Age-related differences in task switching and task preparation: Exploring the role of task-set competition

Patricia Hirsch[1], Tina Schwarzkopp[1], Mathieu Declerck[1], Stefanie Reese[2], and Iring Koch[1]

[1]Institute of Psychology, RWTH Aachen University, Aachen, Germany

[2]Institute of Applied Mechanics, RWTH Aachen University, Aachen, Germany

Authors' note

Patricia Hirsch, Tina Schwarzkopp, Mathieu Declerck, and Iring Koch, Institute of Psychology RWTH Aachen University, Aachen, Germany. Stefanie Reese, Institute of Applied Mechanics, RWTH Aachen, Aachen, Germany. Mathieu Declerck is now at the Aix-Marseille Université, Marseille, France.

This research was supported by a seed fund awarded to Iring Koch and Stefanie Reese by the Human Technology Center (HumTec) of RWTH Aachen University, which is funded by the Excellence Initiative of the Wissenschaftsrat and the Deutsche Forschungsgemeinschaft (DFG).

Correspondence concerning this article should be addressed to Patricia Hirsch, Cognitive and Experimental Psychology, Institute of Psychology, RWTH Aachen University, Jägerstr. 17-19, D-52066 Aachen, Germany. E-mail may be sent to patricia.hirsch@psych.rwth-aachen.de

Abstract

The present study focused on the role of task preparation in age-related task-switching deficits. In Experiment 1, we assessed the preparatory reduction of alternation costs (i.e., alternating-task conditions vs. single-task conditions) in twenty-two older adults (65-78 years) and 22 young adults (20-28 years) by varying the response-stimulus interval (RSI) in a task-switching paradigm with a predictable task sequence and univalent stimuli. In Experiment 2, in which new groups of 22 older adults (65-78 years) and 22 young adults (18-24 years) took part, we replicated Experiment 1 with bivalent stimuli, which were associated with both tasks and thus increased task-set competition. Whereas in Experiment 1, in which we used univalent stimuli, there were no age-related differences in the preparatory reduction of alternation costs, the data showed impaired task preparation in old age with bivalent stimuli in Experiment 2. These data support the notion that task-preparation deficits in old age occur particularly in situations of increased task-set competition. *(156 words)*

Keywords:

Age-related task-switching deficits; task preparation; task-set competition

1. Introduction

Aging is accompanied by a decrease in cognitive control (see Craik & Salthouse, 2000, for a review), which is defined as the ability to flexibly adjust goal-directed behaviour to constantly changing situational demands (Miller & Cohen, 2001). Age-related deficits in cognitive control have often been explored in studies requiring task switching (see, e.g., Wasylyshyn, Verhaeghen, & Sliwinski, 2011, for a meta-analysis). In these studies, older adults typically show larger performance costs when they are required to switch between tasks than young adults.

Switching-related performance costs are usually reduced when there is sufficient time available to prepare for a task switch (e.g., see Kiesel et al., 2010, for a review). Some studies provide evidence that older adults are able to prepare for a task switch at least as effectively as young adults (e.g., Hartley, Kieley, & Slabach, 1990; Kramer, Hahn, & Gopher, 1999; Experiment 2; Lawo & Koch, 2012). However, other studies observed an impaired task preparation in old age (e.g., Hsieh & Wu, 2010; Kramer et al., 1999; Experiment 3; Lawo, Philipp, Schuch, & Koch, 2012). Thus, studies about the effect of age on task preparation revealed mixed findings.

In the present study, we re-examined the effect of age on task preparation. In Experiment 1, we assessed switching-related performance costs and age-associated differences in the preparatory reduction of these costs using univalent stimuli. In Experiment 2, we explored whether such age-related differences are exacerbated when task-set competition is increased by using bivalent stimuli.

1.1. Task switching and accounts of switching-related performance costs

In the task-switching paradigm, subjects switch between two tasks or repeat them across trials. Performance is typically slower and more error prone in task switches than in repetitions (see Kiesel et al., 2010, for a review). Depending on the experimental design, a distinction is drawn between three measures reflecting the increased cognitive demands in switch trials.

One of these measures is the *alternation cost*. This cost is computed by contrasting performance in single-task blocks, which are by definition repetition trials, with performance in alternating-task blocks, in which the task changes after each trial, and thus, no immediate task repetitions occur (e.g., Jersild, 1927).

Using mixed-task blocks where, in addition to switch trials, repetition trials are also included, *mixing costs* can be analyzed as a further index of performance deterioration. These costs are computed as the difference between the performance in repetition trials of mixed-task blocks and the performance in single-task blocks (e.g., Rubin & Meiran, 2005).

Finally, *switch costs* can be assessed as a third measure of performance degradation. These costs are calculated in mixed-task blocks by contrasting performance in repetition trials with that in switch trials (e.g., Rogers & Monsell, 1995).

Switching-related performance costs have been shown to be reduced when there is sufficient time available to prepare for the upcoming task (see Kiesel et al., 2010, for a review). Preparatory processes in task switching can be investigated by varying the cue-stimulus interval (CSI) in unpredictable task sequences (e.g., Meiran, 1996) or the response-stimulus interval (RSI) in predictable task sequences (e.g., Rogers & Monsell, 1995).

Different accounts have been proposed to explain the performance deterioration in switch trials and the reduction of this deterioration with preparation time. According to the proactive interference (PI) account by Allport, Styles, and Hsieh (1994), performance in switch trials is impaired because the target task set was irrelevant in the previous trial and therefore inhibited, whereas the non-target task set was relevant and received additional activation. In switch trials, this causes interference “in the form of continued priming of the previous task (competitor priming) and suppression (negative priming) of the currently intended task” (p. 293). Switching-related performance costs are reduced with preparation time because with long intervals, there is more time available for task-set dissipation than with short intervals, resulting in less interference in switch trials.

In contrast to the PI account, reconfiguration models assume that in switch trials, a task-set reconfiguration takes place which results in an increased activation of the relevant task set in working memory (e.g., Meiran, 2000; Rogers & Monsell, 1995). These reconfiguration processes (e.g., task-set updating and the readjustment of task-set activation levels) are time-consuming, leading to slower responses in switch trials than in repetition trials. With long intervals, there is more time available for these reconfiguration processes than with short intervals, resulting in reduced switching-related performance costs.

1.2. Accounts of cognitive aging and the effect of age on task-switching performance

Numerous studies have addressed the question of whether there are age-related decreases in task-switching performance and of whether these decreases are the result of general limitations in the processing speed or of process-specific limitations. According to accounts of general processing limitations (e.g., general slowing hypothesis; Salthouse, 1996), the older adult’s poorer performance in different tasks is due to a general decrease in processing speed in all cognitive processes. The reason for this decline may lie in an age-related reduction in the efficiency with which neurons transfer information (Cerella, 1985).

