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Age Differences in Response Selection for Pure and Mixed Stimulus-Response Mappings and Tasks

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Abstract

Two experiments examined effects of mixed stimulus-response mappings and tasks for older and younger adults. In Experiment 1, participants performed two-choice spatial reaction tasks with blocks of pure and mixed compatible and incompatible mappings. In Experiment 2, a compatible or incompatible mapping was mixed with a Simon task for which the mapping of stimulus color to location was relevant and stimulus location irrelevant. In both experiments older adults showed larger mixing costs than younger adults and larger compatibility effects, with the differences particularly pronounced in Experiment 1 when location mappings were mixed. In mixed conditions, when stimulus location was relevant, older adults benefited more than younger adults from complete repetition of the task and stimulus from the preceding trial. When stimulus location was irrelevant, the benefit of complete repetition did not differ reliably between age groups. The results suggest that the age-related deficit associated with mixing mappings and tasks is primarily due to older adults having more difficulty separating task sets that activate conflicting response codes.

Keywords

Aging; Attention; Response Selection

PsycINFO classification

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1. Introduction

For most tasks, older adults show longer reaction time (RT) than do younger adults (e.g., Earles & Salthouse, 1995; Salthouse, 1996). Research has suggested that the longer RT exhibited by older adults is due to deficiencies in working memory, attention, and executive control (e.g., Mayr, 2001). Evidence for such deficiencies comes from task-switching studies in which participants perform two distinct tasks on different trials, and their performance for these mixed trial blocks is compared to that for pure trial blocks in which only one of the tasks is performed.

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Older adults typically show a greater overall mixing cost than younger adults: RT increases more for older than younger adults in the mixed blocks (e.g., Kray & Lindenberger, 2000; Meiran, Gotler, & Perlman, 2001). In contrast, older adults show at most a small deficit compared to younger adults in specific switch costs associated with a change of the task on the current trial from that on the preceding trial. Moreover, older adults show little if any deficit in the ability to prepare for a cued task or response set (Hahn, Andersen, & Kramer, 2004; Meiran et al., 2001; Proctor, Vu, & Pick, 2006). Thus, an age-related deficit exists in processes associated with maintaining and selecting between two task sets, but not those involved in preparing for the task set or executing the task switch.

The age-related deficit in overall mixing costs is especially pronounced when the two tasks share the same response set (Mayr, 2001), which implies that conflict in response selection produces particular difficulty for older adults. Several other studies have also provided evidence that the increase in RT for older adults is due to decreased efficiency of response-selection processes (e.g., Eppinger, Kray, Mecklinger, & John, 2007; Meiran & Gotler, 2001). However, those studies have not explored the influence of stimulus-response (S-R) mappings on age-related differences in performance in detail, as we do in the present study.

Differences in RT and accuracy between various mappings of stimuli to responses are called stimulus-response compatibility (SRC) effects. SRC effects are considered to be the phenomena that provide the most pure measures of response-selection difficulty (Sanders, 1998). They have been shown to be larger for older than younger adults in many situations (see Proctor, Vu, & Pick, 2005). Age-related changes in response-selection processes have not been examined for tasks in which compatible and incompatible location mappings or a location mapping and a color-to-response mapping (with stimulus location irrelevant) are mixed. Yet, the former allows examination of whether older adults have difficulty when mapping rules conflict, and the latter of whether older adults have difficulty switching between spatial and nonspatial dimensions. The purpose of the present study was to conduct such examinations with the goal of identifying the mechanisms underlying the response-selection difficulty experienced by older adults.

1.1. SRC and Simon effects

SRC effects have been studied extensively using two-choice tasks for which left and right stimuli are mapped to left and right keypress responses (Proctor & Vu, 2006). In that situation, RT is shorter for the compatible mapping of left stimulus to left response and right stimulus to right response than for the incompatible mapping of left stimulus to right response and right stimulus to left response. A similar benefit of spatial correspondence, called the Simon effect, occurs in two-choice tasks for which stimulus location is irrelevant and responses are to be based on a relevant stimulus dimension, often color (Simon, 1990; see Lu & Proctor, 1995, for a review). If the right response is assigned to a red stimulus and the left response to a green stimulus, RT will be shorter when the red stimulus occurs in the right location and the green stimulus in the left location than when their locations are opposite. The Simon effect is at most half the size of the two-choice SRC effect obtained when stimulus location is relevant (Proctor & Vu, 2006).

