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Age-Related Differences in Switching Between Cognitive Tasks: Does Internal Control Ability Decline With Age?

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The present study tested the hypothesis that older adults establish a weaker task set than younger adults and therefore rely more on stimulus-triggered activation of task sets. This hypothesis predicts that older adults should have difficulty with task switches, especially when the stimuli–responses are associated with multiple, competing tasks. Weak task preparation, however, could actually benefit older adults when performing an unexpected task. The authors tested this prediction in Experiment 1 using a repeating AABB task sequence, with univalent and bivalent stimuli intermixed. On some univalent trials, participants received an unexpected task. Contrary to the authors' predictions, expectancy costs were not smaller for older adults. Similar findings were obtained in Experiments 2 and 3, in which the authors used a task-cueing paradigm to more strongly promote deliberate task preparation. The authors found no disproportionate age effects on switch costs but did find age effects on bivalence costs and mixing costs. The authors conclude that older adults do experience extra difficulty dealing with stimuli associated with 2 active tasks but found no evidence that the problem specifically stems from an increased reliance on bottom-up task activation rather than top-down task preparation.

Keywords: cognitive control, aging, task switching, expectancy cost

Research on cognitive aging has revealed widespread slowing of cognitive processing among older adults (e.g., Craik & Salthouse, 2000). This slowing can be especially severe when performing tasks that require a high degree of cognitive task control. For instance, when there is a need to switch between tasks, cognitive control might serve to activate the relevant task set and deactivate the irrelevant task set. Several studies have found that older adults experience difficulty establishing task control settings in the face of conflicting stimulus information (e.g., Kramer, Hahn, & Gopher, 1999; Kray & Lindenberger, 2000; Mayr, 2001; Mayr & Liebscher, 2001), which have led to various proposals that aging is associated with an internal control deficit.

The present study tested one particular type of internal control deficit in which older adults establish weaker task sets (top-down) than younger adults and therefore rely more on stimulus-triggered (bottom-up) activation of task sets. In our paradigm, participants sometimes received a stimulus uniquely associated with a task they were not expecting. The main question was whether older adults, by virtue of establishing a weaker task, would show smaller costs of task-expectancy violations.

Age-Related Differences in Task Switching

Two principal methods have been used to study task switching. One is the alternating runs paradigm (AABB) wherein *switch costs* are computed as the difference in response time (RT) between task switches and task repetitions (e.g., Rogers & Monsell, 1995). The other is the task-cuing paradigm wherein the task sequence is random, and the upcoming task is explicitly signaled by a task cue (e.g., Meiran, 1996). Despite a variety of methods, previous task-switching studies have generally produced similar results. One robust finding is that switch costs are larger when each stimulus is associated with both active tasks (bivalent stimuli) than when each stimulus is associated with its own unique task (univalent stimuli; e.g., Lien, Ruthruff, & Kuhns, 2006; Ruthruff, Remington, & Johnston, 2001). The stimulus itself in the bivalent condition provides no indication of what task is to be performed, thus forcing participants to exert cognitive control to perform the proper task and to consistently respond correctly. Another common finding, known as the *mixing cost*, is that task-repetition RT is longer within blocks containing both tasks (mixed blocks) than within blocks containing only one task (pure blocks).

Researchers in aging have produced divergent views regarding age effects on cognitive control (for a recent review, see Allen, Ruthruff, & Lien, 2007). Kray and Lindenberger (2000), for instance, found age effects in mixing costs but not in switch costs (see also Hartley, Kieley, & Slabach, 1990; Kramer et al., 1999;

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Salthouse, Fristoe, McGuthry, & Hambrick, 1998). They argued that older adults have difficulty maintaining multiple task sets in working memory. Mayr (2001) further clarified the source of age effects in mixing costs by manipulating the degree of overlap between stimuli and between responses of the competing task sets (the color task vs. the shape task). The stimuli could be bivalent ("ambiguous" in Mayr's terminology) or univalent ("unambiguous"). The responses could have no overlap (left and right keys for the color task, top and bottom keys for the shape task), conceptual overlap (different left and right keys for the color and shape tasks), or complete overlap (the same left and right keys for both tasks). Age effects on mixing costs were limited to the condition in which there was complete overlap between the stimuli and between the responses of the tasks (bivalence). He attributed the age effect in mixing costs to a problem associated with "an updating process that 'cleans up' internal control settings" (p. 106). These findings also suggest that some previous failures to obtain age differences can be attributed to the use of incomplete overlap between tasks, making task switching relatively easy.

De Jong (2000, 2001) has proposed a related account. He found that, for younger adults, switch costs arise entirely from failures to utilize available control capabilities on some task-switch trials (*goal neglect*). Accordingly, task-switch trials with a long response–stimulus interval (RSI) should contain a mixture of trials on which participants fully prepare and trials on which they completely fail to prepare. In other words, the fastest task-switch trials with a long RSI (most of which should involve full preparation) should resemble the fastest task-repetition trials. De Jong confirmed this prediction using an analysis of cumulative distribution function of RTs (but see Lien, Ruthruff, Remington, & Johnston, 2005). De Jong (2001) argued that if older adults are as capable as younger adults in preparing for a task, then they should show a similar pattern. The data suggested otherwise. Using bivalent stimuli–responses and a long RSI, De Jong found the fastest task-switch RTs for older adults never approached their fastest task-repetition RTs. He concluded that older adults have a reduced capacity for goal selection.

In summary, the studies discussed above (despite some notable differences) point to the conclusion that, when the stimulus and response are bivalent (associated with more than one task), older adults have more difficulty than younger adults in internal (top-down) control over task-set selection. In the following section, we discuss one specific hypothesis built upon these findings and a novel approach to testing it.

Internal Control Deficit Hypothesis

The internal control deficit hypothesis we tested in the present study assumes that older adults have weaker internal control over task settings than do younger adults, and older adults compensate by relying more on external stimulus control over task settings. This hypothesis is consistent with neurophysiological evidence that the frontal and prefrontal cortices responsible for internal control show large reductions in gray matter volume with age (e.g., Coffey et al., 1992). Weaker internal control settings could occur because older adults are less able to inhibit the just-performed task set (now irrelevant) or because older adults fail to fully prepare the new task set. Although previous findings favor the latter (e.g., De Jong, 2001), the proposed internal control deficit hypothesis does not explicitly distinguish between these two alternatives.

If older adults have weaker internal control, they might compensate by relying more on external task control, that is, allowing stimuli to prime the associated task set. For univalent stimuli, associated with only one task, this strategy should be very effective, and hence no age effects should be observed. Bivalent stimuli, however, should pose a special challenge for older adults. Because older adults are not strongly biased towards the relevant task, they may perform both tasks to some degree on the presented stimulus. They may then require additional (time-consuming) cognitive control to resolve the competition between tasks.

Although the reliance on external task control rather than internal task control would penalize older adults under most conditions, it might actually prove to be an advantage under specific circumstances. Consider, for example, when a person strongly expects to perform one task (e.g., letter classification) yet receives a stimulus uniquely associated with a completely different task (e.g., a colored box associated with a color task). Younger adults can establish a strong bias towards the expected task, and thus their task settings should not be easily overridden by a stimulus associated with the unexpected task. Accordingly, an additional (time-consuming) act of internal task control would be needed to readjust their task settings. Older adults, however, are hypothesized to establish a weaker task set for the expected task. They rely more strongly on external task control, allowing the presented stimulus to prime the proper task set. Therefore, they should have relatively little trouble adjusting to a stimulus associated with the unexpected task. Thus, older adults might actually show less task expectancy cost than would younger adults. The present study tested this prediction. To provide converging tests, we also examined age effects in switch costs (which have produced somewhat mixed results in previous studies).