In contrast to accounts of general limitations in the processing speed, accounts of process-specific limitations assume that there are age-related impairments only in some cognitive processes and that these impairments are not a result of a decrease in processing speed (e.g, inhibitory deficit theory; Lustig, Hasher, & Zacks, 2007; Hasher & Zacks, 1998). Hence, to demonstrate such specific changes in cognitive processing, one needs to show that these changes cannot be explained by proportional slowing (see, e.g., Kray, 2006).

Research on the effect of age on task-switching abilities showed that there are age-related deficits in mixing costs (e.g., Reimers & Maylor, 2005; Verhaeghen & Cerella, 2002; Wasylyshyn et al., 2011), whereas age-related differences in switch costs are frequently non-existent (e.g., Hartley, Kieley, & Slabach, 1990; Wasylyshyn et al., 2011) or only moderate (e.g., Kray & Lindenberger, 2000). The age-associated increase in mixing costs has been shown to be disproportional to the older adults' baseline performance (Kray, 2006), suggesting a process-specific account.

Mixing costs supposedly index cognitive processes of updating and maintaining two task sets in working memory (Mayr, 2001). Thus, these findings suggest that older adults' performance in task switching is hampered by a decline in these processes than by the requirement to switch between tasks. Alternation costs include additional costs due to flexible switching requirements, but these costs seem to be not age-specific (see Wasylyshyn, Verhaeghen, & Sliwinski, 2011, for a meta-analysis). Hence, the mechanisms leading to age-related differences in alternation costs should be the same as those reflected by mixing costs.

Mayr (2001) demonstrated that age-associated differences in switching-related performance costs are large when task-set competition is increased and the internal differentiation between task sets is difficult. For example, task-set competition is increased when stimuli and/or responses are bivalent. In contrast to univalent stimuli, which are linked to one task only, bivalent stimuli are associated with two tasks, resulting in competing task sets and in an increased difficulty of task-set differentiation. When the responses for two tasks are separated, hence with no overlap between the response specifications of the tasks, the responses are univalent and the competition between the response sets is low. In contrast, the response set-up is bivalent and task-set competition is increased when responses for two tasks overlap physically (i.e., same set of response keys) or conceptually (i.e., two tasks are mapped onto different hands, but the same spatial mapping is used in both tasks). When stimuli and/or responses are bivalent, the maintenance and updating of task sets in working memory is particularly difficult because there is a high competition and interference between them. Thus, univalent and bivalent stimuli as well as responses differ in the recruitment of working memory processes.

In addition to studies which explored whether older adults show larger switching-related performance costs than young adults, there are also studies that focused especially on age-associated differences in the preparatory reduction of switching-related performance costs. Several studies suggested intact task-preparation ability in old age comparable to that in young adults (e.g., Hartley et al., 1990; Lawo & Koch, 2012; Meiran, Gotler, & Perlman, 2001). However, some studies showed an age-related decrease in the preparatory efficiency (e.g., Hsieh & Wu, 2001; Kramer et al., 1999; Experiment 3; Lawo et al., 2012). Lawo and colleagues (2012), who found an age-related deficit in the preparatory reduction of alternation costs, argued that this deficit indicates that preparation processes involved in the updating of task set in working memory are impaired in old age.

A reason for the inconsistent data pattern may lie in vast methodological differences between these studies. Apart from the stimuli and tasks, these differences concern, for example, the number of tasks (two vs. three), the type of the preparation interval (RSI vs. CSI), its duration, and the way of its variation (within blocks vs. across blocks).

Yet, in spite of these differences, a comparison of the existing studies suggests that older adults show impaired preparatory efficiency especially in situations with increased task-set competition, which hampers the maintenance and updating of task sets in working memory and hence increases the demands on working memory processing. In the study by Lawo and colleagues (2012), task-set competition was more pronounced than in the above reviewed studies because, in addition to bivalent stimuli, Lawo and colleagues (2012) used three tasks and subjects were required to differentiate between three instead of two competing task sets. This study suggests that age-related preparatory deficits in the context of increased task-set competition might contribute to age-related effects in switching-associated performance costs. Consequently, it is important to explore task-set competition, switching-related performance costs in old age, and age-related differences in preparation effects together. Since Mayr (2001) did not explore age-related differences in preparatory processes and the above reviewed studies about task preparation in old age used exclusively bivalent stimuli, there is currently little clarity on the impact of task-set competition on age-associated differences in preparatory processes.

1.3.The present study

In the present study, we investigated whether task-set competition contributes to age-related deficits in task switching and task preparation by varying the RSI and comparing task switching performance with univalent stimuli (Experiment 1) to that with bivalent stimuli (Experiment 2). The goal was to replicate the finding of increased switching-related performance costs in old age in situations with high task-set competition (Mayr, 2001) and to extend the negative effect of task-set competition to task-preparation effects in old age. This would indicate that age-related differences in task preparation are increased particularly when working memory demands are high.

In the study by Lawo and colleagues (2012), which suggested age-related preparatory deficits, the task changed after each trial and hence task preparation was explored using alternating-task blocks. Since subjects have to switch back and forward in such blocks, alternation costs instigate strong competition and thus might be a more sensitive measure for age-related deficits in task preparation than mixing costs and switch costs. For this reason, we explored age-related differences in the preparatory efficiency based on alternation costs.

To assess the preparatory efficiency, we chose RSIs of 100 ms and 600 ms as preparation intervals because for predictable task sequences, Rogers and Monsell (1995) showed that RSIs up to 600 ms are used for the active preparation of a task switch and that there is no evidence for passive decay of the prepared task sets with RSIs of this length. Moreover, they demonstrated that for longer preparation intervals, there is no further preparatory reduction of switching-related performance costs, indicating that preparatory processes in predictable task sequences may take about 600 ms to accomplish.

2. Experiment 1

In Experiment 1, we aimed to examine age-related differences in the preparatory efficiency under situations of low task-set competition in a task-switching paradigm with a varying RSI and a predictable task sequence including a task switch after each trial. In contrast to most previous studies, we used univalent stimuli to reduce task-set competition by decreasing the interference between potential relevant task sets at the stimulus level.

We hypothesized that performance is slower and more error prone in alternating-task blocks than in single-task blocks, resulting in alternation costs and that the long RSI is used for task-set updating, leading to a reduction of these costs. Since due to the use of univalent stimuli, task-set competition and demands on working memory were low in Experiment 1, we examined whether there are still age-related effects in alternation costs and in task-preparation effects under these conditions.

