs and SCs were of similar magnitude within the voluntary switching procedure, MCs were much larger than SCs within the cued switching procedure. There was no interaction between age and procedure, $F(1, 147) = 1.48$, $p = .23$, $\eta_p^2 = .01$, but the three-way interaction between age, procedure, and cost was significant, $F(1, 147) = 8.26$, $p < .01$, $\eta_p^2 = .05$. The data underlying this three-way interaction suggest that although older adults incurred greater overall costs, both groups incurred comparable patterns of MCs and SCs in voluntary task switching. However, in cued switching older adults displayed much larger MCs than expected based on their SCs.

This interpretation was further evaluated by testing the simple effects of age and cost separately for the voluntary and cued switching procedures (all comparisons were confirmed using Scheffe's correction to adjust for Type I error). The effect of age remained significant for voluntary switching, $F(1, 49) = 12.63$, $p < .001$, $\eta_p^2 = .15$, but the effect of cost, $F(1, 49) = 1.36$, $p = .25$, $\eta_p^2 = .03$, and the interaction, $F(1, 49) = 0.10$, $p = .76$, $\eta_p^2 < .01$, were not significant. This suggests that although older adults were slower at voluntary switching, the relative magnitude of MCs and SCs did not change with age. However, for cued switching, both the effects of age, $F(1, 49) = 21.64$, $p < .0001$, $\eta_p^2 = .35$, and cost, $F(1, 49) = 88.75$, $p < .0001$, $\eta_p^2 = .64$, were significant, as well as the interaction, $F(1, 49) = 12.88$, $p < .001$, $\eta_p^2 = .21$. This interaction suggests that, although older adults were slower than younger

adults and MCs were generally larger than SCs, older adults incurred disproportionately large MCs during cued switching.

Task Rates and Switch Rates

In the coin flipping task, subjects were instructed to choose between heads and tails outcomes on each trial in order to generate a string of responses resembling a likely outcome for a series of coin flips. Similarly, in the voluntary task switching procedure, subjects were instructed to choose, in a random fashion (“as if flipping a coin”), whether to perform the magnitude or parity task on each trial. Therefore, the coin flipping task provided a baseline measure of random selection without the demand of additional task execution, such that “heads vs. tails” represented opposing tasks rather than “magnitude vs. parity.” In order to determine whether participants demonstrated a selection bias in either of these conditions (i.e., favoring one task over another), a measure of *task rates* was examined. A 2 (Age: Young vs. Old) $\times$ 2 (Condition: Control vs. Voluntary) mixed ANOVA failed to indicate an effect of age, $F(1, 49) = 0.26$, $p = .61$, $\eta_p^2 < .01$, or condition, $F(1, 49) = 0.24$, $p = .63$, $\eta_p^2 < .01$, and there was no interaction, $F(1, 49) = 0.93$, $p = .34$, $\eta_p^2 = .02$. Furthermore, the 95-percent confidence intervals for younger and older adults' task rates both included 50-percent. This indicates that neither during the coin flipping nor voluntary task switching conditions did participants demonstrate a selection bias that may have influenced their switch rates.

Therefore, a 2 (Age: Young vs. Old) $\times$ 2 (Condition: Control vs. Voluntary) mixed ANOVA was also used to test for age differences in switch rates – the rate at which participants switched back-and-forth between competing tasks – during the coin flipping and voluntary switching procedures (see Figure 3). One subject from the older age group was excluded from the switch rate analysis for switching almost continuously during the coin flipping task (i.e., switch rate = .99). This was the only subject in either condition who displayed a switch rate more than three standard deviations from the mean. A main effect of age, $F(1, 48) = 6.72$, $p < .02$, $\eta_p^2 = .24$, indicated that older adults switched less frequently than younger adults, and a large main effect of condition, $F(1, 48) = 139.84$, $p < .0001$, $\eta_p^2 = .74$, indicated that switch rates were much lower in the voluntary switching condition than in the coin flipping task. The interaction between age and condition did not quite reach significance, $F(1, 48) = 2.94$, $p = .09$, $\eta_p^2 = .06$. Although, post hoc contrasts using Scheffe's correction for Type I error indicated that younger and older adults demonstrated comparable switch rates (.58 and .53, respectively) in the coin flipping task, $F(1, 48) = 1.47$, Scheffe's adjusted $p = .69$, whereas older adults displayed a significantly lower switch rate (.29 versus .39) in the voluntary switching procedure, $F(1, 48) = 9.66$, Scheffe's adjusted $p < .04$. The only case in which the 95-percent confidence interval of the mean included a 50-percent switch rate was for older adults performing the coin flipping task (switch rate = .53).