Most accounts of SRC and Simon effects distinguish two response-selection routes (Hommel & Prinz, 1997): automatic (or direct) and intentional (or indirect). Stimuli tend to activate their corresponding responses through the direct route by way of long-term S-R associations. This activation is thought to be the cause of the Simon effect and to contribute to the SRC effect, which is also a function of the indirect route. Activation through this latter route is considered to be based on the mappings defined as relevant for the task, which are sometimes called short-term, or task-specific, S-R associations (e.g., Zorzi & Umiltà, 1995). Translation of the relevant

stimulus code into a response code via the indirect route is quicker when the relevant S-R mapping is compatible than when it is incompatible.

Older adults show larger SRC effects than younger adults, and the relative cost of incompatibility tends to be greater in tasks that require multiple transformations to select the correct response than in simpler tasks (see Proctor et al., 2005; Smulders, Kenemans, Jonkman, & Kok, 1997). For example, Smulders et al. showed an SRC effect that was twice as large for older than younger adults for a task in which the digit 2 or 3 was presented in a left or right location, with location designating the left or right hand (compatibly in some trial blocks and incompatibly in others) and the digit specifying the finger (index or middle) to press. However, the few studies such as theirs that used multiple-transformation tasks have not systematically examined factors that contribute to the difficulty that older adults experience with incompatible S-R mappings.

1.2. Mixed mappings and tasks

As indicated, mixing paradigms, which require selection between different S-R mappings or tasks, provide a convenient way to systematically examine the decrement in older adults' performance on tasks requiring multiple transformations. With one variation of this procedure, compatible and incompatible trials are mixed within a trial block, and a mapping signal indicates which mapping is appropriate for any given trial. The mapping signal can be a nonspatial stimulus feature such as the horizontal or vertical orientation of a centered line (Shaffer, 1965) or the color of the stimulus (Heister & Schroeder-Heister, 1994; Vu & Proctor, 2004). With mixed mappings, participants must maintain representations of both location mappings in working memory, identify the mapping signal, choose the representation that is appropriate for the current trial, switch the task set to that mapping if it is different from the mapping on the previous trial, and apply the mapping to select the correct response. Because there is complete overlap between the stimulus and response dimensions, and the two mappings assign the stimuli to opposite responses, there should be a high degree of conflict during response selection.

Studies with younger adults show that the SRC effect is eliminated when mappings are mixed (Vu & Proctor, 2004). The most widely accepted account for the elimination of the SRC effect under mixed conditions is that the direct response-selection route is suppressed (De Jong, 1995; Proctor & Vu, 2002). If older adults have more difficulty suppressing the direct route, their SRC effect should not be reduced as much under mixed conditions as that for younger adults. Simon (1968) reported an experiment in which mapping was cued by a signal (one of two vertically oriented red lights in the center of the display) presented in advance of the imperative stimulus (a green light located to the left or right). The SRC effects were larger for older than younger adults and, for both age groups, the effects tended to be smaller when the cuing interval was short (100 ms) than when it was long (1,500 ms). However, the influence of cuing interval on the SRC effect was not significant for either age group. The likely reason why the SRC effect was not eliminated for younger adults is that the mapping signal always preceded the target stimulus, even at the short cuing interval, allowing at least some time for advance preparation of the cued mapping (De Jong, 1995; Shaffer, 1965). More important, these data are equivocal about whether the SRC effect for older adults is reduced or eliminated when mappings are mixed since their effect was slightly, but not significantly, smaller at the short than long interval.

In a second variation of the mixing procedure, trials for which location is relevant are mixed with trials for which location is irrelevant (i.e., a Simon task) and another stimulus dimension (e.g., color) is relevant (Marble & Proctor, 2000; Proctor, Vu, & Marble, 2003). As with the mixed mapping procedure, a mapping signal designates whether location is relevant or irrelevant for the current trial, but unlike that procedure, only a single location-relevant

mapping is in effect within a trial block. The procedure of mixing location-relevant and irrelevant tasks is more similar to that of most task-switching studies because the two trial types can be treated as distinct tasks. The comparison of performance on compatible and incompatible location-relevant trials with this procedure again provides an index of age-related changes in response-selection difficulty. Moreover, the influence of the location-relevant mapping on the Simon effect allows examination of whether older adults suffer more interference from the location mapping that is in effect for the alternative task.