2.1. Method

2.1.1. Participants

Twenty-two young adults (11 women; range: 20-28 years; *M* = 22.5) and 22 older adults (11 women; range: 65-78 years; *M* = 70.9) participated in the experiment[1]. The subjects were recruited from the participant pool of the Institute of Psychology of the RWTH Aachen University and they were paid for their participation (10€) or received course credit. All subjects gave written consent to take part in the study after the experiment had been fully explained and they filled in a demographic questionnaire (see Table 1). The age groups did not significantly differ with regard to the number of years of formal education (young adults: 15.3 years; older adults: 15.5 years; two-tailed *t*-test: $t(42) = 0.25$, $p = .80$). All subjects had normal or corrected-to-normal vision and none of them reported suffering from neurological diseases.

To ensure that there were no subjects with cognitive impairments, the subjects performed the screening instrument DemTec (Kessler, Calabrese, Kalbe, & Berger, 2000). The scores were comparable across groups (young adults: 17.6; older adults: 17.3; two tailed *t*-test: $t(42) = 1.52$, $p = .51$) and they were all below the cut-off indicative for mild cognitive impairment (MCI) or dementia.

2.1.2. Stimuli, tasks, and responses

The stimuli consisted of a fixation cross (+), digits (*1* to *9*, without 5), and capital letters (consonants: *G, K, M, R*; vowels: *A, E, I, U*)[2]. The fixation cross was presented at screen centre, where it stayed the entire experiment. Digits and letters were 2.0 cm in height and 1.6 cm in width, and were displayed in white Arial font on a black 17 inch screen placed at a distance of approximately 50 cm. Digits appeared to the left of the fixation cross and letters to the right of the fixation cross, or vice versa, counterbalanced across subjects. The distance from the stimuli to the fixation cross was 7.5 cm.

The tasks were to categorize digits as odd or even and to categorize letters as consonant or vowel, emphasizing speed and accuracy. These tasks were performed using the index and middle finger of the hand corresponding to the stimulus presentation location. We used the keys *W*, *E*, *O*, and *P* of a keyboard as response keys. The leftmost response of each hand was used either for the even or the consonant classification and the rightmost response for the odd or vowel classification. A reminder of key assignment was placed at the bottom of the screen.

2.1.3. Procedure

The experiment was run with E-Prime 1.1 (Psychology Software Tools, Inc. Pittsburgh, PA) in a single session with one subject at a time and started with one single-task block of 41 trials for each task type, followed by two alternating-task blocks, each consisting of 81 trials. After this, one single-task block of 41 trials was once again performed for each task. Prior to each single-task block, 5 practice trials were administered when the digit and the letter tasks were performed for the first time. The alternating-task blocks were preceded by 8 practice trials.

In each single-task block, one of the two tasks was performed repeatedly. The stimuli were presented on one side of the screen and disappeared immediately after a response was executed. The next character occurred after a random RSI of 100 ms or 600 ms.

In alternating-task blocks, participants performed both tasks in alternating order. Hence, there was a fixed task sequence with a task switch after each trial. The stimuli were displayed alternately to the left and right of the fixation cross and disappeared directly after response execution. The RSI varied like in single-task blocks. One of the two alternating-task blocks started with the digit task and the other with the letter task.

The stimuli were presented randomly with the stipulation that no character was repeated in two consecutive trials and that all stimuli appeared equally often. Whether the subjects initially performed the digit or the letter task was counterbalanced across participants. The RSI varied randomly with the stipulation that there was the same number of short and long RSIs in each block[3]. Thus, there was the same number of trials with a short RSI and a long RSI across single-task blocks and alternating-task blocks. There was no time limit for responding and no error feedback.

Design. The 2x2x2 mixed design included the independent within-subjects variables task transition (repetition trials vs. switch trials) and RSI (100 ms vs. 600 ms). Age group (young vs. older adults) was a between-subjects variable.

2.2. Results and Discussion

Practice trials, the first trial in each block, error trials, and trials following an error were excluded from reaction time (RT) analysis. Moreover, trials with RTs exceeding 3 *SD* from each individual's mean RT (per condition) were discarded as outliers (1.8% for each age group). Separate analyses of variance (ANOVAs) were run on mean RTs (see Figure 1) and error rates (see Table 2).

Since the use of mean RTs for a performance comparison of young and older adults is linked to the problem of age-related differences in baseline performance, we employed a logarithmic transformation that rescaled RTs of both age groups to a common scale, making them less susceptible to differences in overall speed (e.g., Kray & Lindenberger, 2000). Significant effects in log RTs indicate that age-related performance differences are disproportional to age-associated differences in the baseline performance (Faust, Balota, Spieler, & Ferraro, 1999). Thus, log RTs take general slowing into account (Salthouse, 1985). To confirm the results concerning significant effects of age groups on mean RT data, we repeated the analysis with log RTs.

--- Figure 1 and Table 1---

The ANOVA on RTs showed a main effect of task transition, $F(1, 42) = 66.75$, $p < .001$, $\eta_p^2 = .61$, indicating alternation costs of 164 ms (switch trials: 819 ms; repetition trials: 655 ms). Furthermore, the main effect of RSI was reliable, $F(1, 42) = 107.17$, $p < .001$, $\eta_p^2 = .72$. Responses were slower after a short RSI than a long RSI (775 ms vs. 700 ms), reflecting an RSI effect of 75 ms. The interaction of task transition and RSI was also significant, $F(1, 42) = 8.14$, $p < .01$, $\eta_p^2 = .16$, resulting in reduced alternation costs with long RSI (179 ms vs. 148 ms).

Moreover, there was a main effect of age group, $F(1, 42) = 44.93$; $p < .001$, $\eta_p^2 = .52$, reflecting longer RTs in older than in young adults (859 ms vs. 616 ms). Even though there was a clear numerical trend toward larger alternation costs in older than in young adults (202 ms vs. 125 ms), the interaction of task transition and age group was non-significant, *F*(1, 42) = 3.68, $p = .06$, $\eta_p^2 = .08$. The interaction of age group and RSI was reliable, *F*(1, 42) = 11.01, $p < .01$, $\eta_p^2 = .21$, indicating that older adults showed a larger RSI effect than young adults (99 ms vs. 51 ms). However, the three-way interaction of task transition, RSI, and age group was not significant, *F*(1, 42) = 1.49, $p = .24$, $\eta_p^2 = .03$. Apart from the age-related difference in baseline performance, *F*(1, 42) = 61.01, $p < .001$, $\eta_p^2 = .59$, all interactions with age group (including the interaction with RSI, *F*(1, 42) = 3.01, $p = .10$, $\eta_p^2 = .06$) were non-significant when using log RTs, all *ps* > .23.