The Present Study

The present methodology is based on Ruthruff et al.'s (2001) study with younger adults. In that study, the authors were interested in how task expectancy (expected vs. unexpected) and task recency (task repetition vs. task switch) interact to produce the readiness for an upcoming task. To ensure that participants had sufficient time to engage in task preparation, they used an alternating-runs paradigm with a long, constant RSI of 2,500 ms. The tasks were to determine the color of a box or the identity of a letter (univalent stimuli). The critical manipulation was whether participants received the task they were expecting or another task. Results showed that the effects of task expectancy and task recency were generally additive, suggesting that they influence different processing stages. Ruthruff et al. further speculated that there is a task reconfiguration stage (influenced by task expectancy) followed by response selection (influenced by task recency).

We adopted Ruthruff et al.'s (2001) design with one major modification to create a stronger need for internal task control, which may be critical for revealing age effects. Whereas they used univalent stimuli only, we intermixed bivalent and univalent stimuli within blocks. The presence of bivalent stimuli (which afford the performance of both active tasks) strongly encourages participants to maintain strong internal task control to consistently respond correctly. The effect of this preparation is then assessed on univalent trials, which could contain either the expected task or the unexpected task (e.g., participants expect to perform a letter task, but instead receive a colored box). As discussed below, our data show especially large expectancy costs, indicating that we were in fact successful in encouraging strong task preparation.

We used several converging tests of the internal control deficit hypothesis. The primary indicator was the *task-expectancy* effect, which can be measured only on *univalent* trials. According to the internal control deficit hypothesis, older adults are less able than are younger adults to establish a mental set for the expected task set and compensate by relying more on external task control. Accordingly, older adults might actually have less difficulty than younger adults in dealing with unexpected tasks. The second indicator was the *switch cost*. We focused on switch costs for *bivalent* trials only, which require the most cognitive control and have been found to be the most sensitive to cognitive aging. The internal control deficit hypothesis we proposed in the present study predicts that older adults will establish a weaker task set and thus produce larger switch costs than will younger adults. The third indicator was the *bivalence cost*. By necessity, we assessed these costs using *expected* trials only (in our methodology, unexpected trials cannot be bivalent). If older adults have an internal control deficit, they should have extra difficulty with bivalent trials, producing larger bivalence costs than younger adults.

Experiment 1

In Experiment 1, we used a repeating AABB task sequence. Several steps were taken to encourage advance preparation. First, a long, constant RSI allowed sufficient preparation time. Second, on bivalent stimulus trials, the irrelevant stimulus attribute was always associated with a response that was incompatible with the correct response. Thus, failing to prepare for the proper task would typically result in an error. Third, a summary of participants' performance was provided at the end of each block. To make participants more aware of their performance and more accountable, we instructed them to write down their performance on a summary sheet. According to the internal control deficit hypothesis, older adults (relative to younger adults) should produce smaller task-expectancy costs but larger switch costs and bivalence costs.

Method

Participants. There were 48 younger adults and 28 older adults who participated in this study. Younger adults were undergraduates at Oregon State University who participated in exchange for extra course credit. Their mean age was 21 years (SD = 2 years, range: 18–27 years). Older adults were individuals who resided in the same community as the university who were paid $15/hr. Their mean age was 70 years (SD = 6 years, range: 62–82 years). All participants had normal or corrected-to-normal visual acuity and normal color vision.

Apparatus and stimuli. Stimuli were presented on IBM-compatible microcomputers. The average viewing distance was 55 cm. A 12 cm × 12 cm frame consisting of four boxes was presented in the screen's center (see Figure 1). The univalent stimulus was a filled colored square (red, green, or blue) or a white letter (*I*, S, or *O*). The bivalent stimuli were white letters centered inside the colored square. Each side of the colored square was 2.3-cm long. The letters were 1.5-cm tall and 0.4-cm, 1.0-cm, and 1.2-cm in width for *I*, *S*, and *O*, respectively.

Design and procedure. On each trial, participants performed either a color task or a letter task. For the color task, participants pressed the *m* key for red, the < key for green, and the > key for blue. For the letter task, participants pressed the *m* key for *I*, the < key for *S*, and the > key for *O*. They used the index, middle, and ring fingers of their right hand.

The first stimulus of each block appeared in the top-left box. Each subsequent stimulus appeared in the box located immediately clockwise from the previous one. The task performed depended on the location of stimulus. For half of the participants, the top two locations were assigned to the color task and the bottom two locations were assigned to the letter task (producing a repeating task sequence of color-color-letter-letter). For the other participants, the assignment was reversed. For the first three practice blocks, the words *COLOR* and *LETTER* appeared outside of the frame but next to the particular locations associated with that task.

For the bivalent condition, the colored square and the letter appeared simultaneously, with the letter always located inside the square. For the univalent condition, only the letter or the colored square appeared in the center of the box. The identity of the relevant stimulus was chosen randomly, with the restriction that each stimulus appeared equally as often within each block. The identity of the irrelevant stimulus was selected randomly, with the restriction that the relevant and irrelevant stimuli were to always correspond to different responses.

To encourage advance preparation, we followed Lien et al. (2005) and described the tasks within the context of a game. Each trial started with a fixation cross for 1,400 ms in the center of the box. After a 500-ms blank period, the stimulus appeared. After participants responded, or 4,000 ms had elapsed since stimulus onset, feedback (an error beep and a frowning face on error trials, a yellow smiley face on correct trials) was presented for 400 ms. The fixation cross for the next trial appeared 100 ms later. Consequently, the total RSI was 2,400 ms.

Participants performed 4 practice blocks, followed by 10 experimental blocks. Each block contained 40 trials (20 univalent and 20 bivalent), consisting of 4 warm-up trials (always bivalent-expected) and 36 experimental trials. The first two practice blocks contained expected trials only. The subsequent 2 practice blocks and the 10 experimental blocks contained 8 unexpected trials each. Excluding practice blocks and warm-up trials, 20% of the trials were an unexpected task. These unexpected trials were always univalent trials. Each unexpected trial was followed by 2 trials with the expected task; these "recovery" trials were not analyzed.

Participants were instructed to emphasize both speed and accuracy. After each block, participants received feedback regarding their mean RT and accuracy for that block. To promote diligence, they were instructed to write down their performance for each task after each block. They were also encouraged to rest before beginning the next block.

Results

We omitted from analysis any task-repetition trial in which the stimulus was the same as the previous stimulus to avoid contamination of task-repetition effects (i.e., switch costs) with stimulus-

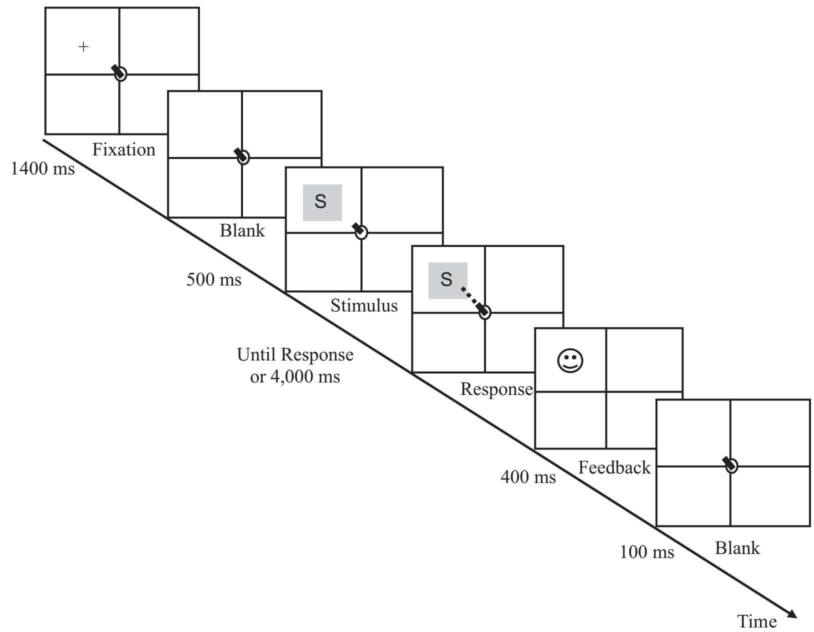

Figure 1. An example of the time course of stimulus presentation in Experiment 1 is represented. In this example, the stimulus (the letter *S* within the gray square, which was a red square in the actual experiment) was bivalent.

repetition effects. In addition, we omitted the trial following an error and the two recovery trials following an unexpected-task trial. For RT analyses, we also omitted error trials. In addition, for younger adults, trials were excluded if RT was less than 200 ms or greater than 2,100 ms. For older adults, trials were excluded if RT was less than 200 ms or greater than 3,550 ms.[1] These RT cutoff values were chosen because they eliminated an approximately equal percentage of trials (0.5%) for each age group. The resulting mean RT and proportion of error (PE) are shown in Table 1 for each condition for each age group.

