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Old Age Is Associated With a Pattern of Relatively Intact and Relatively Impaired Task-Set Switching Abilities

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In three experiments, we examined the effects of old age on the reaction time (RT) decrement associated with task alternation. Old age was associated with increased *mixing-cost*, which is the RT difference between two conditions: *mixed-task*, where trials involving two tasks were intermixed, and *single-task*, where all the trials involved the same task. Old age was also associated with an increased *switching-cost*, which is the RT difference between trials in which the task was just changed and trials in which it was repeated. There was also indication of a slowed passive dissipation of task set adopted in the preceding trial. In contrast to these impairments, old age was also associated with an almost intact ability to prepare for an upcoming task switch. This ability was indicated by a normal reduction in switching-cost due to an increase in the time allowed to prepare for the switch. We discuss the implications of the results in relation to theories of task-switching and to the underlying brain mechanisms, especially with respect to the effect of old age on the prefrontal cortex.

PERFORMANCE in everyday situations involves frequent changes of immediate behavioral goals or mental sets. Because set switching seems to be relevant for adaptive behavior, studying how it is affected by old age is highly important. Furthermore, research suggests that, like other executive control functions, set-switching ability involves the prefrontal cortex (Eslinger & Grattan, 1993; Rogers, Sahakian, Hodges, Polkey, Kennard, & Robbins, 1998; Owen et al., 1993; Shallice, 1994; Stuss, Shallice, Alexander, & Picton, 1995), and that age-related decline in cognitive functions is partly due to the associated age-related changes in the prefrontal cortex (e.g., Moscovitch & Winocur, 1992; Raz, Gunning-Dixon, Head, Dupuis, & Acker, 1998; West, 1996). Thus, it is reasonable to predict that aging will influence task-switching ability.

Component Processes in Task Switching

There are several cognitive paradigms to study set-switching ability, including the Psychological Refractory Period paradigm (e.g., Pashler, 1998) and the Attentional Blink paradigm (e.g., Visser, Bischof, & Di Lollo, 1999). In the present study, we employed the task-switching paradigm (Allport, Styles, & Hsieh, 1994; Fagot, 1994; Jersild, 1927; Rogers & Monsell, 1995). In this paradigm, participants rapidly switch between two or more reaction-time (RT) tasks that are typically performed on the same set of stimuli. In the present experiments, the participants switched between Task A (e.g., *up–down* discrimination) and Task B (e.g., *right–left* discrimination) performed on target stimuli located in one of four quadrants of a 2 × 2 grid, the upper left quadrant, for example. Previous work has shown that switching tasks is associated with a sizable decrement in performance. Some authors have argued that the decrement comprises several component processes (Fagot, 1994; Rogers & Monsell, 1995). In the following section, we will present our theoretical framework concerning component processes in task-switching (Meiran, 1996, 2000a, 2000b; Meiran, Chorev, & Sapir, 2000; Meiran, Levine, Meiran, & Henik, 2000), which has guided the present investigation.

Following Fagot (1994) and Los (1999, 2000), we distinguish among three experimental conditions. (Please see Figure 1.) In explaining these conditions, we mark each trial in a sequence by the task being performed (e.g., Task A). The first condition is *single task* (e.g., AAA . . . or BBB . . .), where a sequence of trials involves the same task. The other two conditions are included in mixed-task blocks, where trials involving Task A and Task B are intermixed. *Switch trials* (e.g., AA<u>B</u>AA . . .) are those in which the task is different from the task in the preceding trial. *No-switch trials* (e.g. A<u>A</u>BA<u>A</u> . . .) are those in which the task is the same as the task in the preceding trial. The reaction time (RT) difference between single-task (fastest) and switch trials (slowest) is termed *alternation cost.* As we argue below, alternation cost does not represent a single entity and is therefore decomposed into two large components: *mixed-list cost* (no-switch RT minus single task RT) and *switching-cost* (switch RT minus no-switch RT).

Like alternation cost, switching-cost does not represent a single ability, and is thus decomposed into subcomponents. The decomposition is made possible in the cuing version of the task-switching paradigm (De Jong, 1995; Meiran, 1996; Shaffer, 1965). In that paradigm, the tasks are ordered randomly and each trial begins with an instructional cue indicating which task to perform on the upcoming target stimulus.

An important advantage of the cuing paradigm is that it allows for a tight control over two intervals which theoreti-

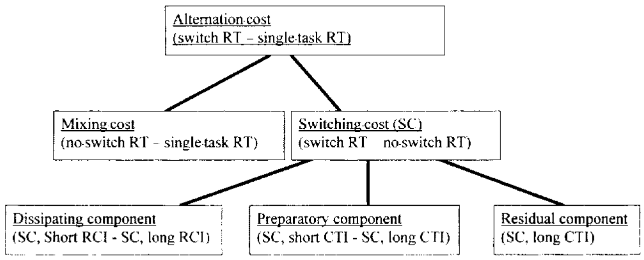

Figure 1. Components of alternation cost. From Meiran, Chorev, and Sapir (2000).

cally represent two distinct processes. One interval, the *Response-Cue Interval* (RCI), is that period of time between the response in Trial N-1 and the cue in Trial N. During this period, participants have not yet been informed which task is next. Thus, participants are unlikely to use the RCI for preparation (see Meiran, Chorev, & Sapir, 2000, for an empirical support). Nonetheless, the results also indicate that extending the RCI resulted in a reduction in switching-cost. Given the considerations mentioned so far, this reduction in switching-cost is attributed to passive dissipation of the task set adopted in the previous trial.

We also manipulated task-preparation time, the *Cue-Target Interval* (CTI), and found that increasing it sharply reduced switching-cost (e.g., Meiran, 1996; Meiran, Chorev, & Sapir, 2000). The reason why the CTI represents preparation is that the instructional cue has already been given, enabling participants to know which task is next and to prepare for it. Finally, even when given ample time to prepare, switching-cost is not usually eliminated. Thus, the three subcomponents of switching-cost include [set] *dissipation component*, related to cost that is reduced by increasing RCI; *preparatory component*, reflecting cost reduced by increasing CTI; and *residual component*, the switching-cost given a very long CTI.

There are a number of indications that these various components of alternation cost represent separate abilities. These indications are based on empirical dissociations, namely, variables that affect the components differentially. We shall mention three examples. First, Meiran, Chorev, and Sapir (2000) found that practice within a single experimental session resulted in a reduction in the preparatory component of switching-cost but did not affect the residual component. A second session of practice reduced residual cost without affecting preparatory cost. Moreover, practice did not modulate the dissipation component.

Second, the valence of task elements (such as stimuli and the responses) also indicates dissociations. A *univalent* element is relevant in only one task, while a *bivalent* element is relevant in two tasks. Using the present paradigm as an example, a univalent target stimulus may be one positioned centrally along the *up–down* axis but on the right side of the *right–left* axis. In this example, only the *right–left* dimension is task relevant. In comparison, an upper left target is considered a bivalent stimulus because the vertical and horizontal axes are both task relevant. Meiran (2000b) found that the preparatory component of switching-cost was almost eliminated when the target stimulus was univalent.

Response valence refers to whether the same physical response is used in more than one task. In the example above, pressing one key to indicate *up* or *left* is considered a bivalent response because the physical key-press is relevant in both tasks. When each of the four nominal responses, *up*, *down*, *right*, and *left*, is mapped to a separate key-press, these responses are considered univalent because each response is relevant for one task only. Meiran (2000b) found that residual cost was eliminated by using univalent responses, while preparatory cost was preserved (see Appendix, Note 1).

Finally, the components were dissociated with respect to congruency. Congruency is relevant when using bivalent response setups where, for example, pressing one key to indicate *up* and *left* and pressing the other key to indicate *right* and *down*. In the example, trials involving the upper left and the lower right target stimuli are considered *congruent* because the same key-press is considered as the correct response in either task. In contrast, trials involving upper right or lower left targets are considered *incongruent* because each of the two task–rules indicates a different key-press as the correct response. Fagot (1994) found that switching-cost was not affected by congruency while mixing-cost was strongly reduced in the congruent condition compared to the incongruent condition. Fagot's conclusion may have been a little extreme since, in our lab, we typically find a small effect of congruency on residual switching-cost, which sometimes reaches statistical significance. Nonetheless, the dissociation is evident in that the effect of congruency on mixing-cost is much stronger than its effects on residual cost.