These results are in line with previous studies that have demonstrated a pronounced *repetition bias* during the voluntary switching procedure (Arrington & Logan, 2004; Terry, 2005). However, this is the first indication that this effect may be more pronounced among older adults. These studies have also demonstrated a small *alternation bias* during a separate binary random selection task, whereas in the present study this alternation bias during the coin flipping task was only significant for younger adults. Furthermore, at least two studies have demonstrated positive correlations between switch rates and RTs during voluntary task switching, such that subjects who established higher switch rates tended to incur larger MCs (Mayr & Bell, 2006) or perform repetition trials more slowly (Terry, 2005). A similar pattern of correlations emerged in the current study (see Table 2), such that there was a significant positive correlation between switch rates and repetition trial RTs for older adults, $r(23) = .54$, $p < .01$, and this correlation approached significance for younger adults, $r(24) = .$

37, $p = .07$. However, switch rates were not correlated with switch trial RTs for younger, $r(24) = .18$, $p = .38$, or older adults, $r(23) = .08$, $p = .68$, respectively. This relationship suggests that participants who switch between tasks more frequently also perform repetition trials more slowly, either due to an abbreviated repetition benefit or by resisting task perseveration through slower repetition trial performance. Possible explanations for this finding will be examined in the discussion.

Baseline Speed & Switch Rates

The following analyses were conducted in order to determine whether age differences in mixed-task performance during cued and voluntary switching could be fully accounted for by two unique factors: baseline speed and switch rates. For the cued switching procedure, age differences in single-task RTs were used as a covariate to adjust RTs for repetition and switch trials during mixed-task performance. After covarying for differences in single-task speed, age differences in switch trial speed were no longer significant, $F(1, 49) = 0.79$, $p = .38$, $\eta_p^2 = .02$, although age differences in repetition trial speed remained significant, $F(1, 49) = 7.45$, $p < .01$, $\eta_p^2 = .13$. For the voluntary switching procedure, age differences both in single-task RTs and mixed-task switch rates were used as covariates to adjust RTs for repetition and switch trials during mixed-task performance. Covarying for single-task speed fully accounted for age differences in switch trial speed, $F(1, 49) = 0.35$, $p = .56$, $\eta_p^2 < .01$, and switch rate was not a significant predictor of switch trial performance. However, although both single-task speed and switch rate accounted for significant variance in repetition trial speed, age differences in repetition trial speed remained significant, $F(1, 49) = 4.93$, $p = .03$, $\eta_p^2 = .10$.

These results suggest that age differences in switch trial speed both in the cued and voluntary switching procedures were well predicted by age differences in baseline speed. However, age differences in repetition trial speed could not be fully explained by baseline speed or switch rate, implying that some other factor beyond general slowing must also contribute to older adults' slowed performance on this particular type of trial. We explored this issue by examining age differences in the repetition benefit incurred on task repetition trials in the two switching procedures.

Repetition Benefit

Because mean differences between younger and older adults' repetition trial speed in mixed-task conditions could also be influenced by changes in efficiency throughout a "run" of task repetitions, age differences in RTs were examined across the first four repetitions in a run (see Figure 4). The following analysis was conducted to determine whether differences in the RT benefits accrued throughout task runs may have contributed to the presence of mean age differences in repetition trial speed between the two switching procedures. A 2 (Age: Young vs. Old) $\times$ 2 (Condition: Cued vs. Voluntary) $\times$ 4 (Repetition: 1-4) mixed ANOVA indicated significant main effects for all three variables, such that older adults were slower, $F(1, 49) = 49.13$, $p < .0001$, $\eta_p^2 = .55$, cued switching took longer, $F(1, 338) = 63.42$, $p < .0001$, $\eta_p^2 = .16$, and RTs for earlier positions in a run tended to be slower than for later positions, $F(3, 338) = 23.36$, $p < .0001$, $\eta_p^2 = .17$. This latter result indicates that performance quickened when participants performed the same task across consecutive trials. However, the only interaction to reach significance was the age by condition effect, $F(1, 338) = 21.69$, $p < .0001$, $\eta_p^2 = .06$. This suggests that although younger adults accomplished similar levels of performance throughout a run in the cued and voluntary switching procedures, older adults remained slower at performing task repetitions throughout a run in cued switching relative to voluntary switching. This finding indicates that compared to voluntary switching older adults incurred a consistent "overhead" cost in cued switching that did not change throughout runs of task repetitions.