Table 1
Mean Response Times in Milliseconds (and Proportion of Error) in Experiment 1 as a Function of Age Group, Stimulus Valence, Task Expectancy, and Task Transition

Valence and task expectancy	Task transition: Repetition	Switch	Switch cost
	Younger adults		
Univalent			
Expected	568 (.019)	626 (.026)	58 (.007)
Unexpected	802 (.041)	817 (.053)	15 (.012)
Bivalent			
Expected	715 (.069)	785 (.114)	70 (.045)
	Older adults		
Univalent			
Expected	916 (.012)	1,023 (.009)	107 (−.003)
Unexpected	1,357 (.015)	1,324 (.020)	−33 (.005)
Bivalent			
Expected	1,201 (.031)	1,327 (.042)	126 (.011)

Data were analyzed as a function of age group (younger vs. older), stimulus valence (univalent vs. bivalent), task transition (repetition vs. switch), and task expectancy (expected vs. unexpected). Because stimulus valence and task expectancy are not orthogonal, they cannot be included in the same analysis of variance (ANOVA). Thus, we conducted three different ANOVAs. The first ANOVA assessed the expectancy cost and therefore included univalent trials only. The second ANOVA assessed the switch cost and therefore included bivalent trials only. The third ANOVA assessed the bivalence cost and therefore included expected trials only. Although the second analysis was specifically designed to look for age effects on the switch cost, the other two analyses also included the task transition variable for the sake of completeness.

We first report raw RT analyses and then report log-transformed RT analyses to determine whether there are disproportionate age differences (see Faust, Balota, Spieler, & Ferraro, 1999). In the log-transformed RT analyses, we were interested in verifying whether the interactions of age with other variables are still significant. If not, the age effect can be attributed to generalized slowing (Cerella, 1990; Hartley, 2006; Salthouse, 1996).

Expectancy effects (univalent trials only). For the RT data, older adults were slower than younger adults, $F(1, 74) = 110.08$, $p < .0001$, $MSE = 393{,}543$. Of primary interest in this analysis is the relative task expectancy effect for younger and for older adults. There was a 292-ms expectancy cost, $F(1, 74) = 442.32$, $p <$

[1] We have also conducted data analyses using medians, without RT trimming. Statistical results were similar to the means reported in the present study.

.0001, $MSE = 37{,}928$. The expectancy cost was larger for older (371 ms) than for younger adults (213 ms), $F(1, 74) = 34.96$, $p < .0001$, $MSE = 37{,}928$. However, the log-transformed RT analyses revealed no age effects on expectancy costs, $F(1, 74) = 1.40$, $p = .2406$, $MSE = .0169$, suggesting that there is no disproportionate difference in expectancy costs for older and younger adults.

In addition, the expectancy cost was larger for task-repetition trials (338 ms) than for task-switch trials (246 ms), $F(1, 74) = 51.07$, $p < .0001$, $MSE = 7{,}036$. This interaction was stronger for older adults than for younger adults, $F(1, 74) = 17.72$, $p < .0001$, $MSE = 7{,}036$ (see Figure 2). This age effect was evident even after log transformation of RT, $F(1, 74) = 6.25$, $p < .05$, $MSE = .0027$. The main RT analyses also revealed a switch cost of 37 ms, $F(1, 74) = 26.12$, $p < .0001$, $MSE = 11{,}906$, which did not differ between age groups, $F(1, 74) < 1.0$.

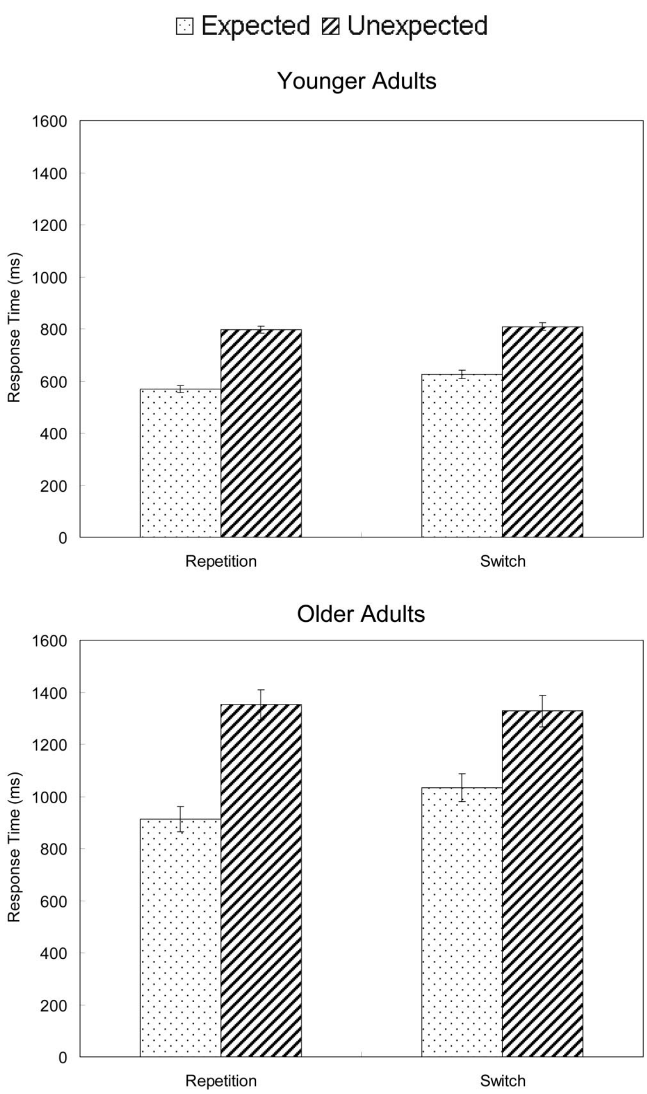

Figure 2. Mean response times for univalent trials as a function of task transition (task repetition vs. task switch) and task expectancy (expected vs. unexpected) for younger adults and for older adults in Experiment 1 are presented. Error bars represent the standard error of the mean.

For the PE data, older adults produced fewer errors (.014) than did younger adults (.035), $F(1, 74) = 20.99$, $p < .0001$, $MSE = .0044$. The overall switch cost was .005, $F(1, 74) = 4.13$, $p < .05$, $MSE = .0022$. PE was .018 higher for unexpected trials than for expected trials, $F(1, 74) = 19.90$, $p < .0001$, $MSE = .0037$. The expectancy effect was .018 larger for younger adults than for older adults, $F(1, 74) = 4.27$, $p < .05$, $MSE = .0037$. No other effects were significant.