In conclusion, we argue that alternation cost does not represent a single ability but comprises several abilities or component processes. This argument is supported by the fact that there are variables which affect the various components differentially. We have used this theoretical framework in trying to understand previous results concerning age-related changes in task-switching performance.

Set-Switching Ability in Old Age

In this next section, we review the literature on task-switching and aging in accordance with the theoretical framework listed above.

Increased alternation cost.—Botwinick, Brinley, and Robbin (1958) asked participants to add numbers (AAA . . .), subtract numbers (BBB . . .), or to systematically alternate between adding and subtracting (ABAB . . .). The results indicate that the elderly were more strongly affected by task alternation than young participants were. Similar results were obtained by Brinley (1965), who extended the results to three different versions of the alternation paradigm. Because the stimuli were presented in a list, the conditions were roughly analogous to discrete presentation with very short intertrial interval (see Fagot, 1994, for a partial support for this assumption). Thus, there was no time allowed for set dissipation or task preparation, and the results indicate the effects of old age on alternation cost.

Increased mixing-cost and switching-cost.—Kray and Lindenberger (2000) used a variety of tasks and looked at old-age effects on switching-cost and on a measure roughly analogous to mixing-cost. Their results indicated large age effects on mixing-costs and a modest effect on switching-cost. Similar results were found by De Jong, Emans, Eenshuistra, and Wagenmakers (1998). Like Kray and Lindenberger (2000), Salthouse, Fristoe, McGuthry, and Hambrick (1998) found moderate effects of age on switching-costs. They used a variety of tasks, discrete presentation, and manipulated task-switching within a block.

Normal preparatory component.—Hartley, Kieley, and Slabach (1990) found that switching-cost was reduced by increasing the CTI, but the rate by which preparation reduced switching-cost was similar in the two age groups. De Jong and associates (1998), Kramer, Hahn, and Gopher (1999), Kray and Lindenberger (2000), and Mayr and Liebscher (in press) have recently reported similar findings. We wish to note that the relatively intact preparatory component in old age probably depends on the use of instructional cues. When no such cues were provided in Experiment 3 in Kramer and colleagues' study, elderly participants did not reduce their switching-costs by preparation. Nonetheless, this issue is not yet resolved because Kray and Lindenberger, who did not use cues either, found normal reduction in switching-cost among elderly subjects. One difference between the two experiments was that in Kramer and coworkers' study, participants switched tasks every fifth trial, which may have placed them under relatively heavy memory demands. In contrast, the tasks in Kray and Lindenberger's study switched every second trial. Regardless of these yet unresolved differences, there is a consensus regarding relatively normal preparatory component in old age when explicit instructional cues are provided.

Slightly increased residual component.—De Jong and colleagues (1998), Kramer and associates (1999), and Kray and Lindenberger (2000) found that old-age effects on the residual costs were rather small and were not always significant (i.e., in the longest preparatory interval after practice in Kray & Lindenberger's study). Moreover, Kramer and colleagues' results as well as those of De Jong (2000) strongly suggest that age differences in the residual component diminish with practice. The only exception is Mayr and Liebscher's (in press) study, showing a slight insignificant trend in the reverse direction.

Old-age effects on the dissipating component.—To the best of our knowledge, no one has yet examined how old age affects the rate of task-set dissipation. Interesting and related evidence for slowed task-set disengagement comes from a study by Mayr and Liebscher (in press). These researchers asked their participants to perform in single-task blocks, task-alternation blocks, and fade-out blocks. The fade-out blocks were composed of 40 alternation trials followed by 80 single-task trials. Moreover, participants were told in advance that a single-task condition will follow, and the shift from the mixed-task condition to the single-task condition was clearly indicated on-line. The shift from the mixed-task condition to single-task condition was initially accompanied by poor performance, but performance improved over trials. The young participants needed only a few trials to return to single-task level of performance. This was not the case for the elderly participants, who were especially slowed in the fade-out blocks and who did not return to single-task levels of performance even after eighty pure-task trials.

Nonetheless, one may distinguish between two levels of sets. At the lower level, there are sets which deal with executing a particular task. For example, the *up–down* task involves a set which determines that the vertical dimension is the relevant stimulus dimension, and the mapping of *up* and *down* to responses. Another type of set involves the overall structure of the experiment, where one may consider an alternation set, which enables the participant to deal with the fact that the tasks change unpredictably. This set may involve attending to the instructional cues. Thus, Mayr and Liebscher's demonstration may indicate the rate by which participants disengaged from the higher-order task-alternation set rather than the rate at which they disengaged from the lower-order task set. An obvious difference between disengaging from the "alternation set" and disengaging from a task set is the time scale. Whereas disengaging from a task-alternation set may take several seconds, disengaging from a task set takes about 1 s (Meiran, Chorev, & Sapir, 2000).

To summarize, the review of the literature suggests that old age is associated with an increase in alternation cost. Nonetheless, the increase is not homogeneous across the various components of alternation cost. First, there seems to be a large increase in mixing-costs coupled with a smaller increase in switching-cost. With regard to switching-cost, only the preparatory and residual subcomponents were studied, and the results indicate a relatively intact preparatory component and a slightly impaired residual component. The purpose of the present study was to support our theoretical interpretation of the literature using a uniform experimental paradigm. To complete the picture concerning all four components, we explored old age effects on the dissipating component, which had not previously been done (see Appendix, Note 2).

General Methods

Participant Recruitment Criteria

We recruited participants who, according to their own reports, did not have a history of psychiatric or neurological disease or head trauma and who did not currently suffer from diabetes, high blood pressure, or other serious vascular problems. These stringent participant-inclusion criteria were adopted because Boone, Miller, and Lesser (1993) suggested that findings relating aging to frontal-lobe functions may reflect the fact that among the elderly adults there is a subgroup who suffer from vascular problems or diabetes. Magnetic resonance imaging results show that these apparently normal participants have large white-matter lesions.

In Experiments 1 and 3, where the two-key response setup was used (Figure 2), half of the participants in each age group were assigned to each response-key combination: either upper left and lower right or upper right and lower left.

Apparatus and Stimuli

All testing was performed using an IBM clone controlled by software written in MEL (Schneider, 1988). Responses were collected with a standard keyboard, and the claimed accuracy in RT recording is to the nearest 1 ms. The stimuli were drawn in white on black using the graphic symbols in the extended ASCII code and included a 2 × 2 grid that was presented at the screen center and subtended a visual angle of approximately 3.4 deg (width) × 2.9 deg (height). The target was the smiling-face character (ASCII code 1) which subtended approximately .3 deg (width) × .5 deg (height). The arrowheads (ASCII codes 16, 17, 30, and 31) subtended approximately .3 deg × .3 deg and were positioned .7 deg from the end of the grid (visual angles are computed assuming 60 cm viewing distance).

The (Hebrew) Vocabulary subset from the Intellectual Differential Aptitude Test battery (Fischman, 1982) was used to estimate premorbid intelligence among the Israeli participants. This test was comprised of 40 multiple-choice questions. Its score is the number correct (0–40), its internal reliability is .89, and its test–retest reliability is .80.

Procedure

The experiment was run as a single session, lasting between 40 min and 1.5 hr, depending on participants' performance. It began with RT testing, after which each participant completed the vocabulary test. The participants were encouraged to stretch between blocks. When the two-key setup was employed (Experiments 1 and 3), the center of the keypad was aligned with the center of the monitor by shifting the entire keyboard to the left. Each experiment consisted of a warm-up block (20 trials) followed by 4–5 experimental blocks. Each trial within a block consisted of an empty grid presented during the RCI, the presentation of the instructional cue presented during the CTI, and the presentation of the target stimulus until the response was given. 400-Hz beeps for 100 ms signaled errors. The task, target location, and CTI (Experiments 1 and 2) were selected randomly on each trial. Hence, the instructional cue did not indicate the upcoming target location, key-press, or precise target onset.