Discussion

Age differences in task switching performance were apparent both in a procedure that emphasized exogenous task selection (i.e., cued task switching; Meiran, 1996), as well as a procedure that emphasized endogenous task selection (i.e., voluntary task switching; Arrington & Logan, 2004). However, the form and pattern of age differences was not equivalent for these two procedures, indicating that the method of task selection is an important factor contributing to age differences in task switching performance. Findings will be discussed with respect to differences in control settings during cued versus voluntary task switching conditions.

Cued Task Switching

In the cued task switching condition, older adults incurred large MCs beyond the degree predicted based on differences in baseline speed, while age differences were minimal for SCs. This pattern of effects – exaggerated MCs and attenuated SCs – supports a task set updating hypothesis of age differences in task switching (Mayr, 2001). This account claims that older adults fail to maintain activation of a previously relevant task set to the same degree as younger adults when faced with ambiguous stimulus information. The task set updating hypothesis has also received support from studies involving event-related brain potentials (ERPs) that have demonstrated characteristic age-related changes in the time course of various ERP latencies (e.g., P3 latency) in a variety of situations that require the encoding, representation, or maintenance of task context (Kray, Eppinger, & Mecklinger, 2005; West, 2004).

Two implications result from this perspective, each of which was supported by the data. First, older adults should be less well prepared for task repetition trials due to their need to update or reactivate the repeated task set on every trial. Indeed, older adults incurred inflated MCs by performing task repetitions more slowly than predicted by baseline speed. Secondly, this need to update the task set on every trial should in fact reduce the amount of additional time needed on switch trials to implement a new versus repeated task set. In fact, older adults' SCs were attenuated such that they were nearly equal to those incurred by younger adults.

It should be considered, however, that the exogenous switching procedure also required subjects to process random task cues on a trial-by-trial basis, thereby ensuring that the relevant task for a forthcoming stimulus could not be determined in advance of the cue. In this case, the finding that older adults incurred inflated MCs might suggest that aging affects one's ability to efficiently process task cues. However, Mayr (2001) presented evidence that this was not the case, and three pieces of evidence in the current data also argue against this account. First, baseline performance during single-task conditions was not affected by the presence or absence of a task cue that reminded subjects of the relevant task on each trial (see Figure 1). Secondly, and more directly, age differences were negligible for SCs, which reflected not only a change in task, but also a change in the cue that signaled the appropriate task (see Figure 2). Therefore, if older adults were especially slow at cue processing, they should have also incurred large SCs due to cue changes on switch trials. Thirdly, older adults displayed a similar repetition benefit as younger adults throughout a run of task repetitions (see Figure 4). Prior studies of cued task switching have demonstrated that similar RT benefits emerge when specific task cues are repeated on consecutive trials (e.g., Logan & Bundesen, 2003).

Voluntary Task Switching

In the voluntary task switching condition, age differences were evident both for SCs and MCs, but within the range predicted based on differences in baseline speed. Alone, these results suggest that age differences in control settings may only emerge when task selection is not under endogenous control. However, older adults' performance in this paradigm was not uncompromised compared to younger adults. Switch rates were significantly lower for older adults (.29 versus .39) and this reduction in switch rates was not predicted by performance on a separate binary random selection task. This finding suggests that older adults failed to initiate task switches as frequently as younger adults when this responsibility was placed under endogenous control. Previous studies of voluntary task switching have consistently indicated some degree of repetition bias (Arrington & Logan, 2004; 2005; Mayr & Bell, 2006; Terry, 2005). However, the current data represent the first demonstration of this effect among older adults and provide preliminary evidence indicating that switch rates may be sensitive to the effects of aging.

Furthermore, switch rates were positively correlated with repetition trial RTs and once age differences in switch rates were taken into account, significant age differences in repetition trial RTs reemerged beyond those predicted by differences in baseline speed. This finding results in two interesting conclusions. First, older adults substantially improved their repetition trial RTs by adopting lower switch rates, thereby creating the impression that no age differences existed beyond those predicted by general slowing. But secondly, the resulting reduction in repetition trial RTs should have been even greater if no other age differences in performance existed beyond general slowing (e.g., age differences in task set updating processes). Therefore, age differences in task set updating processes appeared both in the cued and voluntary task switching procedures; however, these effects were accompanied (and somewhat masked) by additional age differences in switch rates during the voluntary switching procedure.