Switch cost (bivalent trials only). This analysis was restricted to bivalent trials because they require the most cognitive control. Older adults were slower than younger adults, $F(1, 74) = 84.50$, $p < .0001$, $MSE = 331{,}351$. The switch cost was 98 ms, $F(1, 74) = 51.59$, $p < .0001$, $MSE = 18{,}151$, and was larger for older adults (126 ms) than for younger adults (70 ms), $F(1, 74) = 4.73$, $p < .05$, $MSE = 18{,}151$. Nevertheless, the log-transformed RT analyses revealed no age effect on switch costs, $F(1, 74) < 1.0$, suggesting that switch costs are not disproportionately large for older adults.

In the PE analyses, older adults were more accurate (.037) than were younger adults (.092), $F(1, 74) = 8.27$, $p < .01$, $MSE = .0388$. The overall switch cost was .028, $F(1, 74) = 26.92$, $p < .0001$, $MSE = .0045$, and was larger for younger adults (.045) than for older adults (.011), $F(1, 74) = 6.91$, $p < .05$, $MSE = .0045$.

Bivalence costs (expected trials only). To look for age effects on bivalence costs, we compared univalent and bivalent trials (expected trials only). Older adults were slower than younger adults, $F(1, 74) = 85.11$, $p < .0001$, $MSE = 489{,}831$. Mean RT was 224 ms longer for the bivalent condition than for the univalent condition, $F(1, 74) = 340.44$, $p < .0001$, $MSE = 28{,}238$. Older adults showed a larger bivalence cost (295 ms) than did younger adults (193 ms), $F(1, 74) = 37.32$, $p < .0001$, $MSE = 28{,}238$. This age effect was evident even after the log transformation of RT, $F(1, 74) = 7.33$, $p < .01$, $MSE = .0079$, reflecting a disproportionately large bivalence cost for older adults.

Averaging across the univalent and bivalent conditions, the switch cost on RT was 90 ms, $F(1, 74) = 103.68$, $p < .0001$, $MSE = 15{,}382$. Older adults showed a larger switch cost (117 ms) than younger adults (64 ms), $F(1, 74) = 9.61$, $p < .01$, $MSE = 15{,}382$. Switch costs were larger for bivalent stimuli (98 ms) than for univalent stimuli (83 ms), but this difference was not significant, $F(1, 74) = 1.08$, $p = .3018$, $MSE = 10{,}337$.

In the PE analyses, older adults were more accurate (.024) than younger adults (.057), $F(1, 74) = 10.72$, $p < .01$, $MSE = .0223$. PE was .048 higher for the bivalent condition than for the univalent condition, $F(1, 74) = 35.52$, $p < .0001$, $MSE = .0183$. Unlike the RT data, older adults actually showed smaller bivalence costs on PE (.029) than younger adults (.069), $F(1, 74) = 5.30$, $p < .05$, $MSE = .0183$. A closer examination of the data revealed that several younger adults produced especially high error rates in the bivalent condition. To ensure that the age effects in bivalence costs on RT were not due to a speed–accuracy tradeoff, we compared the 28 younger adults (out of 48) with the lowest PEs to the original sample of 28 older adults. This analysis revealed similar bivalence costs on PE for younger (.029) and older (.027) adults, $F < 1.0$. However, older adults still produced larger bivalence costs on RT (295 ms) than did younger adults (142 ms), $F(1, 54) = 33.98$, $p < .0001$, $MSE = 28{,}895$. Thus, the age effects in bivalence costs on RT were not due simply to a speed–accuracy tradeoff.

The overall switch cost on PE was .015, $F(1, 74) = 27.98$, $p < .0001$, $MSE = .0026$. Younger adults showed a larger switch cost (.026) than did older adults (.004), $F(1, 74) = 10.03$, $p < .01$, $MSE = .0026$. The switch cost was larger for the bivalent condition (.028) than for the univalent condition (.002), $F(1, 74) = 14.90$, $p < .001$, $MSE = .0033$.

Discussion

Experiment 1 was designed to test a specific prediction derived from the internal control deficit hypothesis. According to this hypothesis, older adults are less able than younger adults to establish a mental set for the expected task, and thus they rely more on external task control. Therefore, older adults should more easily overcome the (weak) preparation bias toward the expected task in response to the presence of a stimulus associated with the unexpected task. That is, older adults should produce a smaller expectancy cost than younger adults. Contrary to this prediction, the expectancy cost on RT was actually larger for older adults than for younger adults.

The internal control deficit hypothesis also predicts that older adults should produce larger switch costs and bivalence costs than should younger adults. Seemingly consistent with this prediction, older adults showed larger switch costs and bivalence costs than did younger adults on raw RT. Of these age effects, however, only the increased bivalence costs were significant after we applied a log transformation to the RT data. The significant age effect on bivalence costs, by itself, is consistent with an internal control deficit of the type we hypothesized. Alternatively, it could also reflect a reduced ability to inhibit irrelevant response activation. In other words, perhaps older and younger adults prepare task sets to a similar degree, and both experience a similar amount of irrelevant response activation from the irrelevant task, but older adults are less able to inhibit the irrelevant response activation or otherwise isolate it from the processing of the relevant stimulus. Alternatively, older adults might benefit more in the univalent condition because they rely more on stimulus-driven processing than do younger adults, producing a larger bivalence cost (i.e., a larger univalence benefit). We return to this issue in the General Discussion.

Experiment 2

In Experiment 1, we used a repeating AABB sequence in which tasks were consistently assigned to particular locations. In such a design, it is conceivable that participants eventually fall into a rhythm or rely on location priming of task set, rather than deliberately preparing for the expected task on each trial (e.g., Gotler, Meiran, & Tzelgov, 2003). In an attempt to encourage more deliberate task preparation, therefore, in Experiment 2 we used an explicit task-cuing paradigm with a random task sequence. In this paradigm, participants must rely fully on the task cue presented before each stimulus in order to respond correctly (see Koch, 2003).

Method

Participants. We drew 48 new younger adults and 28 new older adults from the same participant pool as in Experiment 1. The mean age of younger adults was 21 years ($SD = 3$ years, range: 18–34 years). The mean age of older adults was 69 years ($SD = 6$ years, range: 62–86 years). All participants had normal or corrected-to-normal visual acuity and color vision.

Apparatus, stimuli, and procedure. The apparatus, stimuli, and procedure were the same as in Experiment 1, except that we used a cuing paradigm. Instead of consistently associating tasks with positions on the screen, all stimuli appeared in the screen center. Each trial started with a visual task cue (*Color* or *Letter*) for 1,400 ms. After a 500-ms blank period, the stimulus appeared. The probability of an unexpected task was the same as in Experiment 1.

Results

The data analysis was similar to that of Experiment 1. Application of RT cutoffs (shorter than 200 ms or longer than 2,550 ms for younger adults; shorter than 200 ms or longer than 4,000 ms for older adults) eliminated approximately 0.5% of trials for each age group. The resulting mean RT and PE are shown in Table 2.

Expectancy effects (univalent trials only). The results of Experiment 2 generally resembled those of Experiment 1. For the RT data, older adults were slower than younger adults, $F(1, 74) = 45.69$, $p < .0001$, $MSE = 532{,}173$. Of primary interest is the relative task expectancy cost for younger and older adults. The overall expectancy cost on RT was 326 ms, $F(1, 74) = 459.12$, $p < .0001$, $MSE = 47{,}361$. As in Experiment 1, this expectancy cost was larger for older adults (388 ms) than younger adults (263 ms), $F(1, 74) = 17.67$, $p < .0001$, $MSE = 47{,}361$. However, the log-transformed RT analyses showed no age effects on expectancy costs, $F(1, 74) < 1.0$, indicating that older adults did not show a disproportionately large expectancy cost.