The ANOVA on error rates disclosed a main effect of task transition, *F*(1, 42) = 12.38, $p < .01$, $\eta_p^2 = .23$, reflecting alternation costs of 1.0% (switch trials: 1.8%; repetition trials: 0.8%). The interaction of task transition and RSI was non-significant, *F*(1, 42) = 4.02, $p = .051$, $\eta_p^2 = .09$, but there was a trend toward a reduction of error-related alternation costs with long RSI (1.5% vs. 0.5%). All other effects were not significant, too, all *ps* > .18.

In summary, we found a slowdown in general performance in older adults, as it is commonly observed in task-switching studies (e.g., Kray & Lindenberger, 2000). In line with findings about age-related effects in mixing costs (see Wasylyshyn et al., 2011, for a review), we found an age-associated increase in alternation costs (even though it was not significant at the .05 level), but these costs were not disproportionally larger in old adults, and thus, general slowing as a potential explanation for age-related effects in these costs could not be excluded. Importantly, the RSI-based reduction of alternation costs did not differ across age groups[4].

3. Experiment 2

In Experiment 1, we found an indication for an age-related increase in alternation costs and no age-associated differences in the preparatory reduction of these costs under situations with low task-set competition. To explore whether task-set competition influences the size of age-related effects in these costs and in their preparatory reduction, we ran Experiment 2[5], in which we increased task-set competition by using bivalent instead of univalent stimuli. Task-set competition results in interference, thus making the differentiation between task sets more difficult. As univalent stimuli are associated with just one task, they generate only one response, thereby resulting in low interference between task sets. In contrast, bivalent stimuli include features relevant to two tasks, and thus, can elicit two potential responses. Bivalent stimuli induce, due to the increased interference resulting from the activation of the competing stimulus-response rules, greater performance costs than univalent stimuli (e.g., Rogers & Monsell, 1995) and larger age-related effects therein (Mayr, 2001).

We expected performance to be slower and more error prone with bivalent stimuli, which should be reflected by increased alternation costs. Moreover, we assumed that older adults would suffer more from increased task-set competition and would therefore show larger alternation costs and, in contrast to the findings of Experiment 1, a smaller preparatory reduction of these costs than young adults.

3.1. Method

3.1.1. Participants

A new group comprising 22 young adults (11 women; range: 18-24 years; *M* = 22.4 years) and 22 older adults (11 women; range; 65-78 years; *M* = 71.1 years) participated in exchange for partial fulfilment of course requirements or financial compensation (8€). All participants gave informed consent, filled in a demographic questionnaire, and performed the DemTec. The age groups did not differ with regard to the educational level (young adults: 15.1 years; older adults: 14.0 years; two-tailed *t*-test: $t(42) = 1.08$, $p = .29$). All participants had normal or corrected-to-normal vision and they reported to be in good health and free of neurological diseases. The DemTec scores were comparable across age groups (young adults:

17.6; older adults: 17.1; two-tailed *t*-test: $t(42) = 1.01$, $p = .32$) and all participants were found to be within normal age-related limits.

3.1.2. Stimuli, tasks, and responses

We used digits (*1* to *9*, without 5) as stimuli. The tasks were to decide whether the digits were even or odd and to judge whether they were smaller or greater than 5. There was a fixed task sequence with a task switch after each trial. Digits appearing to the left of a centrally positioned fixation cross required a parity judgement and those occurring to the right of the fixation cross a magnitude judgement (counterbalanced across subjects). The response keys and the effectors were the same as in Experiment 1. The leftmost response of each hand was used either for the even or the smaller classification, and the rightmost response for the odd or greater classification.

3.1.3. Procedure and design.

The procedure and the design were identical to those used in Experiment 1.

3.2. Results and discussion

We used identical outlier criteria (young adults: 1.6%; older adults: 1.8%) and error definitions as in Experiment 1. Data analyses were based on mean RT (see Figure 1) and error rates (see Table 2)[6].

The ANOVA on RTs yielded significant main effects of task transition, $F(1, 42) = 374.46$, $p < .001$, $\eta_p^2 = .90$, and RSI, $F(1, 42) = 89.54$, $p < .001$, $\eta_p^2 = .68$, resulting in alternation costs of 457 ms (switch trials: 1,143 ms; repetition trials: 686 ms) and in an RSI effect of 83 ms (short: 956 ms; long: 873 ms). As indicated by a reliable interaction of task transition and RSI, $F(1, 42) = 20.56$, $p < .001$, $\eta_p^2 = .33$, alternation costs were reduced after a long RSI (492 ms vs. 422 ms).

As expected, there was also a main effect of age group, $F(1, 42) = 60.06$, $p < .001$, $\eta_p^2 = .59$, reflecting faster responses for young than for older adults (758 vs. 1070 ms).

Moreover, the interaction of task transition and age group was significant, $F(1, 42) = 15.18$, $p < .001$, $\eta_p^2 = .27$, indicating that alternation costs were larger for older than for young adults (549 vs. 365 ms). The interaction of age group and RSI was not significant, $F(1, 42) = 0.60$, $p = .44$, $\eta_p^2 = .01$, and the three-way interaction of task transition, RSI, and age group fell just short of significance, $F(1, 42) = 3.15$, $p = .08$, $\eta_p^2 = .07$. However, the RSI-based reduction of alternation costs was numerically smaller for older adults than for young adults (42 ms vs. 98 ms). Separate 2x2 ANOVAs with the within-subject factors task transition and RSI showed that for young adults, the RSI based reduction of alternation costs was significant, $F(1, 21) = 20.19$, $p < .001$, $\eta_p^2 = .49$, whereas for older adults, the interaction of task transition and RSI was non-significant, $F(1, 21) = 3.76$, $p = .07$, $\eta_p^2 = .15$. However, for older adults, there was a numerical trend toward smaller alternation costs after a long RSI than a short RSI. Note that when using log RTs, apart from the main effect of age group, $F(1, 42) = 66.46$, $p < .001$, $\eta_p^2 = .62$, the interaction of task transition, RSI, and age group actually became significant, $F(1, 42) = 6.71$, $p < .05$, $\eta_p^2 = .14$. Hence, the RSI-based reduction of alternation costs was disproportionally smaller for older than young adults. All other age-related effects were non-significant when using log RTs, all *p*s > .31.

To better illustrate the difference in the preparatory reduction of alternation costs, we calculated the proportional preparation effect (in %), using the formula proposed by Lawo and colleagues (2013). To calculate the proportional preparation effect, we divided the preparation benefit for a trial type (mean $\mathrm{RT}_{\text{short RSI}}$ – mean $\mathrm{RT}_{\text{long RSI}}$) by the mean RT (0.5*[mean $\mathrm{RT}_{\text{short RSI}}$ – mean $\mathrm{RT}_{\text{long RSI}}$]). Then, we subtracted the proportional preparation effect in repetition trials from that in switch trials. For young adults, the preparatory reduction of alternation costs (in proportional scores) was 9.1%; for older adults, it was 0.3% (see Figure 2).