As in the mixed mapping studies, the SRC effect for younger adults is eliminated when the location-relevant task is mixed with the location-irrelevant task. Additionally, the Simon effect for the location-irrelevant task increases when the location-relevant mapping is compatible and reverses to favor noncorresponding responses by about the same amount when the mapping is incompatible (Marble & Proctor, 2000; Proctor & Vu, 2002). We are aware of no study that has compared performance of older and younger adults using the mixed task paradigm. If older adults have a deficit in the ability to suppress response activation through the direct route, then they should show less reduction in the SRC effect when tasks are mixed than younger adults do, as well as a lesser tendency for the task-defined location mapping to influence the Simon effect on the location-irrelevant trials.

Mixing two location mappings may have different influences on the SRC effect than mixing location-relevant and irrelevant tasks because the situations differ in their cognitive demands. For mixed location mappings, the dimension to which the mapping should be applied (stimulus location) is known, and uncertainty exists about which mapping to apply to that dimension. For mixed location-relevant and irrelevant tasks, the mapping of stimulus locations to responses is known, but whether location or color will be relevant is uncertain. Consequently, with mixed tasks, only one response is mapped to a particular stimulus location, and uncertainty is a matter of whether to select that response or to respond instead on the basis of color. Proctor and Vu (in press) obtained empirical evidence with younger adults that mixing location mappings is more difficult than mixing location-relevant and irrelevant tasks. Their participants performed with mixed mappings in one experiment and mixed tasks in another, with the two mappings or tasks distinguished by whether the location information was conveyed by left-right physical position or the meaning of a centered location word “left” or “right”. This mode distinction reduced the influence of mixing for the location-relevant and irrelevant tasks but not for the compatible and incompatible mappings, suggesting that a salient cue (the mode distinction) is of little benefit to response selection when spatial stimulus codes are mapped to both responses. These data imply that more processing resources must be devoted to deciding whether to apply compatible and incompatible mappings than whether to apply a known location mapping or to respond to color. If so, then older adults’ performance should be affected relatively more in comparison to that of younger adults by mixing mappings than tasks.

When compatible and incompatible spatial mappings are mixed, the mapping of the current trial can be a repetition of that from the previous trial or a switch, and complete repetition of the stimulus and response of the previous trial occurs only when both the mapping and stimulus position repeat. For younger adults, complete repetitions yield the best performance, although there are also benefits for repeating just the mapping (Vu & Proctor, 2004). Because task-switching studies show little age-related deficit in switch costs, older adults most likely will exhibit similar sequential effects as younger adults. With regard to the Simon effect, sequential effect analyses often show that the Simon effect is evident only for trials on which the previous trial was corresponding (e.g., Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). This result has been interpreted as suggesting that the direct route is suppressed following a noncorresponding trial (Stürmer et al., 2002; Wühr, 2005; but see Hommel, Proctor, & Vu, 2004). If older adults are less capable than younger adults of dynamically suppressing and

releasing suppression of the direct route on a trial-to-trial basis, then their sequential effects in the Simon task should be reduced.

Because older adults show longer mean RT than younger adults, it is important to examine the RT distributions for the two age groups. For SRC proper, the advantage for the compatible mapping typically increases across the RT distributions (Roswarski & Proctor, 1996; Vu & Proctor, 2004). With younger adults, mixing flattens the SRC distribution function (Vu & Proctor, 2004); thus, comparing the RT distribution functions of older and younger adults will allow evaluation of whether the age-related differences in the SRC effect are due to shifting the entire RT distributions or to changes in shapes of the functions. The visual Simon effect tends to be largest for fast responses and decrease as RT lengthens (De Jong, Liang, & Lauber, 1994; Hommel, 1993). This result is often interpreted as indicating that there is rapid automatic activation of the corresponding response, which then dissipates. If this activation does not occur when a location-relevant task is intermixed, because the direct route is suppressed, then the Simon effect should not be largest at the fast end of the RT distributions. Additionally, if older adults show differential abilities in suppression than younger adults, their distribution functions should change in shape and not simply be shifted.