Analysis

Trials immediately following an error or an RT that exceeded 5 sec were excluded from all analyses. RT in the remaining trials was not analyzed if it exceeded 5 sec or if the response was erroneous. The mean RT (or the proportion of errors) per condition served to represent a given participant in the following analyses. Alpha level was set at .05 in all of the analyses.

In addition to the main analyses of mean RT, we also ran backup analyses on the mean logarithm of RT (LogRT). Results concerning the latter analysis are reported only if there were discrepancies concerning statistical significance of interactions with age. An advantage of LogRTs is that differences between logarithms represent proportions, thus controlling for general slowing. However, we do not wish to place an emphasis on the analysis of LogRT since general slowing cannot account for our results. Specifically, we found that old age was associated with a pattern of relatively intact and relatively impaired abilities.

Experiment 1

The goal of the present experiment was to examine the effects of old age on all the components of alternation cost, except for set dissipation. Since the same participants performed in the mixed-task condition and the single-task condition (as needed to measure mixing-costs), we also examined whether Mayr and Liebscher's fade-out results replicated in our paradigm. We used bivalent responses (two-key response setup (Figure 2). It was decided that the single-task block would always come after the mixed-task condition, because introducing the single-task condition first might have caused the practiced task to become easier than the unpracticed task. We wished to avoid this scenario given the evidence that participants choose special strategies when they switch between tasks of unequal difficulty levels (Allport et al., 1994; Allport & Wylie, 2000; De Jong, 1995).

Given the literature reviewed, we predicted that mixing-cost would be increased among the elderly. This prediction is indicated by the two-way interaction between age and mixing. With respect to switching-cost, we predicted a significant two-way interaction between CTI and task-switching, coupled with a significant simple effect of task-switching in the long CTI. This pattern of significant effects indicates the preparatory and the residual components of switching-cost, respectively. We also predicted a significant two-way interaction between age and task-switching, and an insignificant triple interaction among age, CTI, and task-switching. The latter pattern of significant results indicates that old age is associated with a relatively unimpaired preparatory component and an increased residual component.

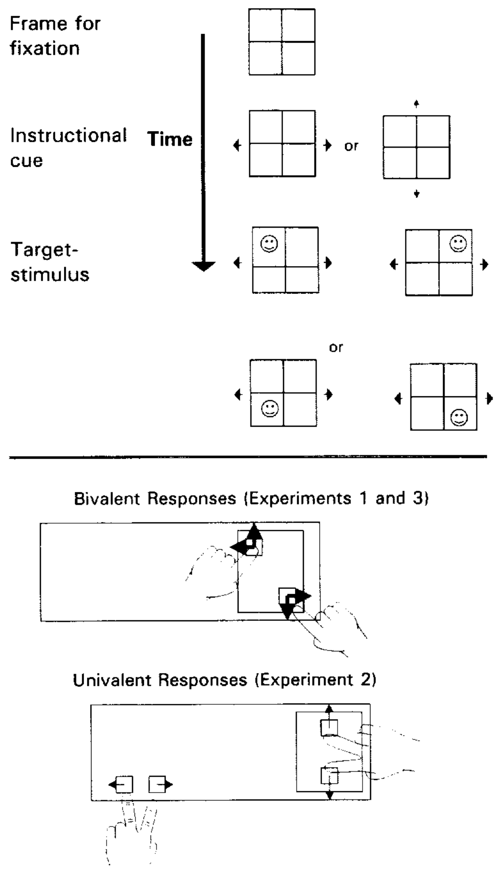

Figure 2. A schematic description of the experimental paradigm.

Table 1. Participant Characteristics

	Experiment 1		Experiment 2		Experiment 3	
	Old	Young	Old	Young	Old	Young
n	16[a]	16	15	15	22	22
Age	68.3	24.1	70.3	25.8	73.5	23.5
(min–max, *SD*)	(64–76, 3.5)	(20–29, 2.3)	(66–74, 2.4)	(22–38, 2.9)	(69–80, 3.2)	(19–33, 3.5)
Sex (m/f)	8/8	6/10	6/9	6/9	13/9	5/17
Vocabulary[b]	30.6	33.5	30.6	32.4	See Methods for details	
(*SD*)	(5.3)	(3.5)	(5.6)	(2.9)		
Education in years	12.4	12.9	13.3	13.0	13.5	13.0
(*SD*)	(3.2)	(1.2)	(2.6)	(1.9)	(2.5)	(0)

[a]Four additional elderly participants were excluded because of an extremely high error rate (see Methods for details). The data of these participants are not reported in the table.

[b]Vocabulary scores in Experiments 1 and 2 could range from 0 to 40.

Methods

Participants

Although 16 young participants and 20 elderly participants were tested, 4 elderly participants committed more than 50% errors in the incongruent condition and their results were not analyzed. All the participants were members of a kibbutz in southern Israel, who volunteered to participate in the study in return for 50 New Israeli Shekel (NIS) (approximately $12). We conducted the study in a kibbutz because it is a relatively closed community; hence, the two age groups were matched along many dimensions such as background, education, and occupation (see Table 1). Half of the participants in each response combination condition performed the *up-down* task in the single-task condition, and half of them performed the *right-left* task. The differences between the age groups in education, gender, and vocabulary did not reach statistical significance.

Procedure

There were four mixed-task blocks (80 trials each) followed by one single-task block (80 trials). The constant RCI was 2,032 ms, and the randomly varying CTI was 116 and 1,016 ms. The RCI was determined according to results by Meiran, Chorev, and Sapir (2000), who found very slow reduction in switching-cost as a result of increasing the RCI beyond .5 s. Obviously, the instructional cues changed across trials in the mixed-task condition and were constant in the single-task condition. Participants were explicitly informed of the transition to single-task conditions.

Results and Discussion

Mixed-Task Performance

RT.—The main analysis was conducted according to age and to four within-participant independent variables: block (1–2 vs 3–4), task-switching (switch, no-switch), CTI, and congruency. There were between 14 and 20 analyzable RTs per condition, on average, and Table 2 includes the relevant means.

All the main effects were significant, including age, $F(1, 30) = 22.53$, $MSE = 4{,}395{,}127$, which showed that the elderly participants responded more slowly than the young participants (737 vs. 1,389 ms) (see Appendix, Note 3). Of interest is the triple interaction (see Figure 3) among age, task-switching, and congruency: $F(1,30) = 4.42$, $MSE = 60{,}016$ ($p = .17$ in LogRTs). This interaction reflects the

Table 2. Mean RT (ms) and Proportion of Errors (PE)-Experiment 1: Cue-Target Interval (CTI)

Age Group	CTI(ms)			Switch	No-Switch	Switching-Cost	Single-Task
Young	116	Congruent	RT	862	741	121	537
			PE	.00	.00	.00	.01
		Incongruent	RT	956	806	150	572
			PE	.05	.01	.04	.02
	1,016	Congruent	RT	660	617	43	497
			PE	.00	.00	.00	.00
		Incongruent	RT	773	720	53	540
			PE	.03	.00	.02	.00
Old	116	Congruent	RT	1,517	1,199	318	723
			PE	.00	.00	.00	.00
		Incongruent	RT	1,887	1,453	434	793
			PE	.20	.09	.11	.02
	1,016	Congruent	RT	1,205	1,059	146	682
			PE	.01	.00	.01	.00
		Incongruent	RT	1,558	1,232	327	757
			PE	.16	.08	.07	.01

fact that among the elderly, congruency interacted significantly with task-switching $F(1,30) = 11.79$, $MSE = 60{,}016$, resulting in a larger congruency effect in the switch condition relative to the no-switch condition. However, the equivalent simple interaction did not approach significance in the young group, $F < .3$. The significant two-way interactions of age with task-switching, $F(1,30) = 14.97$, $MSE = 196{,}192$, $\eta^2 = .33$, and with congruency, $F(1,30) = 6.64$, $MSE = 360{,}832$, $\eta^2 = .18$, are revealing, in spite of being qualified by the triple interaction. They indicate that the elderly suffered greater switching-costs and showed larger congruency effects compared to the young participants. An additional significant interaction involving age included block, $F(1,30) = 4.26$, $MSE = 242{,}966$, $\eta^2 = .12$ (not significant (*ns*) in LogRT). The interaction reflects the fact that the elderly subjects gained more from time on task than the young participants did. In addition, there was a significant two-way interaction between CTI and task-switching, $F(1, 30) = 19.99$, $MSE = 41{,}319$ (Figure 4). As usually found, task-switching–cost was reduced by increasing the CTI, indicating the preparatory component. Block interacted significantly with task-switch, $F(1,30) = 11.02$, $MSE = 30{,}212$, and with congruency, $F(1,30) = 4.19$, $MSE = 34{,}413$, reflecting that time on task resulted in smaller congruency effects (see Appendix, Note 4) and smaller switching-costs. It is important to note that the triple interaction among age, CTI, and task-switching did not approach significance $F = 1.04$, $\eta^2 = .03$. Coupled with the significant interaction between age and task-switching, the results indicate a relatively normal preparatory component in old age and an enlarged residual component. A planned contrast indicated that the residual switching-cost (measured at the longest CTI) differed significantly between the two groups, $F(1,30) = 11.58$, $MSE = 9{,}789$, $\eta^2 = .28$.