For the error rates, there was a main effect of RSI, $F(1, 42) = 5.58$, $p < .05$, $\eta_p^2 = .12$, with responses being more error-prone after a short RSI than a long RSI (3.1% vs. 2.4%). No other effects were significant, all $ps > .40$.

In summary, increasing task-set competition resulted in age-related differences in the preparatory reduction of alternation costs. This specific preparation deficit in old age cannot be explained on the basis of general slowing and confirms the findings by Lawo et al. (2012).

4. Comparing age-related effects across Experiment 1 and 2

To examine the impact of the stimulus valence on age-related effects in alternation costs more directly, we compared alternation costs across Experiment 1 and Experiment 2 by calculating a 2x2x2x2 ANOVA with the within-subjects variables task transition (repetition trials vs. switch trials) and RSI (100 ms vs. 600 ms) as well as the between-subjects variables age group (young vs. older adults) and stimulus valence (univalent vs. bivalent). In the following, to avoid redundancy, we report only effects including the stimulus valence variable (i.e., Experiment 1 vs. 2)[7].

There was a significant main effect of stimulus valence, $F(1, 84) = 42.69$, $p < .001$, $\eta_p^2 = .34$, indicating that the increase in the stimulus-elicited set competition resulted in longer RTs (univalent: 737 ms; bivalent: 914 ms). The interaction between stimulus valence and task transition was also reliable, $F(1, 84) = 89.76$, $p < .001$, $\eta_p^2 = .52$. Alternation costs occurring in the context of bivalent stimuli were larger than alternation costs resulting from univalent stimuli (457 ms vs. 164 ms). The interaction of stimulus valence and RSI was non-significant, $F(1, 84) = 0.47$, $p = .50$, $\eta_p^2 = .01$. However, the interaction of stimulus valence, task transition, and RSI was reliable, $F(1, 84) = 4.26$, $p < .05$, $\eta_p^2 = .05$. The RSI-based reduction in alternation costs was greater for bivalent stimuli than for univalent stimuli (70 ms vs. 31 ms).

Moreover, with univalent stimuli, the difference in overall alternation costs between young and older adults was 77 ms and with bivalent stimuli, it increased up to 184 ms, but the interaction of stimulus valence, task transition, and age group was non-significant, $F(1, 84) = 3.00$, $p = .09$, $\eta_p^2 = .04$ (log RTs: $F(1, 84) = 0.15$, $p = .69$, $\eta_p^2 = .01$). Importantly though, the four-way interaction of stimulus valence, task transition, RSI, and age group was significant for both mean RTs, $F(1, 84) = 4.64$, $p < .05$, $\eta_p^2 = .06$, and log RTs, $F(1, 84) = 4.15$, $p < .05$, $\eta_p^2 = .05$ (see Figure 2 for the preparatory reduction of alternation costs in proportional scores). Age-related differences in the RSI-based reduction in alternation costs were greater with bivalent stimuli than with univalent stimuli (56 ms vs. -26 ms), indicating that older adults show task-preparation deficits in particular when the task-set competition is increased, such as with bivalent stimuli. All other interactions with stimulus valence and age group were significant neither for the mean RT data, all *ps* > .14, nor for the log RT data, all *p*s > 16.

The ANOVA on error rates disclosed a main effect of stimulus valence, $F(1, 84) = 17.01$, $p < .001$, $\eta_p^2 = .17$, indicating more error-prone responses with bivalent stimuli than with univalent stimuli (2.8% vs. 1.3%). All other effects including the valence variable were non-significant, all *p*s > .15.

To sum up, we found evidence for performance deteriorations due to an increase in stimulus-driven set competition. This increase resulted in larger alternation costs and, specifically, in age-related differences in the preparatory reduction of these costs, indicating that task-preparation deficits in old age occur especially when the differentiation between task sets is difficult, confirming recent findings by Lawo et al. (2012) on age-related preparation deficits when overall task-set competition is high.

5. General discussion

The aim of the present research was to examine the effect of task-set competition on the preparatory reduction of switching-related performance costs in old age. To this end, we compared age-associated differences in the preparatory reduction of alternation costs occurring in the context of univalent vs. bivalent stimuli (Experiment 1 vs. 2).

In Experiment 1 with univalent stimuli, age-related deficits in alternation costs were moderate and disappeared when using log RTs. Importantly, alternation costs were reduced with long RSI, but this reduction did not differ across age groups. Apart from the difference in overall speed between age groups, no age-related effect remained significant when using log RTs, suggesting a strong role of general slowing on age-related performance differences.

In Experiment 2 with bivalent stimuli, we found reliable age-associated effects in alternation costs. Importantly, an age-related task-preparation deficit was now found, which was significant when using log RTs, indicating that general slowing cannot account for this finding. Confirming the findings by Mayr (2001), a direct comparison of Experiments 1 and 2 revealed that increasing task-set competition results in performance deteriorations in terms of larger alternation costs and heightened age-related effects in these costs. Moreover, the comparison showed that task-set competition results in impaired task preparation in old age.

In the present experiments, we found a RSI-based reduction in alternation costs. Yet, in Experiment 2, in which we used bivalent stimuli, this reduction was larger for young than for older adults. This finding conforms to that of Lawo and colleagues (2012), who explored task-switching performance under increased task-set competition and also found evidence for impaired task preparation in older adults. The existence of a task-preparation deficit in old age in the context of bivalent stimuli and the absence of this deficit in situations with univalent stimuli suggests, along with the findings of Lawo et al. (2012), that an increase in task-set competition has a negative impact on the older adult’s ability to prepare for an upcoming task. Thus, older adults cannot prepare for a task switch as effectively as young adults when the internal differentiation between task sets is difficult, so that working memory demands are particularly increased.

Most existing studies on age-related effects in task preparation explored generally whether there are age-associated differences in the preparatory efficiency. In contrast to these studies, we investigated whether the preparatory efficiency in old age is influenced specifically by task-set competition. Hence, our goal was to isolate the effect of task-set competition on age-related differences in task-preparation effects.

The novel finding of the present study is that task-set competition at the level of stimuli represents a factor decreasing the preparatory efficiency in older adults. There are three possible explanations for this deficit. First, the age-related task-preparation deficit might result from impaired task-set updating abilities in old age. Second, task-set maintenance might be more difficult for older adults than for young adults. This would indicate that age-related differences in task preparation are not primarily due to impaired task-set updating abilities, but are rather due to impaired maintenance abilities in old age. Third, there might be an age-related decline in both abilities. However, there are many studies providing evidence that maintenance abilities are relatively intact in old age, whereas processing components of working memory declines with age (e.g., Bopp & Verhaeghen, 2005; Craik, 1977; Dobbs & Rule, 1989; Park et al., 2002). Moreover, for predictable task sequences, there is no evidence for passive decay of task sets in preparation intervals up to 600 ms (e.g., Rogers & Monsell, 1995). Thus, working memory maintenance and task-set dissipation seem to play no important role when task preparation is assessed in predictable task sequences with relatively short preparation intervals. This suggests that in the present study, age-related task-set updating deficits are the source for the reduced preparatory efficiency in old age.