2. Experiment 1: Mixed Spatial Mappings

In Experiment 1, older and younger adults performed two-choice spatial-reaction tasks with compatible and incompatible mappings, presented in separate trial blocks or mixed within a block. We evaluated whether mixing impaired the performance of older adults more than that of younger adults, and why. Two mechanisms that may lead to age-related differences in RT with mixed mappings are (a) general slowing, according to which age-related differences in RT will be proportional to baseline RT levels, and (b) reduced ability to suppress automatic response tendencies. To evaluate whether the age-related differences in RT due to mixed mappings can be attributed to general slowing, we compared logarithm-transformed RT (logRT) as well as RT for older and younger adults (Hahn et al., 2004; Ratcliff, 1993). To determine whether an age-related deficiency exists in ability to suppress the direct response-selection route, we compared the SRC effects for older and younger adults with pure and mixed mappings.

2.1. Method

2.1.1. Participants—Sixteen older adults (range: 55–82 years; $M = 71.2$; $SD = 7.95$; 12 females and 4 males) were recruited from Purdue University and its surrounding communities, and 16 younger adults (range: 18–22 years; $M = 19.4$; $SD = 1.36$; 8 females and 8 males) from Introductory Psychology courses at Purdue. Older adults were paid \$10/hour, and younger adults received experimental credits. All older adults had at least a high-school education, were in good health, and reported no visual deficits beyond any correctable with glasses.

2.1.2. Apparatus and stimuli—Micro Experimental Laboratory (2.01) was used to present stimuli, control response registration, and time events. The stimuli were solid red or white discs (1-cm diameter; 1.14°) displayed on a 14" VGA color monitor at a viewing distance of 50 cm. The stimuli were presented 6.7-cm (7.63°) left or right of the screen center. Responses were made by pressing the "z" key with the left-index finger and the "/" key with the right-index finger on a QWERTY keyboard.

2.1.3. Procedure—Each participant performed four trial blocks, with a break of a couple of minutes between each block. The first two blocks were the pure-compatible and pure-incompatible mapping conditions, counterbalanced for order. For the pure-mapping condition, half of the stimuli were red and half were white, but color was irrelevant. For the pure-compatible block, participants responded to stimulus location by pressing the corresponding

key. For the pure-incompatible block, participants responded to stimulus location by pressing the noncorresponding key. The final two blocks were the mixed-mapping condition. For the mixed-mapping condition, half of the participants responded to white stimuli with the corresponding response and red stimuli with the noncorresponding response, and half with the opposite relation. The pure blocks were performed prior to the mixed blocks for all participants to avoid a possible carryover to the pure blocks of the reduction of the SRC effect in the mixed blocks. Such carryover has been shown to occur more for older than younger adults (Mayr, 2001; Spieler, Mayr, & LaGrone, 2006).

Each block consisted of 200 trials, which yielded 200 trials for each mapping in the pure- and mixed-mapping conditions. For all trials, the stimulus remained on the screen until a response was made. The stimulus sequence was randomized, with a 1-s intertrial-interval. Participants were to respond as quickly and accurately as possible. RT was measured from stimulus onset to depression of a response key. For an incorrect response, a 400-hz tone was presented for 500-ms, followed by a blank interval of 500-ms, and the 1-s intertrial-interval.

2.2. Results

The first 20 trials of each block were excluded from analysis in this experiment and Experiment 2. Trials for which RT was < 200 ms or > 3000 ms were also excluded (0.3% of trials for younger adults and 1.0% for older adults, differences that were not statistically significant). Mean correct RT and percentage error (PE) were computed for each participant as a function of condition (see Table 1). The RT and PE data were submitted to Condition (pure or mixed) $\times$ Mapping (compatible or incompatible) $\times$ Age (younger or older) analyses of variance (ANOVAs), with age as the only between-subjects factor (see Table 2). Statistical significance was set at $\alpha = .05$, using the Huynh-Feldt correction for violations of sphericity.