Errors.—There were virtually no errors in the congruent condition (0% and .2% for young participants and elderly participants, respectively). In the incongruent condition, the young participants committed 2.4% errors and the elderly ones committed 13.2% errors. Given these results showing virtually zero errors in the congruent condition, we restricted the analysis to the incongruent condition. None of the effects reached significance. Most importantly, speed–accuracy tradeoff did not qualify any of the effects involving age.

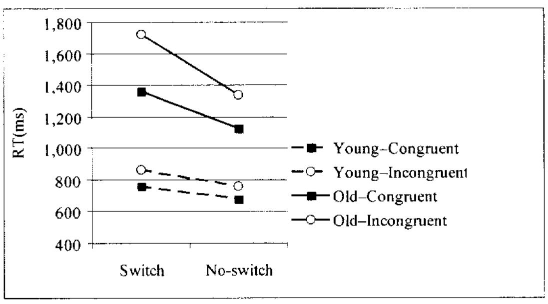

Figure 3. Mean RT (ms) according to age, task-switching, and congruency: Experiment 1.

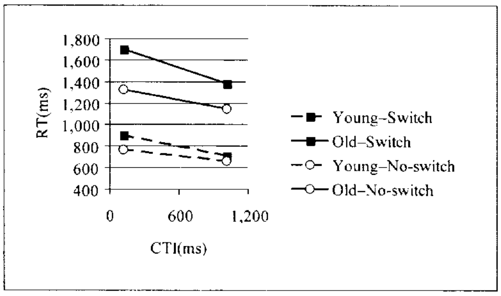

Figure 4. Mean RT according to age, task-switching, and CTI: Experiment 1. CTI = Cue-Target Interval. The triple interaction was nonsignificant.

Single-Task Performance

Errors.—There were virtually no errors in the single task condition: .4% and 0% in the congruent condition for the young participants and the elderly participants, respectively, and 1.2% in both groups in the incongruent condition. All the remaining analyses were thus conducted exclusively on RTs.

Adjustment to single-task conditions.—In the first analysis we wished to examine whether Mayr and Liebscher's results concerning fade-out could be replicated using our paradigm. Unlike Mayr and Liebscher, we decided to include the single-task condition at the end of the experiment for the reasons specified above. Consequently, there was no single-task baseline. Our partial solution to the problem was to analyze the no-switch trials together with the single-task trials. Each block in the mixed-task condition was subdivided to two miniblocks of 40 trials each. Each of the resulting miniblocks was represented by the mean RT in the no-switch trials. The single-task trials were arranged into miniblocks of 8 trials each. Thus, each participant was represented by 18 means, representing between 17 and 20 RTs (mixed) and between 7 and 8 RTs (single), on average. A two-way analysis of variance (ANOVA) was conducted according to age and miniblock, and both the main effect for age group, $F(1,30) = 20.56$, $MSE = 789{,}560$, and for miniblock, $F(17,510) = 9.79$, $MSE = 27{,}129$ were significant, as well as the interaction, $F(7,510) = 6.61$, $MSE = 32{,}237$ (see Figure 5).

In order to explore the interaction, we analyzed the mixed-task trials separately (the first 8 miniblocks), and the two-way interaction between miniblock and age did not approach significance ($F = 1.38$), while the two main effects remained significant. The linear component of the interaction approached significance, however: $F(1,30) = 3.04$, $p = .09$, $MSE = 65{,}005$, $\eta^2 = .09$ (not significant in LogRT), indicating that the elderly gained more from mixed-task practice than the young participants did. We then analyzed the transition from the mixed-task condition to the single-task condition (miniblocks 8 and 9). The results indicated a significant main effect of age, while both the main effect of miniblock and the interaction did not approach significance. The transition results indicate that performance in the last mixed-task miniblock and the first single-task miniblock did not differ significantly. Finally, we analyzed the single-task trials only (miniblocks 9–18). In the final analysis, both main effects were significant as well as the interaction, $F(9,270) = 7.23$, $MSE = 10{,}697$. As shown in Figure 5, the elderly subjects showed faster and more pronounced improvement in performance than the young participants. This impression was confirmed statistically by tests of the polynomial components of the interaction of which the linear and quadratic components reached significance, $F(1,30) = 12.40$, 16.15, $MSE = 29{,}621$, 16,425, $\eta^2 = .29$, .35, respectively.

To summarize, time on task improved no-switch performance, but the learning rate was only slightly faster among the elderly participants compared to the young participants. The level of performance in the first single-task miniblock was similar to that in the last mixed-task halfblock. Finally, time on task improved single-task performance beyond the best level achieved in the mixed-task condition. Moreover, this improvement continued longer among the elderly participants compared to the young ones.

Another important issue concerns effects of old age on mixing-costs. To examine this issue, we compared the last six mixed-task miniblocks to the last six single-trial miniblocks. We chose these miniblocks in order to reduce to a minimum the effect of adjustment to single-task conditions (examined above), while at the same time keeping a sufficient number of trials to analyze. Of interest is the interaction between mixing (mixed vs single) and age, which was significant, $F(1,30) = 13.09$, $MSE = 175{,}944$, $\eta^2 = .30$. This result confirms the conclusion that old age has a relatively pronounced effect on mixing-cost.

Main analysis of the single-task condition.—For the reasons specified above, we excluded the first miniblock and analyzed the results according to age, CTI, and congruency. There were between 7 and 10 analyzable RTs per condition, on average, and the relevant results are presented in Table 2.

All the main effects were significant including age, $F(1, 30) = 11.97$, $MSE = 218{,}264$, CTI, $F(1,30) = 25.84$, $MSE = 3{,}469$, and congruency, $F(1,30) = 23.75$, $MSE = 8{,}319$. None of the interactions were significant, including the interaction between age and congruency, $F = 2.12$, $MSE = 8{,}319$, $\eta^2 = .07$. Although the main effect of congruency was significant, it was much smaller (39 and 72 ms among the young participants and the elderly ones, respectively) than in the mixed-task condition. The relevant comparison

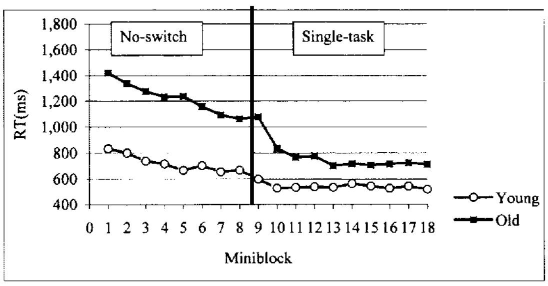

Figure 5. The interaction between miniblock and age: Experiment 1. The first eight miniblocks represent the no-switch trials in the mixed-task conditions, and the last ten miniblocks represent single task performance.

is with no-switch trial in the mixed-task conditions. Congruency effects were much larger in these conditions, 84 and 213 ms, among the young participants and the elderly participants, respectively.