Hence, our contribution to the literature on age-related deficits in task switching is that we identify a specific situation that hampers task-set updating in old age. Moreover, our findings indicate that differences in such situational characteristics might be the reason for the mixed findings about the effect of age on task preparation in the existing literature. For future research, an important goal will be to further isolate the effect of age on task preparation by identifying further situational characteristics that influence task-set updating in old age.

The finding that task-set competition affects task preparation in older adults has important implications for theories on cognitive aging in general and in particular for accounts of process-specific limitations in old age. There were no age-related differences in the preparatory reduction of alternation costs in the context of univalent stimuli, indicating that in the case of low task-set competition, updating processes in working memory are not impaired by age. However, increasing task-set competition by using bivalent stimuli resulted in disproportionally reduced preparation effects in older adults. This provides evidence that there are process-specific limitations in old age, affecting the updating ability. For older adults, these findings mean that even when there is an impaired task-set updating ability in old age, they are able to compensate this deficit when task-set competition is weak, resulting in task-preparation effects comparable to those of young adults. Hence, situational characteristics, here in terms of task-set competition, seem to determine whether deficits in this ability can be compensated. In addition to global deficits in certain cognitive processes, theories of cognitive aging should also be able to account for such compensatory effects.

Apart from the finding of reduced preparatory efficiency in old age due to increased task-set competition, our study showed age-related effects in alternation costs. However, overall, alternation costs were not disproportionally larger in older than young adults, suggesting that general slowing may account to some part for the increased general costs in the present study, which in turn points to the important role of decreased preparation in age-related task-switching impairments.

Mayr (2001) showed that age-related differences in task switching are large and disproportional when response-sets physically overlap. The age-related increase in performance costs resulting from conceptual overlap was similar to when there was no overlap between response sets. These findings are in line with other studies which failed to demonstrate age-related effects in mixing costs when using univalent or highly natural responses that eliminated the need of maintaining arbitrary S-R mappings in working memory (e.g., Bojko, Kramer, & Peterson, 2004; Brinley, 1965; Mayr & Kliegl, 2000; Salthouse, Fristoe, McGuthry, & Hambrich, 1998). In the present experiments, there was only conceptual response-set overlap. Hence, we may assume that age-related effects would have been even stronger if we had used physically overlapping task sets, which induce additional task-set competition at the level of responses.

6. Conclusions

The data suggest that preparatory deficits in the context of increased task-set competition contribute to age-related performance deficits. In fact, the preparatory reduction of switch-related performance costs may be a particularly sensitive measure of age-associated effects, provided that task-set competition is high and overall task selection difficulty is large.

References

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Ulmità & M. Moscovitch (Eds.), *Attention and performance XV: Conscious and nonconsicious information processing* (pp. 421-452). Cambridge, MA: MIT Press.

Bopp, K. L., & Verhaeghen, P. (2005). Aging and verbal memory spans: A meta-analysis. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 60,* 223-233. http://dx.doi.org/10.1093/geronb/60.5.P223

Bojko, A., Kramer, A. F., & Peterson, M. S. (2004). Age equivalence in switch costs for prosaccade and antisaccade tasks. *Psychology and Aging, 19,* 226-234, http://dx.doi.org/10.1037/0882-7974.19.1.226

Brinley, J. F. (1965). Cognitive sets, speed and accuracy of performance in the elderly. In A. T. Welford & J. E. Birren (Eds.), *Behavior, aging, and the nervous system* (pp. 114–149). Springfield, IL: Mason.

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin, 98*, 67-83. http://dx.doi.org/10.1037

Craik, F. I. M. (1977). Age differences in human memory. In J. E. Birren & K. W. Schaue (Eds.), *Handbook of the psychology of aging* (pp. 384-420). New York, NY: Nostrand Reinhold.

Craik, F. I. M., & Salthouse, T. A. (2000). *The handbook of aging and cognition.* Mahwah, NJ: Erlbaum.

De Jong, R. (2000). An intention-activation account of residual switch costs. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and Performance XVIII* (pp. 357-376). Cambridge, MA: MIT Press.

Dobbs, A. R., & Rule, B.G. (1989). Adult age differences in working memory. *Psychology and Aging, 4,* 500-503. http://dx.doi.org/10.1037/0882-7974.4.4.500

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for social, behavioral, and biomedical sciences. *Behavior Research Methods, 39,* 175-191. http://dx.doi.org/10.3758/BF03193146

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin, 125,* 777-799. http://dx.doi.org/10.1037/0033-2909.125.6.777

Hartley, A. A., Kieley, J. M., & Slabach, E. H. (1990). Age differences and similarities in the effects of cues and prompts. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 523–537. http://dx.doi.org/10.1037/0096-1523.16.3.523

Hasher, L., & Zacks, R. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108*, 356-388. http://dx.doi.org/10.1016/0010-0285(74)90015-2

Hsieh, S., & Wu, M. (2010). Age differences in switching the relevant stimulus dimension in a speed same-different judgment paradigm. *Acta Psychologica, 135,* 140-149. http://dx.doi.org/10.1016 /j.actpsy.2010.05.010

Jersild, A.T. (1927). Mental set and shift. *Archives of Psychology, 89,* 5-82.

Kessler, J., Calabrese, P., Kalbe, E., & Berger, F. (2000). DemTect. Ein neues Screening-Verfahren zur Unterstützung der Demenzdiagnostik. *Psycho, 6*, 343–347.

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching—A review. *Psychological Bulletin, 136,* 849-874. http://dx.doi.org/10.1037/a0019842

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: explorations of executive control processes in the task switching paradigm. *Acta Psychologica, 101,* 339-378. http://dx.doi.org/10.1016/S0001-6918(99)00011-6

Kray, J. (2006). Task-set switching under cue-based versus memory-based switching conditions in younger and older adults. *Brain Research, 1105,* 83-92. http://dx.doi.org/10.1016/j.brainres.2005.11.016

Kray, J., & Eppinger, B. (2006). Effects of associative learning on age differences in task-set switching. *Acta Psychologica, 123,* 187-203. http://dx.doi.org/10.1016/j.actpsy.2005.12.009

Kray, J., Karbach, J., & Blaye, A. (2012). The influence of stimulus-set size on developmental changes in cognitive control and conflict adaption. *Acta Psychologica, 140,* 119-128. http://dx.doi.org/10.1016/j.actpsy.2012.03.005.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15,* 126–147. http://dx.doi.org/10.1037/a0034937

Lawo, V., & Koch, I. (2012). Examining age-related differences in auditory attention control using a task-switching procedure. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 69,* 237-244. http://dx.doi.org/10.1093/geronb/gbs107

Lawo, V., Philipp, A. M., Schuch, S., & Koch, I. (2012). The role of task preparation and task inhibition in age-related task-switching deficits. *Psychology and Aging, 27,* 1130-1137. http://dx.doi.org/10.1037/a0027455

Lustig, C., Hasher, L., & Zacks, R. (2007). Inhibitory deficit theory: Recent developments in a “new view”. In D. S. Gorfein & M. Collin (Eds.), *Inhibition in cognition* (pp. 145-162). Washington, DC: American psychological Association.