2.2.1. Reaction time—All effects were significant (see Table 2). Older adults' RT was 316 ms longer than that of younger adults. Overall, the mixing cost was 323 ms, and the SRC effect was 90 ms. The mixing cost was larger for older adults ($M_s = 536$ ms in pure blocks and 960 ms in mixed blocks; mixing cost = 425 ms) than younger adults ($M_s = 322$ ms in pure blocks and 543 ms in mixed blocks; mixing cost = 221 ms), and the SRC effect was larger for older adults (158 ms) than younger adults (23 ms). Across both age groups, the SRC effect obtained in the pure-mapping condition (150 ms) was reduced in the mixed-mapping condition (32 ms).

The three-way interaction showed that the reduction in magnitude of the SRC effect from pure to mixed conditions was larger for older than younger adults: For younger adults the SRC effect of 52 ms in the pure condition was eliminated in the mixed condition (-6 ms), as is typically found. For older adults, the SRC effect of 247 ms in the pure condition was reduced to 70 ms in the mixed condition. Thus, although the amount of reduction of the SRC effect with mixed mappings was larger for older than younger adults, the older adults still showed a substantial SRC effect because their initial effect for the pure mapping blocks was much larger than that of the younger adults.

For the ANOVA of logRT (see Table 2), only the Condition $\times$ Age interaction was no longer statistically significant, $p > .11$: Although the mixing cost for older adults (425 ms) was almost twice that for younger adults (221 ms), the difference was not large enough to reject the null hypothesis that the mixing cost is proportionally the same for the two age groups. Of importance, the two-way interaction of age with mapping still was significant, indicating that the SRC effect for older adults was larger than proportional, as was the three-way interaction of those variables with condition. This latter interaction indicates that the reduction in the SRC effect with mixed mappings was also larger than proportional for older adults, or, in other words, that the effect of mixing was larger than proportional for the compatible mapping (being an 84% increase for younger adults and a 125% increase for older adults), $F(1, 30) = 8.47$, p

< .01, but not for the incompatible mapping (being a 55% increase for younger adults and a 51% increase for older adults), $F < 1.0$.

2.2.2. Percent error—The only significant main effect was condition, yielding a mixing cost of 4.1%. The two-way interaction of Condition $\times$ Age was not significant, indicating that mixing increased PE for both younger and older adults). The two-way interactions of Condition $\times$ Mapping and Mapping $\times$ Age were significant, as was the three-way interaction of these variables. For the pure condition, younger and older adults showed similar SRC effects (1.7% and 1.5%, respectively), but for the mixed condition, younger adults showed a negative SRC effect (-3.8% ; i.e., a lower error rate for the incompatible mapping) whereas older adults showed a positive effect (1.1%). Thus, with mixed mappings, older adults were faster at responding when the mapping was compatible than when it was not, and they made slightly fewer errors.

2.2.3. RT distribution analysis—RT for each participant in each condition was ranked from shortest to longest and divided into 10 RT bins. The SRC effect for each bin was obtained by subtracting RT for the compatible trials from RT for the incompatible trials. These data were submitted to a 2 (Condition: pure versus mixed) $\times$ 10 (Bin: 1–10) $\times$ 2 (Age: young versus old) ANOVA. Only the terms involving bin were of interest. The main effect of bin was significant, $F(9, 270) = 24.22$, $MSE = 7,910$, $p < .001$, indicating that the SRC effect increased across bins (see Figure 1). Bin entered into two-way interactions with age and condition, $F_s(9, 270) = 13.82$, $MSE = 7,280$, $p_s < .001$. The former interaction indicates that the increase in SRC effect across bins was larger for older than younger adults, whereas the latter shows that the increasing function was significant for the pure condition but not the mixed condition. Furthermore, the three-way interaction of all variables was significant, $F(9, 270) = 4.18$, $p = .033$, indicating that the difference in functions between the pure and mixed conditions was larger for older than younger adults (see Figure 1, in which the SRC effect for the pure condition increases about 600 ms across bins for older adults compared to about 100 ms for younger adults, while the RT functions for the Mixed condition are relatively flat for both age groups).

2.2.4. Sequential analysis—For the mixed condition, RT was analyzed as a function of mapping transition (repeat/switch), stimulus-position transition (repeat/switch), mapping (compatible/incompatible), and age (younger/older). The main effects of mapping transition and stimulus-location transition were significant, $F_s(1,30) > 62.82$, $MSE = 7,309$, $p_s < .001$, indicating benefits for mapping repetition and stimulus repetition. The two-way interaction of these variables was also significant, $F(1,30) = 23.47$, $p < .001$: The benefit of stimulus-position repetition was larger when the mapping repeated (190 ms) than when it switched (87 ms).