Task repetitions preceding the switch trial.—Given the analysis of single-task performance, one possibility is that when the same task repeats for a few trials, this mimics single-task performance, resulting in a larger decrement in performance when the task is switched. In order to test this possibility, we classified the trials according to the number of task repetitions which preceded them. Four levels were formed: zero (meaning that the preceding trial was a switch trial), 1, 2, and 3 or more. Longer sequences of repeated task were relatively rare (less than 6%), and consisted of about 2 trials per cell, on average. We then conducted an ANOVA according to age, task-switching, CTI, and preceding task repetitions. Preceding task repetitions was not associated with any significant source of variation. Thus, we can rule out the explanation above for short sequences of repeated tasks. It is possible that the results would have resembled single-task results had we examined longer sequences of repeated tasks.

In summary, the results indicate that old age was associated with an increase in both mixing-cost and switching-cost. With respect to switching-cost, its preparatory component was barely influenced by old age while the residual component was increased among elderly participants. In agreement with Fagot (1994), we found increased congruency effects in the mixed condition. It is interesting to note that the results suggest that components that are relatively strongly influenced by congruency (mixing-costs) are also relatively strongly influenced by old age. This issue was examined in Experiment 2.

Experiment 2

One goal of Experiment 2 was to explore the reasons for elevated residual costs among the elderly. The results of Experiment 1 suggested that the differential effects of congruency in the two age groups contributed significantly to this effect. Namely, while congruency effects were considerably increased in the task-switching condition among the elderly participants, this effect was smaller in order of magnitude among the young participants. The question was whether there are additional reasons for enlarged residual costs in elderly adults. Therefore, we employed the four-key (univalent) response setup where the responses were neither congruent nor incongruent. According to Meiran's (2000a) model, univalent responses are predicted to be associated with zero residual costs. This prediction was confirmed in an experiment on normal young adults (Meiran, 2000b). The question was whether the same would be true for elderly adults.

The second goal was to examine the time course of task preparation in detail. For that purpose, we included four CTIs rather than just two CTIs. We reasoned that a differential rate of preparation would result in relatively enlarged age differences in switching-costs in intermediate CTIs. This is because when the CTI is short, both groups are minimally prepared for the task-switch, whereas when the CTI is very long, both groups are maximally prepared. In intermediate CTIs, the elderly participants might be less prepared than young participants and exhibit larger switching-costs (see Appendix, Note 5).

Methods

Participants

All the participants were members of a single kibbutz in southern Israel, although a different kibbutz than the one in Experiment 1. The difference between age groups in years of education and vocabulary did not approach statistical significance (Table 1), and the sex distribution was identical. Usually, elderly adults have better vocabulary scores than young participants, but in the present experiment, the numerical trend was reversed. One reason may be that, in this population, all the elderly volunteers had immigrated to Israel 40 to 50 years ago, and although they were proficient in Hebrew (the language of the test), it was not their mother tongue. In contrast, the young participants were born in Israel, and Hebrew was their mother tongue.

Procedure

The experiment was similar to Experiment 1 except that the participants used the four-key setup (Figure 2) instead of the two-key setup. For that purpose, the center of the keyboard was aligned with the center of the monitor. RT testing began with warm-up (20 trials) followed by four identical blocks (96 trials each). The trial structure was similar to that in Experiment 1 except that the constant RCI was 1,016 ms and the CTI varied randomly between trials (116, 416, 1,016, 3,016 ms).

Results and Discussion

RT

There were between 21 and 25 analyzable RTs per condition, on average (Table 3). This variation reflects the fact that task-switching was defined retrospectively and that some trials were excluded.

A 2 × 2 × 2 × 4-way mixed model ANOVA was conducted according to age, CTI (116, 416, 1,016, and 3,016 ms), task (*up-down* vs *right-left*) and task-switching (switch, no-switch). There were significant main effects of age, $F(1,28) = 20.75$, $MSE = 939{,}644$, CTI, $F(3,84) = 70.81$, $MSE = 14{,}836$, and task-switching, $F(1,28) = 80.72$, $MSE = 16{,}364$. In addition, the interaction between age and task-switching was significant, $F(1,28) = 11.81$, $MSE = 16{,}364$, $\eta^2 = .30$, as well as the interaction between task-switching and CTI, $F(3,84) = 17.49$, $MSE = 8{,}754$. The triple interaction among age, task-switching and CTI did not approach significance, $F < 1$ (Figure 6). Of interest are two components of this interaction. The quadratic component indicates that age differences in switching-cost were elevated in intermediate CTIs. Such a pattern corresponds to faster task preparation among the young participants relative to the elderly ones, as explained before. This component of the interaction did not approach significance, $F < 1$, $\eta^2 = .02$. The linear component of the triple interaction reflects the fact that one group has shown a greater reduction in switching-cost due to increasing the CTI. This component of the triple interaction was also nonsignificant, $F < 1$, $\eta^2 = .03$, with the young participants showing *less* numerical reduction in switching-cost as compared to the elderly ones. In other words, we replicated the results of Experiment 1, showing that old age barely affected the preparatory component of switching-cost.

Another important issue concerns the magnitude of switching-cost at the longest CTI, which represents residual cost. While this effect was 56 ms and significant among the elderly participants, $F(1,28) = 8.32$, $MSE = 5{,}626$, it was only 12 ms and did not approach significance among the young participants, $F < 1$. Hence, the results concerning residual cost indicate that the associated ability is compromised in old age and that the compromise is partly due to unrelated congruency effects.

Error Rate

There were three significant sources of variation: task-switching, $F(1,28) = 11.63$, $MSE = .003$; CTI, $F(3,84) =$

Table 3. Mean RT (ms) and Proportion of Errors (PE)-Experiment 2: Cue-Target Interval (CTI)

			Up–Down Task			Right–Left Task		
Age Group	CTI(ms)		Switch	No-Switch	Switching-Cost	Switch	No-Switch	Switching-Cost
Young	116	RT	948	766	182	950	813	137
		PE	.05	.02	.03	.04	.01	.03
	416	RT	739	670	69	741	716	25
		PE	.02	.02	.00	.02	.01	.01
	1,016	RT	713	683	30	740	689	51
		PE	.01	.02	−.01	.01	.01	.00
	3,016	RT	702	667	35	707	717	−.10
		PE	.02	.01	.01	.01	.00	.01
Old	116	RT	1,434	1,167	267	1,426	1,195	231
		PE	.08	.02	.06	.07	.00	.07
	416	RT	1,218	1,983	135	1,207	1,041	166
		PE	.04	.02	.02	.04	.04	.00
	1,016	RT	1,093	976	117	1,190	1,058	132
		PE	.04	.02	.02	.03	.02	.01
	3,016	RT	1,098	1,038	60	1,120	1,068	52
		PE	.03	.01	.02	.02	.02	.00

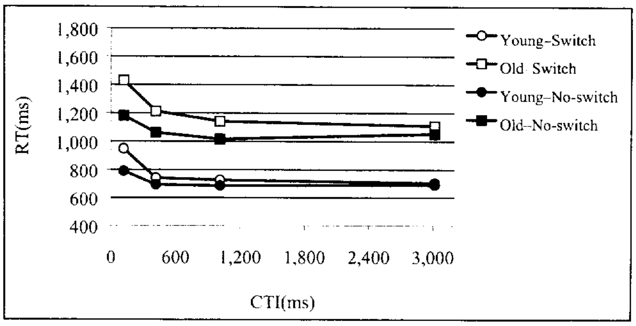

Figure 6. Mean RT (ms) according to age, task-switching, and CTI: Experiment 2. CTI = Cue-Target Interval. The triple interaction was nonsignificant.

12.12, *MSE* = .001; and the interaction between these variables, *F*(3,84) = 9.40, *MSE* = .001. This interaction resulted from a larger task-switching cost in the shortest CTI than in the remaining CTIs. In the shortest CTI, *PE* = .06 and .03 in the switch condition and the no-switch condition, respectively. In the next shortest CTI, *PE* = .03 and .02, the next longest, *PE* = .02 and .02, and in the longest CTI, *PE* = .02 and .01. This observation was supported by a significant contrast comparing the *PE* switching-cost in the first CTI to that in remaining CTIs, *F*(1,28) = 14.25, *MSE* = .012. The triple interaction involving age, CTI, and task-switching was not significant, *F* = 1.42.