The expectancy cost on RT was larger for task-repetition trials (349 ms) than for task-switch trials (303 ms), $F(1, 74) = 8.56$, $p < .01$, $MSE = 10{,}881$. Unlike Experiment 1, however, the underadditivity of task expectancy and task transition was similar for both older adults and younger adults (see Figure 3), $F(1, 74) = 2.24$, $p = .1389$, $MSE = 10{,}881$. The overall switch cost on RT was 47

Table 2
Mean Response Times in Milliseconds (and Proportion of Error) in Experiment 2 as a Function of Age Group, Stimulus Valence, Task Expectancy, and Task Transition

Valence and task expectancy	Task transition		
	Repetition	Switch	Switch cost
Younger adults			
Univalent			
Expected	617 (.021)	654 (.033)	37 (.012)
Unexpected	892 (.049)	905 (.051)	13 (.002)
Bivalent			
Expected	730 (.059)	760 (.094)	30 (.035)
Older adults			
Univalent			
Expected	861 (.023)	963 (.017)	102 (−.006)
Unexpected	1,283 (.022)	1,317 (.030)	34 (.008)
Bivalent			
Expected	1,109 (.062)	1,172 (.106)	63 (.044)

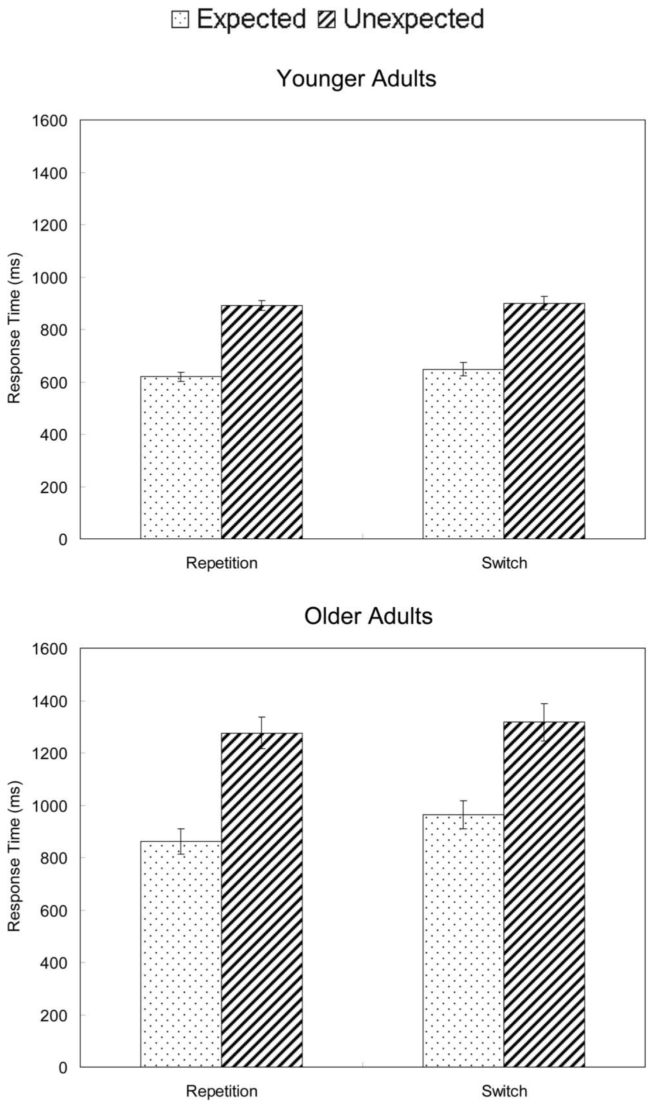

Figure 3. Mean response times for univalent trials as a function of task transition (task repetition vs. task switch) and task expectancy (expected vs. unexpected) for younger adults and for older adults in Experiment 2 are presented. Error bars represent the standard error of the mean.

ms, $F(1, 74) = 23.81$, $p < .0001$, $MSE = 15{,}845$. This switch cost was larger for older adults (68 ms) than for younger adults (25 ms), $F(1, 74) = 6.34$, $p < .05$, $MSE = 15{,}845$.

PE was .015 higher for unexpected tasks than for expected tasks, $F(1, 74) = 10.56$, $p < .01$, $MSE = .006$. No other effects were statistically significant.

Switch costs (bivalent trials only). Older adults were slower than younger adults, $F(1, 74) = 53.19$, $p < .0001$, $MSE = 311{,}358$. The switch cost on RT was 47 ms, $F(1, 74) = 9.37$, $p < .01$, $MSE = 21{,}898$. Although the switch cost was larger for older adults (63 ms) than for younger adults (30 ms), the difference was not significant, $F(1, 74) = 1.25$, $p = .2678$, $MSE = 21{,}898$. The log-transformed RT analyses showed that switch costs were not disproportionately large for older adults, $F(1, 74) < 1.0$.

In the PE analyses, the overall switch cost was .040, $F(1, 74) = 20.28$, $p < .0001$, $MSE = .0083$. No other effects were significant.

Bivalence costs (expected trials only). Analyses of bivalence costs showed results similar to those of Experiment 1. Older adults were slower than younger adults, $F(1, 74) = 49.03$, $p < .0001$, $MSE = 486{,}881$. Mean RT was 169 ms longer in the bivalent condition than in the univalent condition, $F(1, 74) = 195.09$, $p < .0001$, $MSE = 27{,}415$. Older adults showed a larger bivalence cost (229 ms) than younger adults (110 ms), $F(1, 74) = 27.58$, $p < .0001$, $MSE = 27{,}415$. As in Experiment 1, this age effect remained in the log-transformed RT analyses, $F(1, 74) = 10.43$, $p < .01$, $MSE = .0076$.

The switch cost on RT was 58 ms, $F(1, 74) = 28.93$, $p < .0001$, $MSE = 21{,}026$. Older adults showed a larger switch cost (83 ms) than younger adults (34 ms), $F(1, 74) = 5.94$, $p < .05$, $MSE = 21{,}026$. Neither the interaction of stimulus valence and task transition nor the interaction of these variables with age was significant, $F\text{s}(1, 74) \leq 1.53$, $p\text{s} \geq .2197$, $MSE = 12{,}687$.

In the PE analyses, the switch cost was .021, $F(1, 74) = 21.59$, $p < .0001$, $MSE = .0050$. PE was .057 higher in the bivalent condition than in the univalent condition, $F(1, 74) = 81.49$, $p < .0001$, $MSE = .0084$. Older and younger adults produced similar bivalence costs on PE (.064 vs. .050, respectively), $F(1, 74) = 1.37$, $p = .2456$, $MSE = .0084$. The interaction of stimulus valence and task transition was significant, $F(1, 74) = 10.81$, $p < .05$, $MSE = .0059$; the switch cost on PE was larger for the bivalent condition (.040) than for the univalent condition (.003).

Discussion

Experiment 2 replicated Experiment 1 in our use of a cuing paradigm intended to promote more deliberate advance preparation for the upcoming task. To determine whether explicit cuing actually improved preparation, we conducted between-experiment comparisons of raw RTs on the expectancy and bivalence costs. Results showed that the expectancy cost was larger in Experiment 2 (326 ms) than in Experiment 1 (292 ms), $F(1, 148) = 4.94$, $p < .05$, $MSE = 13{,}735$. This finding suggests that the cues did in fact promote stronger advance preparation. Also consistent with improved preparation, mean RT for expected, bivalent trials tended to be shorter in Experiment 2 (891 ms) than in Experiment 1 (940 ms), $F(1, 148) = 1.60$, $p = .2085$, $MSE = 108{,}947$, although the difference was not statistically significant.[2]

Despite the relatively strong advance preparation, the key results of Experiment 2 were in line with those in Experiment 1. The expectancy cost on raw RT was still significantly larger for older adults than for younger adults, inconsistent with our internal control deficit hypothesis. This finding suggests that, like younger adults, older adults are able to establish a strong mental set for the expected task. As do younger adults, older adults pay a heavy cost when this expectancy is violated. Older adults exhibited larger switch costs and bivalence costs on raw RT. As in Experiment 1, however, only the age effect on bivalence costs was still significant after we applied a log transformation.