Mayr, U. (2001). Age differences in the selection of mental sets: The role of inhibition, stimulus ambiguity, and response-set overlap. *Psychology and Aging, 16*, 96-109. http://dx.doi.org/10.1037/0882-7974.16.1.96

Mayr, U., & Kliegl. R. (2000). Complex semantic processing in old age: Does it stay or does it go? *Psychology and Aging, 15,* 29-43. http://dx.doi.org/10.1037//0882-7974.15.1.29

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 22,* 1423-1442. http://dx.doi.org/10.1037/0278-7393.22.6.1423

Meiran, N. (2000). Modelling cognitive control in task-switching. *Psychological Research, 63,* 234-249. http://dx.doi.org/10.1007/s004269900004

Meiran, N., Gotler, A., & Perlman, A. (2001). Old age is associated with a pattern of relatively intact and relatively impaired task-set switching abilities. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 56,* 88-102. http://dx.doi.org/10.1093/geronb/56.2.P88

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167–202. http://dx.doi.org/10.1146/annurev.neuro.24.1.167

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N., S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging, 17,* 299-320. http://dx.doi.org/10.1037/0882-7974.17.2.299

Reimers, S., & Maylor, E. A. (2005). Task switching across the life span: Effects of age on general and specific switch costs. *Developmental Psychology, 41,* 661–671. http://dx.doi.org/10.1037/0012-1649.41.4.661

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207-231. http://dx.doi.org/10.1037/0096-3445.124.2.207

Rubin, O., & Meiran, N. (2005). On the origins of the task mixing cost in the cueing task-switching paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 1477-1491. http://dx.doi.org/10.1037/0278-7393.31.6.1477

Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of Psychology and Aging* (pp. 400-426). New York: Van Nostrand Reinhold.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403-428. http://dx.doi.org/10.1037//0033-295X.103.3.403

Salthouse, T. A., Fristoe, N. M., McGuthry, K. E., & Hambrick, D. Z. (1998). Relation of task switching to speed, age, and fluid intelligence. *Psychology and Aging, 13,* 445–461. http://dx.doi.org/10.1037//0882-7974.13.3.445

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: A review of meta-analyses. *Neuroscience and Biobehavioral Reviews, 26,* 849–857. http://dx.doi.org/10.1016/S0149-7634(02)00071-4

Wasylyshyn, C., Verhaeghen, P., & Sliwinski, M. J. (2011). Aging and task switching: A meta-analysis. *Psychology and Aging, 26,* 15–20. http://dx.doi.org/10.1037/a0020912

Footnote

---

[1] Given an alpha of .05 and a sample size of 22 subjects per age group, the statistical power to detect large age-related differences in alternation costs and preparation effects (cohen's *d* = .80) was .84 (Faul, Erdfelder, Lang, & Buchner, 2007).

[2] In the present study, we used a small stimulus-set size because there is evidence that age-related differences in switching-related performance costs occur mainly in situations with small stimulus-set sizes (e.g., Kray & Eppinger, 2006; Kray, Karbach, & Blaye, 2012).

[3] Please note that Rogers and Monsell (1995) found RSI-based preparation effects in predictable task sequences only when they varied the RSI between blocks and not when they varied the RSI within blocks. However, in a similar study, De Jong (2000) observed preparation effects even with random RSIs. Hence, the type of the RSI manipulation does not seem to be a critical factor with regard to the occurrence of RSI-based preparation effects.

[4] Experiment 1 was conducted in combination with a dual-task experiment, which we do not report here. The order of these experiments was counterbalanced across subjects. An ANOVA with the additional between-subjects variable experiment order (Experiment 1 followed by the dual-task experiment vs. vice versa) showed that the findings of Experiment 1 did not differ depending on which experiment was performed first (all *p*s > .36).

[5] Experiment 2 was run in combination with a further task-switching experiment, in which we assessed mixing costs. However, since this experiment is not fully comparable with Experiment 1 and Experiment 2, we do not report the 'mixing cost' experiment here. The

---

order of Experiment 2 and the 'mixing cost' experiment was counterbalanced across participants and an ANOVA with the between-subjects variable experiment order (Experiment 2 followed by the 'mixing cost' experiment vs. vice versa) showed that the experiment order did not affect the performance in Experiment 2 (all *ps* > .32).

[6] The use of bivalent stimuli enabled us to distinguish between incongruent trials and congruent trials, and hence, to additionally analyze age-related effects in congruency effects. A trial is incongruent when the stimulus evokes different responses for two tasks. In contrast, a trial is congruent when the stimulus requires the same key press in both tasks. Indeed, we found more erroneous responses to incongruent stimuli than to congruent stimuli (congruency effect: 1.2%), $F(1, 42) = 5.05$, $p < .05$, $\eta_p^2 = .11$. However, this congruency effect was not modulated by age. For the RT data, the congruency effect was not significant, $F(1, 42) = 2.78$, $p = .13$, $\eta_p^2 = .06$. All interactions including congruency and age group showed *ps* > .26 in both error and RT data.

[7] Since we used the data of Experiment 1 and Experiment 2 twice (separate analysis of Experiment 1 and Experiment 2 as well as the data of both experiments in a joint analysis), the error probability might have been increased for the between-experiment comparison.

Table 1. Demographic information.

	n	Sex (% female)	Age range (in years)	Mean age (in years)	Education (in years)	DemTec Scores
Experiment 1						
Young adults	22	50	20-28	22.5	15.3	17.6
Old adults	22	50	65-78	70.9	15.5	17.3
Experiment 2						
Young adults	22	50	18-24	22.4	15.1	17.6
Old adults	22	50	65-78	71.1	14.0	17.1

Table 2. Task-switching performance in Experiment 1 and Experiment 2: mean error rates (in percentage; SD in parenthesis) as a function of task transition (switch vs. repetition in single-task blocks), response-stimulus interval (RSI; 100 vs. 600 ms), and age group (young vs. older adults).