Error Types

The four-key version of the paradigm enables the identification of task errors. These are responses in which the task is wrong, but the choice within the task is correct, e.g., in the *right-left* task, responding *up* to an upper right target stimulus. Task errors are especially relevant in the present context since they indicate a difficulty in task-switching and task-mixing. Two other possible errors are choice errors (e.g., responding *right* instead of *left*) and complete errors, where neither the task nor the choice within the task is correct. Complete errors were extremely rare, .05 error per condition, on average, and are therefore omitted from Figure 7.

A separate ANOVA was performed on the rate of task errors according to age, task-switching, and CTI. There was a significant main effect of CTI, *F*(3,84) = 8.89, *MSE* = .647, and of task-switching, *F*(1,28) = 10.38, *MSE* = 1.643. In addition, there was a significant two-way interaction between these variables, *F*(3,84) = 8.41, *MSE* = .624. Age had a marginally significant main effect, *F*(1,28) = 3.40, *p* = .08, *MSE* = 2.372. Task errors were more frequent after switching tasks, but their rate was reduced as a function of preparation, mirroring the effects seen in the RT switching-cost. The fact that age did not significantly interact with task-switching or CTI confirms our conclusions regarding relatively spared task preparation. Namely, task errors were reduced as a result of task preparation (CTI), but the rate of this reduction was statistically the same in the two age groups.

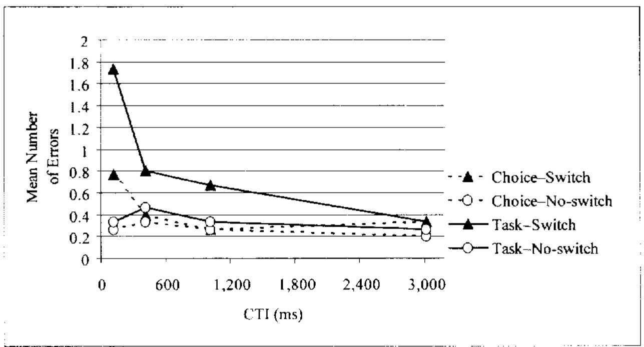

Figure 7. Mean error frequency according to error-type, CTI, and task-switching: Experiment 2.

The results can be summarized as follows. Switching-cost was statistically abolished by task preparation among the young participants, replicating Meiran's (2000b) results. This was not the case for the elderly participants, who exhibited significant residual cost. Hence, the results concerning residual cost indicate that the difficulties older persons have in residual cost is at least partly unrelated to their enlarged congruency effect. In that respect, the results challenge our processing model (Meiran, 2000a, 2000b), which predicts zero residual costs with univalent responses. Apparently, residual costs are influenced by more factors than specified in the model. As found in Experiment 1, the preparatory component of switching-cost was very similar in the two age groups.

Experiment 3

In Experiment 3, we examined the effect of old age on the third component of switching-cost, set dissipation, by employing Meiran, Chorev, and Sapir's (2000) procedure. The CTI was short and constant (117 ms) to permit cue encoding but not preparation. The RCI was manipulated between blocks of trials, rather than within a block, because the RCI was constant in Experiments 1 and 2. Thus, each experimental block may be conceived as a separate experiment, in which RCI is constant. The two-key setup (bivalent response) which was used in Experiment 1 served in Experiment 3. Based on our previous results, we predicted that increasing RCI would result in reducing switching-costs, indicating set dissipation. This prediction is measured by the two-way interaction between RCI and task-switching. Of interest was the triple interaction among age, RCI, and task-switching. This interaction measures the influence of old age on the dissipation component of switching-cost.

Methods

Participants

All of the young participants and 15 of the elderly participants were tested in Toronto, Ontario, Canada, in exchange for course credit or $5 Canadian Dollars (CAD) pay. For these participants, instructions and feedback during practice were given in English. All the young participants were undergraduate students from Erindale College, University of Toronto. Because of an experimenter error, there was not an equal number of elderly participants assigned to each key combination in the group of elderly participants. Therefore, seven additional elderly Israeli volunteers were recruited from the same kibbutz as the participants from Experiment 2, none of whom had participated in Experiment 2. In this experiment, vocabulary scores were available for the elderly participants only. For the 15 elderly participants who were tested in Toronto, the mean Mill-Hill (English) vocabulary score (out of 20) was 15.3 ($SD = 2.3$). In comparison, a representative sample of 40 Erindale College Canadian students had a mean vocabulary score of 14.1. For the seven elderly participants who were tested in Israel, the mean (Hebrew) Vocabulary score (out of 40) was 26.1 ($SD = 9.7$, range 20–33). Because all the young participants were first-year undergraduate students, there was no variability in years of education in this group, which made it impossible to apply a t test to examine group differences in education. Nonetheless, the numerical difference between groups was very small. Sex distribution was significantly different in the two groups ($p < .05$, by Fisher's exact test, two-tailed).

The group of elderly participants was heterogeneous, since most of them were Canadian, and a few were Israeli. We could compare the two groups on RT only. However, mean RT was more strongly influenced by which keys were used than by group. All the Israeli participants used the 1–9 key combination, and their mean RT was 1,750 ms, which compares with 1,724 ms for the four Canadians who used the same keys. This difference was not significant. In contrast, the Canadians who used the 3–7 key combination were faster, 1,470 ms.

Procedure

The stimuli, sequence of events within a trial, and response setup (bivalent) were similar to those employed in Experiment 1. The RCI was 432 ms during the 20 warm-up trials. There were five blocks of experimental trials, each involving a different fixed RCI (132, 232, 432, 1,032, or 3,032 ms). The CTI was constant, 117 ms. Participants were informed that the RCI would be constant in the entire block and that it would be changed between blocks. The order of RCIs was randomly chosen for each participant.

Results and Discussion

RT

Like in Experiment 1, we included congruency as an independent variable instead of task, which was not involved in any significant source of variation in Experiment 2 (Table 4). There were between 17 and 26 analyzable RTs per condition, on average. A $2 \times 2 \times 2 \times 5$-way ANOVA was conducted according to age, task-switching, congruency (congruent vs. incongruent), and RCI. All main effects were significant including age, $F(1,42) = 79.36$, $MSE = 1{,}997{,}094$, congruency, $F(1,42) = 56.28$, $MSE = 79{,}631$, RCI, $F(4,168) = 2.44$, $MSE = 164{,}151$, and task-switching, $F(1,42) = 121.18$, $MSE = 63{,}561$. There were three significant interactions, between task-switching and age, $F(1,42) = 17.64$, $MSE = 63{,}561$, $\eta^2 = .30$ ($p = .11$ in LogRT), between RCI and task-switching, $F(4,168) = 2.49$, $MSE = 164{,}151$, and between congruency and age, $F(1,42) = 6.93$, $MSE = 79{,}631$, $\eta^2 = .14$ (*ns* in LogRT). Of special interest is the triple interaction among age, RCI, and task-switching (Figure 8), which did not approach significance, $F = 1.46$ ($p = .12$ in LogRT). Nonetheless, the theoretically relevant component of the interaction is the quadratic component, which approached significance, $F(1,42) = 3.92$, $p = .054$, $MSE = 30{,}934$, $\eta^2 = .08$ ($p < .05$ in LogRT). This contrast indicates that age differences in switching-cost were elevated in the middle range of the RCI. Such a pattern corresponds to differential set-dissipation rates. Namely, when the RCI is very short, set dissipation did not yet affect either group, and when the RCI is very long, it affected both groups. In between, it had already affected the young participants but did not yet affect the elderly participants.