[2] We believe that the appropriate comparison for the degree of deliberate advance preparation was the mean RT for the expected, bivalent stimulus trials rather than the expected, univalent stimulus trials. Because the univalent stimulus can trigger the corresponding task set automatically, advance preparation might not matter much. However, for proper response to a bivalent stimulus, internal task control is essential.

Experiment 3

Experiment 3 had two main purposes. One was to replicate Experiment 2. A second purpose was to test two explanations for the lack of age effects on switch costs in Experiments 1 and 2. One explanation is that older adults have no difficulty juggling multiple tasks and switching between them. Another explanation was that they do have difficulty juggling multiple tasks, but this difficulty affects both switch trials and repeat trials in the mixed blocks. The latter hypothesis is supported by the finding that older adults produce larger mixing costs; that is, task-repetitions are performed more slowly in mixed blocks than in pure blocks (e.g., Cepeda, Kramer, & Gonzalez de Sather, 2001; Kray & Lindenberger, 2000; Mayr, 2001).

To test this hypothesis, in Experiment 3 we used the cuing paradigm of Experiment 2 but added pure blocks in which only one task was presented repeatedly (e.g., AAAA. . .). Thus, in addition to the expectancy cost, switch cost, and bivalence cost, we could also measure the mixing cost. If older adults have difficulty juggling multiple tasks, as reflected in the mixed blocks, they should produce especially large mixing costs.

Method

Participants. We drew 36 new participants (18 younger adults and 18 older adults) from the same participant pool as in Experiments 1 and 2. The mean age of younger adults was 24 years (SD = 6 years, range: 18–36 years). The mean age of older adults was 74 years (SD = 5 years, range: 60–80). We tested participants' color vision using Ishihara's color test adopted from Kalat (2005). They all had normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, stimuli, and procedure. The apparatus, stimuli, and procedure were the same as in Experiment 2, except, as noted below, to allow inclusion of pure blocks into the design. Participants performed 4 practice blocks (2 pure blocks then 2 mixed blocks), followed by 12 experimental blocks. Note that we slightly increased the total number of blocks from 14 to 16, to compensate for the addition of the pure blocks. The first 2 experimental blocks were pure blocks (one for each task type; the order was counterbalanced across participants), as were the final 2 experimental blocks. The intervening 8 experimental blocks were mixed blocks. This design minimized the number of switches between block types. Each block (both pure and mixed) contained 40 trials (20 univalent stimulus trials and 20 bivalent stimulus trials), consisting of four warm-up trials (always bivalent, expected) and 36 experimental trials. In the mixed blocks, 8 of these 36 experimental trials were unexpected, univalent trials (as in Experiments 1 and 2). Prior to each block, a written message on the computer indicated the type of tasks to be performed in the upcoming block (e.g., "only the color task" or "only the letter task" for the pure blocks).

Results

The analyses of expectancy costs, switch costs, and bivalence costs were similar to those of Experiment 2 (i.e., they used mixed blocks only). We added a fourth analysis to compare pure and mixed blocks. Application of RT cutoffs (shorter than 200 ms or longer than 2,000 ms for younger adults; shorter than 200 ms or longer than 4,000 ms for older adults) eliminated approximately 0.5% of trials for both age groups. The mean RT and PE are shown in Table 3.

Table 3
Mean Response Times in Milliseconds (and Proportion of Error) in Experiment 3 as a Function of Age Group, Block Type, Stimulus Valence, Task Expectancy, and Task Transition

Block type	Task transition: Repetition	Switch	Switch cost
Younger adults			
Pure blocks			
Univalent-expected	495 (.020)		
Bivalent-expected	524 (.017)		
Mixed blocks			
Univalent-expected	592 (.009)	613 (.029)	22 (.020)
Univalent-unexpected	867 (.028)	868 (.033)	1 (.005)
Bivalent-expected	685 (.049)	739 (.086)	54 (.037)
Older adults			
Pure blocks			
Univalent-expected	758 (.017)		
Bivalent-expected	820 (.016)		
Mixed blocks			
Univalent-expected	993 (.012)	1,097 (.006)	103 (−.006)
Univalent-unexpected	1,475 (.016)	1,464 (.016)	−10 (.000)
Bivalent-expected	1,206 (.054)	1,350 (.089)	145 (.035)

Note. The blank cells indicate that there were no observations in that cell.

Expectancy effects (univalent trials in mixed blocks only). The results of Experiment 3 generally resembled those of Experiment 2. For the RT data, older adults were much slower than younger adults, $F(1, 34) = 47.09$, $p < .0001$, $MSE = 207{,}975$. The overall expectancy cost was 344 ms, $F(1, 34) = 215.53$, $p < .0001$, $MSE = 19{,}719$, similar to that of Experiment 2 (326 ms). The expectancy cost was larger for older adults (424 ms) than for younger adults (265 ms), $F(1, 34) = 11.39$, $p < .01$, $MSE = 19{,}719$, replicating Experiment 2. The log-transformed RT analyses showed that expectancy costs were not disproportionately large for older adults, $F(1, 34) < 1.0$.

The main RT analyses also showed that the expectancy cost was larger for task-repetition trials (378 ms) than for task-switch trials (309 ms), $F(1, 34) = 6.26$, $p < .05$, $MSE = 6{,}829$. This under-additive interaction tended to be larger for older adults than for younger adults, $F(1, 34) = 3.07$, $p = .0888$, $MSE = 6{,}829$ (see Figure 4). The overall switch cost in this analysis (restricted to univalent trials) was 28 ms, $F(1, 34) = 7.69$, $p < .01$, $MSE = 3{,}680$. Although this switch cost was larger for older adults (45 ms) than for younger adults (11 ms), the difference was not significant, $F(1, 34) = 2.66$, $p = .1122$, $MSE = 3{,}680$.

For the PE analysis, PE was .01 higher for unexpected tasks than for expected tasks, $F(1, 34) = 6.17$, $p < .05$, $MSE = .0006$. No other effects were statistically significant.

Switch costs (bivalent trials in mixed blocks only). In the switch cost analyses, we included only the bivalent trials in mixed blocks, as in Experiments 1 and 2. Older adults were much slower than younger adults (1,278 ms vs. 712 ms), $F(1, 34) = 48.58$, $p < .0001$, $MSE = 118{,}836$. The overall switch cost on RT was 99 ms, $F(1, 34) = 13.75$, $p < .001$, $MSE = 12{,}905$. As in Experiment 2,