	Young Adults			Older Adults		
	RSI 100 ms	RSI 600 ms	RSI effect	RSI 100 ms	RSI 600 ms	RSI effect
Experiment 1						
Switch trials	2.2 (0.6)	1.8 (0.5)	0.4	2.4 (0.6)	0.7 (0.5)	1.7
Repetition trials	0.8 (0.3)	0.7 (0.3)	0.1	0.8 (0.3)	0.9 (0.3)	-0.1
Alternation costs	1.4	1.1		1.6	-0.2	
Experiment 2						
Switch trials	4.0 (0.6)	2.9 (0.6)	1.1	2.8 (0.6)	1.9 (0.6)	0.9
Repetition trials	3.5 (0.7)	2.8 (0.6)	0.7	2.2 (0.7)	2.2 (0.6)	0
Alternation costs	0.5	0.1		0.6	-0.3	

Figure Captions

Figure 1. Task-switching performance in Experiment 1 and Experiment 2: mean RTs (in ms) as a function of task transition (switch vs. repetition), response-stimulus interval (RSI; 100 ms vs. 600 ms), and age group (young vs. older adults).

Figure 2. Preparatory reduction of alternation costs (proportional scores in %) in Experiment 1 and 2 as a function of age group (young vs. older adults). We first specified the proportional preparation effect by dividing the preparation benefit for a trial type ($RT_{short} – RT_{long}$) by the mean RT in this trial type ($0.5 * [RT_{short} + RT_{long}]$). Then, we calculated the preparatory reduction of alternation costs in proportional scores (in %) by subtracting the proportional preparation effect in repetition trials from that in switch trials. Error bars indicate the standard error of the mean.

Figure 1

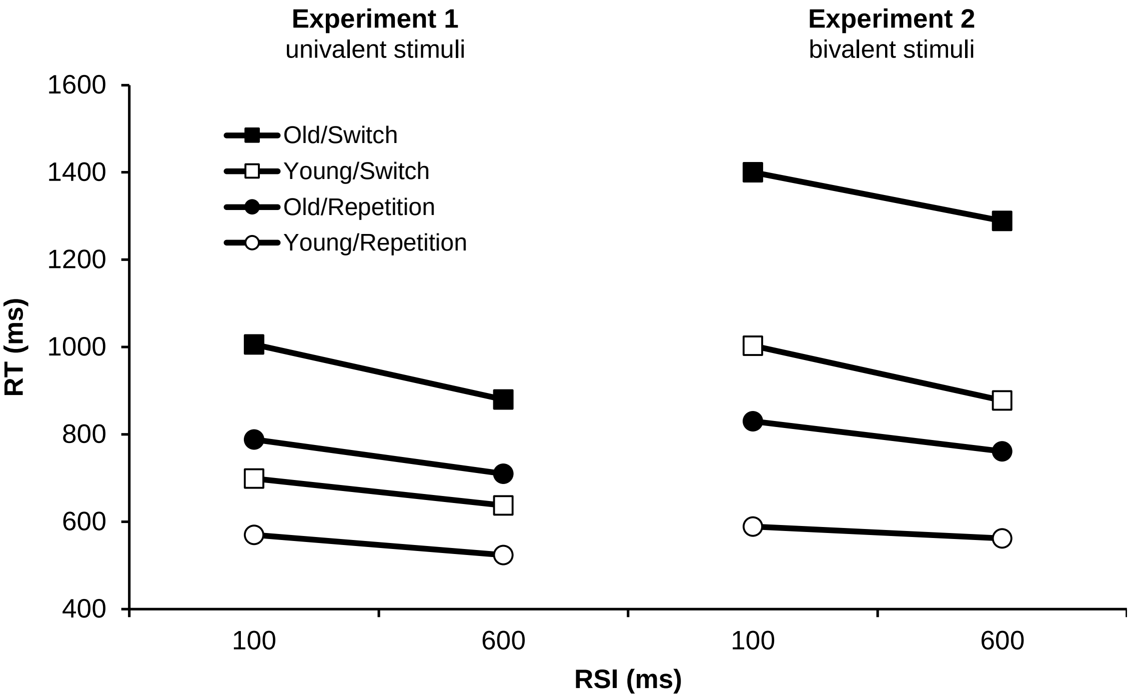
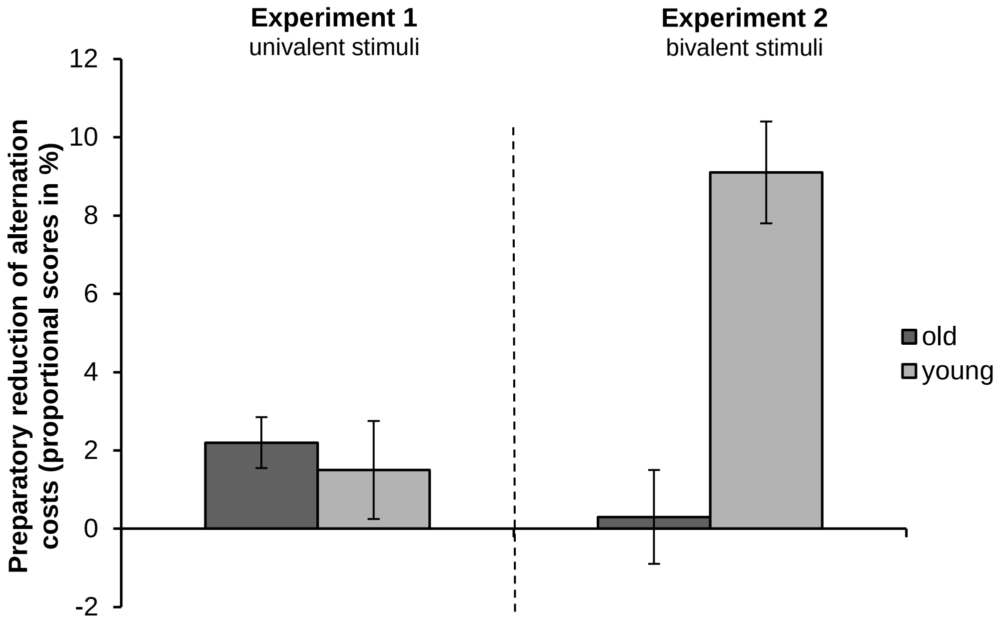

Experiment 1
univalent stimuli
Experiment 2
bivalent stimuli
1600
1400
1200
1000
800
600
400
RT (ms)
Old/Switch
Young/Switch
Old/Repetition
Young/Repetition
100
600
100
600
RSI (ms)

Figure 2


Experiment 1
univalent stimuli
Experiment 2
bivalent stimuli
Preparatory reduction of alternation costs (proportional scores in %)
12
10
8
6
4
2
0
-2
old
young