This finding is not at all surprising with respect to the literature regarding aging and dual-task performance (e.g., Verhaeghen & Cerella, 2002; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). The voluntary task switching procedure comprises similar components as many dual-task paradigms in which two related, yet distinct demands are simultaneously imposed upon the participant. The competing instructions to execute either task (magnitude or parity) as quickly and accurately as possible, while also trying to switch between the tasks in a random fashion may have placed a form of dual-task demand on participants, even though the individual choice-reaction-time tasks were performed in a successive fashion. In most cases, participants failed to meet this secondary demand to establish a seemingly random, 50-percent switch rate, as indicated by a significant reduction both in younger and older adults' switch rates. However, one might expect that this type of dual-task situation would have lead to even greater MCs due to the need for older adults to keep two tasks active in working memory. Yet, the data suggest that older adults did not keep the task as active in mind during voluntary task switching and thereby were able to avoid having to consistently update the current task set on each repetition trial. The switch rate data support this conclusion based on the fact that older adults switched less frequently, possibly as a consequence of not keeping the alternative task active in working memory throughout each task run.

In describing a similar finding, Mayr and Bell (2006) argued that effective endogenous random task selection requires subjects to treat each trial as a "discrete event," rather than performing strings of trials under the same task set in a manner of "continuous flow." If this is the case, subjects who switch more frequently should perform repetition trials more slowly in order to resist perseverating under the same task. As expected, both younger and older adults' switch rates were correlated with their repetition trial RTs (.37 and .54,

respectively), but not their switch trial RTs. These results suggest an interesting dual-task trade-off, such that both age groups managed to reduce MCs at the cost of switch rates. However, this reduction in switch rates during voluntary task switching was greater for older adults, suggesting that they adopted a more persistent within-set mode of processing when task selection was placed under endogenous control. Yet, when differences in switch rates were also considered as a covariate for predicting repetition trial RTs, significant age differences reemerged. This finding suggests that despite older adults' more pronounced repetition bias, they still failed to accrue comparable reductions in RTs as younger adults while performing voluntary task switching.

Conclusions

The current study examined two procedures that have not been directly compared in younger and older adults: Cued task switching and voluntary task switching. Findings indicated that during cued switching, where task selection was under *exogenous* direction, older adults were much slower at updating a repeated task set, but displayed little difference in their ability to efficiently switch between tasks. However, during voluntary switching, where task selection was under *endogenous* control, older adults displayed a similar pattern of mixing costs and switch costs as younger adults, but demonstrated a more pronounced repetition bias by initiating fewer switches between tasks. This differential pattern of findings suggests that, in circumstances where task selections are driven by unpredictable, external factors, age differences in task set updating processes may be more pronounced. Whereas, in situations where changes between tasks are self-initiated, older adults may adopt a more dominant within-set mode of processing that can mask underlying response time differences in task updating processes. Therefore, the method of task selection may be a critical factor in determining how efficiently older adults manage competing tasks when stimuli afford multiple courses of action.

Acknowledgments

This research was supported in part by grants from the National Institute on Aging (Grants R01 AG-26728, 12448).

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Figure 1. Response times (RTs) in milliseconds by trial type (single-task, repetition, or switch) for younger and older adults performing voluntary and cued task switching. Error bars represent standard errors.

Figure 2. Mixing costs (MCs) and switch costs (SCs) in milliseconds for younger and older adults performing voluntary and cued task switching. Error bars represent standard errors.

Figure 3. Switch rates (SRs) for younger and older adults during a binary random selection task (“coin flipping”) and voluntary task switching. Error bars represent standard errors.

Figure 4. Response times (RTs) in milliseconds by run position for younger and older adults performing voluntary and cued task switching. Graph includes data for the first four task repetitions. Error bars represent standard errors.

Table 1
Mean Response Times (in milliseconds) and Accuracy Rates by Trial Type

	Single-Task	Repetition	Switch
Young (Voluntary)	631 (87)	919 (167)	1244 (254)
	.987 (.01)	.974 (.02)	.968 (.04)
Young (Cued)	599 (81)	1010 (187)	1206 (251)
	.982 (.01)	.948 (.04)	.959 (.04)
Old (Voluntary)	803 (108)	1206 (275)	1673 (377)
	.991 (.02)	.984 (.02)	.970 (.06)
Old (Cued)	790 (127)	1523 (313)	1778 (452)
	.989 (.01)	.942 (.06)	.966 (.04)

Note: For single-task trials the only difference between the voluntary and cued switching conditions was the presence or absence of a task cue. Standard deviations are included in parentheses.

Table 2
Correlations Between Switch Rates and Response Times in Voluntary Task Switching

	Repetitions	Switches
Young (n =26)	.37*	.19
Old (n = 25)	.54**	.08

*
 $p < .10$

**
 $p < .01$