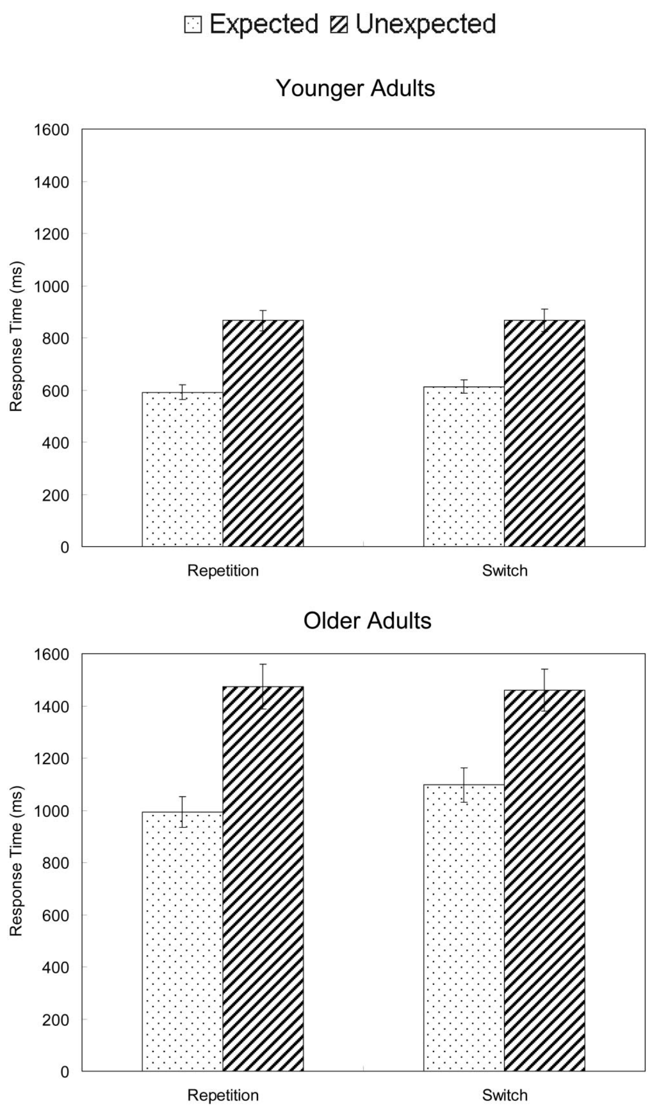

Figure 4. Mean response times for univalent trials in the mixed blocks as a function of task transition (task repetition vs. task switch) and task expectancy (expected vs. unexpected) for younger adults and for older adults in Experiment 3 are presented. Error bars represent the standard error of the mean.

the switch cost was numerically larger for older adults (cost = 145 ms) than for younger adults (cost = 54 ms), but this difference was not statistically significant, $F(1, 34) = 2.86$, $p = .1000$, $MSE = 12{,}905$. The log-transformed RT showed no disproportionate difference in switch costs between these age groups, $F(1, 34) < 1.0$.

In the PE analyses, the overall switch cost was .036, $F(1, 34) = 6.15$, $p < .05$, $MSE = .0038$. No other effects were significant.

Bivalence costs (expected trials in mixed blocks only). These results for bivalence costs were similar to those of Experiment 2. Older adults were slower than younger adults, $F(1, 34) = 50.03$, $p < .0001$, $MSE = 183{,}140$. Mean RT was 171 ms longer in the bivalent condition than the univalent condition, $F(1, 34) = 78.70$, $p < .0001$, $MSE = 13{,}363$. Older adults showed a larger bivalence cost (233 ms) than did younger adults (109 ms), $F(1, 34) = 10.31$, $p < .01$, $MSE = 13{,}363$. The log-transformed RTs showed a trend toward larger bivalence costs for older adults than for younger adults (as in Experiments 1 and 2), but the interaction was not significant, $F(1, 34) = 2.25$, $p = .1430$, $MSE = .0090$.

The switch cost on RT was 81 ms, $F(1, 34) = 19.40$, $p < .0001$, $MSE = 12{,}145$. The switch cost was larger for older (124 ms) than for younger (38 ms) adults, $F(1, 34) = 5.74$, $p < .05$, $MSE = 12{,}145$. Neither the interaction of stimulus valence and task transition nor the interaction of these variables with age was significant, $Fs(1, 34) \leq 2.30$, $ps \geq .1388$, $MSE = 5{,}297$.

In the PE analyses, the switch cost was .021, $F(1, 34) = 5.06$, $p < .05$, $MSE = .0033$. PE was .056 higher in the bivalent condition than in the univalent condition, $F(1, 34) = 52.87$, $p < .0001$, $MSE = .0021$. Older and younger adults produced similar bivalence costs on PE, $F(1, 34) < 1.0$. No other effects were statistically significant.

Mixing costs (expected, task-repetition trials only). Experiment 3 also allowed us to assess age effects on mixing costs. Because all trials in pure blocks were expected repetitions, these trials were compared only to the expected repetition trials from the mixed blocks. The data were analyzed as a function of age (younger vs. older), block type (pure vs. mixed), and stimulus valence (univalent vs. bivalent).

Older adults were slower than younger adults, $F(1, 34) = 43.69$, $p < .0001$, $MSE = 113{,}031$. Mean RT was 220 ms longer for mixed blocks than for pure blocks, $F(1, 34) = 129.86$, $p < .0001$, $MSE = 13{,}383$. Older adults showed larger mixing costs (311 ms) than did younger adults (129 ms), $F(1, 34) = 22.34$, $p < .0001$, $MSE = 13{,}383$, replicating previous studies. Mixing costs were still significantly larger for older adults after we applied a log transformation, $F(1, 34) = 6.92$, $p < .05$, $MSE = .0153$, suggesting that the age effect is not due simply to generalized slowing.

Mean RT was 99 ms longer for the bivalent condition than for the univalent condition, $F(1, 34) = 87.87$, $p < .0001$, $MSE = 4{,}029$. Older adults showed a larger bivalence cost (137 ms) than did younger adults (61 ms), $F(1, 34) = 12.77$, $p < .01$, $MSE = 4{,}029$. Also, the bivalence cost was larger in mixed blocks (153 ms) than in pure blocks (46 ms), $F(1, 34) = 21.15$, $p < .0001$, $MSE = 4{,}847$. Although the difference in bivalence costs between mixed and pure blocks was larger for older than for younger adults, the interaction between block type, stimulus valence, and age neared significance, $F(1, 34) = 3.50$, $p = .0698$, $MSE = 4{,}847$.

In the PE analyses, PE was .013 higher in mixed blocks than in pure blocks, $F(1, 34) = 5.63$, $p < .05$, $MSE = .0011$. In addition, PE was .020 higher in the bivalent condition than in the univalent condition, $F(1, 34) = 18.14$, $p < .0001$, $MSE = .0008$. The bivalence cost on PE was larger in the mixed blocks (.041) than in the pure blocks (−.001), $F(1, 34) = 14.34$, $p < .0001$, $MSE = .0012$. No other effects that involved age were statistically significant, $Fs(1, 34) < 1.0$.

Discussion

In Experiment 3, we replicated the key finding of Experiment 2: The expectancy cost on RT was significantly larger for older adults (424 ms) than for younger adults (265 ms). Thus, we found no evidence that older adults establish a weak task set, and their task set can be more easily reconfigured in response to a univalent stimulus uniquely associated with an unexpected task.

In the analyses of raw RT, switch costs were larger for older adults. However, as in Experiments 1 and 2, this increase was not significant after the log transformation. Age effects on bivalence costs also were significant in the main RT analyses but not in the log-transformation analyses. However, there was a modest trend towards larger bivalence costs for older adults than for younger adults. Note that the interaction was statistically significant in both Experiments 1 and 2. Thus, the overall pattern of data across experiments is consistent with a disproportionate difference in the bivalence costs of younger and older adults.

Another goal of Experiment 3 was to examine whether older adults have more difficulty juggling multiple tasks, a problem that might influence both switch and repetition trials in mixed blocks. Consistent with this prediction, older adults produced larger mixing costs than did younger adults, even after applying the log transformation. This interaction was also significant when the analysis was restricted to bivalent trials only, $F(1, 34) = 5.89$, $p < .05$, $MSE = .0128$.

General Discussion

In the present study, we used a task-switching paradigm to test a specific kind of internal control deficit—older adults establish weak task sets when switching to a new task, and therefore they rely more on external task control. This reduced preparation would make it difficult for older adults to juggle multiple tasks, especially when processing a stimulus associated with multiple task sets. However, reduced preparation for the expected task could actually benefit them when they receive a stimulus uniquely associated with the unexpected task. Contrary to these predictions, all three experiments showed that older adults produced larger expectancy costs on RT than did younger adults. The increase was not significant after applying a log transformation, but the key finding is that we did not observe the predicted decrease for older adults.