Table 4. Mean RT (ms) and Proportion of Errors (PE)- Experiment 3: Response Cue Interval (RCI)

			Incongruent			Congruent		
Age Group	RCI(ms)		Switch	No-Switch	Switching-Cost	Switch	No-Switch	Switching-Cost
Young	132	RT	892	736	156	763	642	120
		PE	.05	.01	.04	.01	.00	.01
	232	RT	946	786	160	870	707	163
		PE	.05	.02	.03	.01	.01	.00
	432	RT	798	700	98	737	633	105
		PE	.06	.03	.03	.01	.00	.01
	1,032	RT	792	698	95	699	595	103
		PE	.05	.03	.02	.00	.00	.00
	3,032	RT	845	760	85	726	653	72
		PE	.04	.03	.01	.00	.00	.00
Old	132	RT	1,863	1,695	168	1,721	1,452	269
		PE	.07	.03	.04	.03	.00	.03
	232	RT	1,904	1,549	355	1,628	1,394	234
		PE	.09	.06	.03	.01	.00	.01
	432	RT	1,846	1,511	336	1,677	1,357	320
		PE	.10	.04	.06	.02	.01	.01
	1,032	RT	1,758	1,469	289	1,567	1,315	252
		PE	.07	.03	.04	.01	.00	.01
	3,032	RT	1,777	1,568	208	1,527	1,374	154
		PE	.06	.03	.03	.02	.01	.01

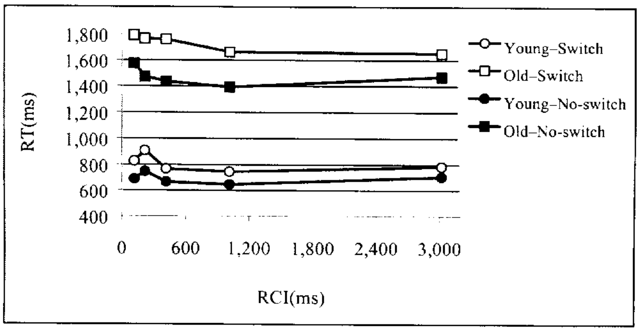

Figure 8. Mean RT (ms) as a function of task-switching, RCI, and age: Experiment 3. RCI = Response-Cue Interval.

Error Rate

There was a significant effect of congruency, $F(1,42) = 17.24$, $MSE = .021$, and task-switching, $F(1,42) = 14.98$, $MSE = .005$. In addition, the interaction between these variables was also significant, $F(1,42) = 11.64$, $MSE = .003$. The interaction reflected the fact that there were very few errors in the congruent condition, $PE = .01$ in both the switch condition and the no-switch condition. In the incongruent condition there were more errors in the switch condition, $PE = .07$, than in the no-switch condition, $PE = .03$.

The results of the present experiment replicate those by Meiran, Chorev, and Sapir (2000), showing that increasing the RCI resulted in smaller switching-costs. The elderly participants had larger switching-costs and congruency effects compared to the young participants, as found in Experiment 1. Curiously, the triple interaction among age, congruency, and task-switching found in Experiment 1 was not replicated. With respect to our critical question, the results suggest a relatively modest influence of old age on set dissipation.

General Discussion

In the present work, we have demonstrated that old age is associated with a pattern of relatively intact and relatively impaired task-switching abilities. The fact that the differential effects were found in the same paradigm validates our interpretation of previous results in the literature (see Appendix, Note 6).

The conclusions are relatively straightforward. Old age had a marked effect on mixing-costs ($\eta^2 = .30$) and congruency effects ($\eta^2 = .14$–$.18$). With respect to mixing-costs, we have successfully replicated Mayr and Liebscher's (in press) fade-out results in our paradigm. The results indicated that old age was associated with a relatively prolonged adjustment to single-task conditions. We have also found that old age did not equally affect the three subcomponents of switching-cost. While old age had a modest influence on the set-dissipation component ($\eta^2 = .08$) and a large influence on the residual component ($\eta^2 = .30$–$.33$), its influence on the preparatory component was negligible ($\eta^2 = .02$–$.03$).

We take these results as strong evidence that (a) task-switching is related to several distinct abilities, and (b) some task-switching abilities are barely influenced by old age while other switching abilities are strongly influenced by old age. The fact that old age effects were large for some components, while nearly absent for other components, rules out general slowing as an alternative explanation. If this explanation were relevant, one would predict that old age would be associated with a relatively uniform effect across the various components. In the remaining discussion, we will suggest which cognitive and brain processes may have mediated effects of old age on task-switching performance.

Cognitive Processes Mediating Old Age Effects on Task-Switching Performance

Our cognitive interpretation is based on a detailed processing model of task-switching (Meiran, 2000a). This model was fit successfully to experimental results, and some critical predictions were confirmed (Meiran, 2000b). It is assumed that performance on a given task makes it necessary to adopt several task sets. Task sets are psychological entities that deal with multivalent task elements. In the present paradigm, two task elements were multivalent: the stimuli and the responses. Hence, two task sets are involved: a stimulus task-set and a response task-set. For yet unknown reasons, participants activate the stimulus task-set while preparing for the upcoming task. Hence, the adoption of the stimulus task-set explains the preparatory component.

Unlike the stimulus task-set, which is activated while preparing for a task switch, the response task-set is assumed to adjust retroactively after response. In the case of a task-switch, this process readies the system for the wrong task. For example, after performing Task A, the response task-set is adjusted to fit the requirements of Task A. When switching to Task B, this implies performing with a suboptimally adjusted response task-set, giving rise to residual costs. In other words, in order to be completely prepared for a given task, participants need to respond a few times, with each response leading to a further partial adjustment of the response task set. Preparing in advance without actually responding is insufficient, since it results in an adjustment of the stimulus task-set but not in an adjustment of the response task-set.

Mixing-costs are explained by the fact that response-set adjustment cannot be completed in mixed-task conditions. The reason is that response-set adjustment is a gradual process, and a small incremental adjustment to Task A, for example, would be quickly cancelled by future adjustment to Task B. In single-task conditions, however, response-set adjustment is consistent since the incremental adjustments do not cancel each other, but, instead, are additive.

Our results indicate a relatively unimpaired preparatory component in old age. According to the model, the results indicate that old age does not influence the activation of stimulus task-sets. It should be noted that the activation of stimulus task-sets is equivalent to selectively attending to the task-relevant dimension. Therefore, our results indicate that old age has a relatively minor influence on the ability to dynamically change the focus of selectivity from one stimulus dimension to another stimulus dimension. In that respect, the present results add to previous demonstrations regarding minor influences of old age on some selective attention processes when the relevant information is cued in advance (e.g., Hartley et al., 1990; Hartley, 1993; Madden, Pierce, & Allen, 1992).

More broadly, our results support the conclusion that some processes which, from the cognitive–theoretic perspective (e.g., Meiran, 1996, for a justification) represent executive control functions, are age-invariant. Another example is age invariance in negative priming in some conditions (e.g., Kieley & Hartley, 1997). The Psychological Refractory Period (PRP) paradigm is also relevant. The paradigm involves presenting stimuli of two tasks (ordered S1, S2) in rapid succession, followed immediately by responses (ordered R1, R2) to these stimuli. The common finding is that R2 is slowed when the interval between S1 and S2 is short. Contemporary models attribute the PRP effect to the fact that S2 processing must halt until the response selection mechanism has completed processing S1 (Pashler, 1998). Results indicate that the PRP effect is larger among elderly adults. However, the strategy employed by young participants and elderly participants is similar in that response selection acts as a bottleneck while other processing stages seem to be executed in parallel (Allen, Smith, Vires-Collins, & Sperry, 1998; Hartley & Little, 1999). The results reviewed above are best explained as showing that elderly adults are slowed in response selection. However, their time-sharing strategies, which represent executive control, are the same as among young participants. In summary, several experimental paradigms, which are believed to tap executive control, indicate age invariance in some conditions and/or processes.

The largest influence on age was found in mixing-cost and in the residual cost. The larger mixing-costs among the elderly participants could be explained by the fact that the elderly participants adjusted the response task-set more fully in single-task conditions. This interpretation is supported by fitting the mathematical model developed by Meiran (2000a) to the results of Experiment 1 (Meiran & Gotler, in press). The results of this analysis are somewhat counterintuitive, showing that the elderly participants were better able than the young participants to take advantage of the single-task conditions. Given the apparent superiority of the elderly participants, it is quite likely that the results concerning mixing-cost represent a compensatory strategy used by the elderly participants rather than impairment. An alternative interpretation, which we cannot rule out, is that single-task conditions are less taxing in terms of working memory. Thus, effects of old age on mixing-costs may be interpreted as yet more evidence for the poor performance of elderly participants on tasks believed to tap working memory (see Salthouse, 1994, for review) (see Appendix, Note 7).