The preceding analyses of expectancy costs included both switch and repeat trials. One might argue, however, that weak preparation for the expected task would benefit older adults most when the unexpected task is a task repetition. On these trials, older adults might remain prepared for the preceding task and thus handle the unexpected repetition particularly gracefully. We therefore conducted a follow-up analysis for each experiment using task-repetition trials only. Even in the log-transformed RT analysis, older adults still produced expectancy costs similar to those of younger adults in all experiments (Fs ≤ 3.78, ps $\geq .0558$, MSEs $\leq .0084$).

As a converging test of the internal control hypothesis, we also examined whether older adults would show a larger switch cost. Although older adults produced larger switch costs on raw RT, this difference was not significant after applying a log transformation. Thus, it might just reflect generalized slowing. We also examined the cost of processing a stimulus associated with both of the active tasks, rather than with just one task (bivalence costs). A reduced ability to prepare for the relevant task should result in larger bivalence costs for older adults. The data across the three experiments were generally consistent with this prediction, even after applying a log transformation designed to correct for generalized slowing. Note that this is the only test consistent with the internal control deficit hypothesis we proposed.

We have concluded that, under the relatively demanding conditions of the present experiments, older adults do not have difficulty establishing a strong set for the upcoming task. It remains possible, however, that older adults experience internal control deficits with different tasks or different types of cognitive control (e.g., a negative priming task; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; an antisaccade task; Nieuwenhuis, Ridderinkhof, De Jong, Kok, & Van der Molen, 2000). In particular, note that in the present study we used distinct stimulus dimensions for each task (color vs. letter identity), making it possible for people to negotiate a task switch in part by focusing on a different stimulus dimension. Cognitive control might be even more difficult when internal control cannot be based on selecting stimulus dimensions (see Meiran & Marciano, 2002); a concrete example would be when performing a greater-or-less-than-5 task and an odd–even task on digit stimuli. Note, however, that it would be very difficult to apply the current expectancy and bivalence manipulations with these tasks—digit stimuli cannot be univalent with respect to them. In summary, although it seems reasonable to conclude that this kind of internal control deficit (i.e., establishing a weak task set) in older adults does not occur generally, it remains an open question whether it occurs under even more demanding conditions. Future research is needed to address this issue.

Notable Findings Regarding Task Expectancy

With respect to expectancy costs, there are two notable findings that warrant further discussion. One finding is that the expectancy cost in the present study (217 ms for younger adults) was almost 10 times larger than that reported by Ruthruff et al. (2001; 26 ms in Experiments 1 and 2). The key difference is that Ruthruff et al. used univalent stimuli only, whereas we intermixed univalent and bivalent stimuli within blocks (although in both cases expectancy costs were assessed with univalent trials only). The presence of bivalent trials presumably induces participants to establish a strong task set, resulting in large costs on univalent trials in which that expectancy is violated.

Another finding is that task-expectancy cost and switch cost interacted significantly underadditively in all experiments. Although this interaction was not the focus of the present experiments, it is worth noting that it differs from the additive finding of Ruthruff et al. (2001; see also Sohn & Carlson, 2000). On the basis of additive factors logic, this finding suggests that task expectancy and task switching influence the same processing stage. This conclusion is consistent with Rogers and Monsell (1995), who assumed that online task-set reconfiguration can be completed only after the onset of an actual stimulus to be processed. In other words, the presence of a stimulus triggers the completion of task-set recognition. It is natural to assume that this same reconfiguration process is triggered by a stimulus associated with an unexpected task but takes longer to complete (i.e., task switching and task expectancy influence the same reconfiguration stage).

Alternatively, one can reconcile the modest underadditivity observed here with Ruthruff et al.'s (2001) conclusion that task expectancy influences a reconfiguration stage and task switching influences a subsequent response-selection stage. For instance, task-switch costs might reflect a slowing of response selection due to carryover of the task set established on the previous trial. This carryover might dissipate during the time-consuming task-set reconfiguration triggered by expectancy violations, reducing switch costs relative to trials without an expectancy violation.

Alternative Explanations for Age Effects on Task Switching

The expectancy cost data argue against the type of internal control deficit we have hypothesized—one in which older adults establish weak task sets and compensate by relying more on bottom-up activation of task sets. Nevertheless, the disproportionate age effects on bivalence costs and mixing costs do suggest some form of age-related deficit. In this section we outline several related possibilities.

First, it is worth considering how one might account for our data while still retaining the general idea that older adults establish a weak task set in advance of a task switch. One challenge is to explain why older adults would not benefit from the weak task set, which should facilitate disengagement from that incorrect task set on unexpected-task trials. One approach is to allow for such a benefit but propose that it is offset by a disproportionate cost of having to reconfigure in response to a univalent stimulus. This type of internal control deficit hypothesis, however, requires rejection of our original hypothesis that older adults have stronger stimulus-triggered task-set activation and an explanation of why essentially the opposite should occur.

Second, the exaggerated mixing costs suggest that older adults do have difficulty juggling multiple tasks (i.e., in mixed-task blocks). One problem might be a reduced ability to completely inhibit the previous task set (but see Mayr, 2001), which would compel older adults to compensate by activating the relevant task set more strongly. This extra task-set activation would be difficult to overcome when the task is unexpected and thus would explain why expectancy costs are still large for older adults.

Third, it is possible that older adults have more trouble suppressing responses partially activated by the irrelevant task (e.g., Hasher & Zacks, 1988) and compensate by using a more controlled mode of processing (see e.g., Lien & Ruthruff, 2004). For instance, to ensure that they emit the task-relevant response, they might try to carefully bind together the relevant stimulus attribute with the relevant response. A controlled mode of processing might also prevent the stimulus from priming associated task sets, such that top-down activation of task set can gain control. Thus, older adults would not fully benefit when presented with a univalent stimulus associated with an unexpected task—their reliance on controlled processing makes it difficult for stimulus-triggered task-priming to take control over task set.

The latter two possibilities assume that participants are in fact strongly preparing for the expected task and thus can easily explain why older adults show large expectancy costs. These possibilities are also supported by DiGirolamo et al.'s (2001) finding that older adults have increased prefrontal recruitment, compared to younger adults, even when the task is expected to repeat. Note that if the extra preparation in mixed blocks occurs even on task-repetition trials, it would also explain the absence of age effects on switch costs, even after RTs were subjected to a log transformation. The extra preparation applied to task-repetition trials in mixed blocks could disrupt performance on task-repetition trials (e.g., by using a controlled mode of processing when a more automatic mode would suffice; see Lien & Ruthruff, 2004, for detailed discussion on this point). This would reduce the repetition benefit for older adults, which also means the switch cost would be reduced.

Conclusion

We tested the hypothesis that when switching between tasks, older adults are less able than younger adults to establish a task set and therefore rely more on stimulus-triggered task activation. If older adults are less strongly biased toward the expected task, they should recover more easily when receiving a stimulus uniquely associated with the unexpected task. All three experiments failed to confirm this prediction. Instead, expectancy costs for older adults were about as large as one would expect given slower overall cognitive processing.

Although we found no evidence for a shift in reliance on external task control rather than internal control, we did observe age effects on bivalence costs and mixing costs. We propose that older adults have difficulty juggling multiple tasks—especially when the stimuli and responses are associated with more than one task—and compensate by preparing more deliberately (this is nearly the opposite of our original hypothesis). For instance, they might rely especially heavily on a controlled mode of processing, even when a more automatic mode of processing would suffice (e.g., on task repetition trials). Additional research is needed to further narrow down the range of possible explanations of age effects on task switching.

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