The interpretation of old-age effects on residual costs is less clear. We can rule out three possible explanations. The first of these is the idea that age differences in residual costs may reflect differential adjustment of the response task-set. This explanation is probably incorrect given the effect measurements in Experiments 1 and 2. The best index for old-age effects on residual costs is the two-way interaction between age and task-switching. Using this index, we have shown that the proportion of age-related variance was similar in Experiment 1, which employed bivalent responses ($\eta^2 = .33$) and Experiment 2, which employed univalent responses ($\eta^2 = .30$). These results may suggest that most of the age-related variance in residual costs is *not* due to the differential adjustment of the response task-set. The reasoning is that response-set adjustment could not contribute to switching-costs in Experiment 2.

Second, we can rule out the idea that, compared to the young participants, the elderly ones may have prepared for a task-switch on a smaller proportion of the trials (see De Jong, 2000, De Jong et al., 1998, for details). This account is also incomplete at best, since it leads to predicting a larger age difference in switching-cost in the long CTIs than in the short CTI, whereas we have found similar age-dependent differences in these CTIs. The reasoning underlying this prediction is that task preparation had not yet taken place in the short CTI. Thus differential preparation could not contribute to age-related differences. In contrast, differential preparation could contribute to age-dependent differences in switching-costs in the long CTIs, where an opportunity to prepare was given.

A third explanation is that the elderly have delayed stimulus-set adjustment until after the target stimulus was presented. Although we cannot rule out this account completely, we do not place too much faith in it. We have fitted our mathematical model to the results of Experiment 1 (Meiran & Gotler, in press) and the results of this analysis indicated a relatively minor difference between the groups in stimulus-set adjustment. A hint concerning a possible explanation comes from a study in preparation, conducted on young adults, in which we compared two conditions involving bivalent responses. In one condition, the responses were compatible (e.g., the upper left key indicated *up* or *left*), while in the other condition, the responses were incompatible (e.g., the upper left key indicated *down* or *right*). We found increased residual cost in the incompatible condition relative to the compatible condition. Given the standard assumptions regarding compatibility, the results of the experiment can be interpreted as showing that residual costs increase when the response selection stage is prolonged. One such condition is old age (e.g., Allen et al., 1998; Allen, Madden, Weber, & Groth, 1993). The fact that Meiran and Gotler's (in press) model fit results also indicated that the major influence of old age was on the speed of response selection and response initiation.

Our results concerning the dissipating component are tentative and thus should be interpreted with caution. Nonetheless, in experiments on young adults, we have shown that the dissipating component is insensitive to strategic manipulations (Meiran, Chorev, & Sapir, 2000). Hence, the influence of age on that component may *not* be taken as evidence for deficient inhibitory processes (e.g, Hasher, Stoltzfus, Zacks, & Rypma, 1991). Rather, the effect is more in line with theories concerning increased levels of cognitive noise in old age (e.g., Krueger & Allen, 1987; Allen, Weber, & May, 1993). In the present case, the fact that an irrelevant task set is still active constitutes cognitive noise.

Brain Functions Mediating Old Age Effects on Task-Switching Performance

A final issue is related to the underlying brain mechanisms. First, although old age affects many parts of the brain, it is widely believed to have an especially marked effect on the prefrontal cortex (e.g., Raz, et al., 1998; West, 1996). Thus, functions that are affected by old age may or may not be related to the prefrontal cortex. However, functions that are not affected by old age are probably not subserved by the prefrontal cortex. There is now relatively direct evidence that alternation cost is elevated following a frontal damage (Rubinstein, Evans, & Meyer, 1994). With respect to specific components, Rogers and colleagues (1998) have measured switching-cost using univalent responses and a long preparatory interval. Thus, they have measured residual costs under conditions that are analogous to those employed in Experiment 2. Their results indicate elevated residual costs among patients with focal left prefrontal lesions, similar to our elderly participants.

Functional imaging studies indicate that alternation cost (the comparison of switch to single-task) is associated with an elevated level of blood oxygenation. This is also true for switching-costs (Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000). A recent functional imaging study by Dove, Schubert, Pollmann, Norris, & von Cramon (1999) used an event-related functional magnetic resonance imaging (fMRI) design to separate cue-related switch activity from target-related switch activity. The authors found that behavioral switching-costs were reduced by increasing the CTI. Importantly, target-related blood oxygenation (related to residual cost and the dissipating component) was found in prefrontal regions, while this was not the case for cue-related activity, reflecting task preparation. A similar conclusion can be drawn from the results by Moulden and colleagues (1998). These authors measured high-density event-related potentials (ERPs) when participants performed in a paradigm similar to the one employed in Experiment 2. The ERPs were locked to the presentation of the instructional cue and, hence, indicate the brain regions involved in the preparation for a task switch. There were three switch-specific ERP components: bi-occipital (N200), parietal (P390), and midfrontal (N430). The bi-occipital component probably reflects the fact that the cues were different in the two tasks and, hence, visual processing changed if there was a task switch. Although there was a midfrontal generator, it is probably unrelated to the preparatory component, because its maximum was reached 430 ms after the presentation of the instructional cue. However, Meiran, Chorev, and Sapir (2000), who used a similar paradigm, found that the task-switching–cost reached its minimum when the CTI reached 430 ms. Because causes must precede their consequences, the midfrontal generator is unlikely to be a major cause for the reduction in the behavioral task-switching–cost during the CTI. Taken together, the results reviewed in this section suggest that the preparatory component of switching-cost is not subserved by prefrontal brain regions, and is thus relatively preserved in old age. In contrast, residual cost is subserved by the prefrontal cortex, which may also be true for mixing-cost and the dissipating component of switching-cost. For this reason, these components of alternation cost are affected by old age.

Conclusions

We have used Fagot's (1994) theory, extended by Meiran, Chorev, and Sapir's (2000), to organize our short review of the literature on task-switching in old age. The theory enabled us to come up with several empirical generalizations. We have supported these generalizations using a new paradigm, which has also enabled us to examine age-related variance in a yet untested component of set dissipation. Thus, the generalizations (perhaps excluding the dissipation component) seem to be relatively stable across a variety of switching paradigms. Our results indicate that some components of switching are age-variant and some are relatively age-invariant. The age-invariant abilities likely reflect the (cued) selective attention to the relevant stimulus dimension, probably subserved by posterior brain regions. In contrast, the age-variant abilities include the disproportional benefit from single-task conditions, and the elevated residual-cost and congruency effects. Some or all of these processes may result from the effects of old age on the prefrontal cortex.

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Appendix

Note 1. This finding is not unique to the present version of the paradigm. A comparison between Rogers and Monsell's (1995) experiments and Rogers and colleagues' (1998) experiment supports the same conclusion. The former paper employed bivalent responses and indicated a large residual cost, while the latter paper used univalent responses and found near zero residual costs among normal participants. The responses in Rogers and associates' paper were vocal (the utterances *vowel, consonant* vs. *odd, even*). Thus, each utterance indicated a single meaning.

Note 2. We should mention the fact that although only eight stimuli are shown (the combination of two instructional cues and four target locations) participants do not seem to learn specific stimulus–response pairs. Such learning is possible for congruent trials, but is impossible for incongruent trials, where the same stimulus is associated with two different responses. Thus, one would predict an interaction between congruency and practice, but such an interaction is not found (see Meiran, 1996, for details).

Note 3. Since all the main effects were qualified by interactions, the remaining main effects are not specified to save space.

Note 4. This is just another example which demonstrates that practice had a larger effect on incongruent trials than on congruent trials, contrary to what researchers would predict assuming that participants learn specific stimulus-response combinations. See Note 2.

Note 5. This trend is reflected in the quadratic component of the triple interaction among task-switching, CTI, and age.

Note 6. Our task analysis may be applicable for discrimination tasks only. A recent study in our lab (Marciano, 1999) indicates significant differences in switching processes between same–different judgments and discrimination tasks.

Note 7. We prefer the former account over the working memory account given the mixed evidence on working memory and aging (for example Belleville, Rouleau, & Caza, 1998, who did not find age effects). Moreover, the former account is based on explicit modeling of the results rather than a verbal description.