Of importance, the three-way interaction of mapping transition, stimulus-position transition, and age was significant, $F(1,30) = 7.38$, $MSE = 7,309$, $p < .012$ (see Figure 2). The benefit of stimulus-position repetition was larger for older than younger adults when the mapping repeated (276 ms vs. 104 ms) than when it switched (114 ms vs. 59 ms). Thus, older adults benefited substantially from complete repetition, though their RT still was longer than that for younger adults. This three-way interaction remained evident in the means for log-transformed RT but fell slightly below the .05 level, $F(1,30) = 3.81$, $MSE = .002$, $p = .060$. The only other interaction involving mapping transition and stimulus-position transition was the interaction of those variables with mapping, $F(1,30) = 26.04$, $MSE = 1,024$, $p < .001$. The SRC effect was 82 ms when the mapping and stimulus position both switched, 36 ms when the mapping repeated, regardless of whether stimulus position repeated or not, and 0 ms when the mapping switched but stimulus position repeated.

2.3. Discussion

For the pure mapping condition, RT was 214 ms longer for older than younger adults. The SRC effect was also larger for older adults (247 ms) than for younger adults (52 ms). Thus, older adults were slower overall and showed a larger SRC effect than younger adults, as is typically found (Proctor, Vu, & Pick, 2005). These effects were both still significant for logRT, indicating that they are larger than proportional.

When mappings were mixed, RT increased more for older adults (425 ms) than for younger adults (221 ms), and PE did, too (5.3% increase for older adults compared to 2.9% for younger adults). This finding replicates the customary finding that overall mixing costs are larger for older than younger adults (e.g., Meiran et al., 2001). The increase in RT in the mixed condition was not proportionally greater for older than younger adults, as indicated by its lack of significance in the logRT analysis, but this was due primarily to the long mean RT for the older adults with a pure incompatible mapping. The compatible mapping in fact showed a significant effect of age group on the mixing costs for the logRT analysis.

Mixing eliminated the SRC effect entirely for younger adults, as is customarily found, but not for older adults (for which the SRC effect with mixed mappings was 70 ms and 1.1%). However, due to the larger SRC effect for RT in the pure condition for older adults, the absolute amount of reduction in the SRC effect was greater for them (177 ms) than for the younger adults (58 ms). If the reduction in SRC effect when mappings are mixed is due to suppression of the direct route, then older adults do not seem to be very deficient in this regard since the SRC effect for RT was reduced more for them than for younger adults.

For both younger and older adults, the size of the SRC effect with pure mappings increased from the first RT bin to the last, as is typically found (e.g., Roswarski & Proctor, 1996). For mixed mappings, the functions were a lot flatter, although they showed somewhat of a U-shape. Except for covering a much larger range, the functions for the older adults were similar in appearance to those for the younger adults. Older and younger adults also showed similar patterns of sequential effects with mixed mappings: Both age groups benefited from repetition of the mapping and of the stimulus location, with the benefit being greatest when both repeated. This benefit of complete repetition was larger for the older adults, though. The qualitative similarity of the distribution and sequential results for older and younger adults suggest that they were performing the tasks similarly.

In summary, older adults show a greater cost of incompatibility than do younger adults. When compatible and incompatible mappings are mixed, the SRC effect is reduced for both older and younger adults, and the changes in the SRC effect across the RT distribution and sequential effects show similar patterns for the two age groups. Thus, the results of Experiment 1 provide little indication that older adults are deficient in their ability to suppress direct activation of the corresponding response when compatible and incompatible mappings are mixed.

3. Experiment 2: Mixing Tasks

Experiment 1 showed that when each spatial stimulus code is mapped to both response codes, older adults have more difficulty performing the task than do younger adults. This additional difficulty experienced by older adults may arise from the response conflict present on all trials that must be resolved to respond correctly (e.g., Mayr, 2001). Experiment 2 was similar to Experiment 1, except that the location-relevant task was mixed with one for which location was irrelevant (i.e., a Simon task). In this case, only a single mapping of stimulus locations to response locations was in effect, and so there was no uncertainty about which mapping to apply once the participant determined that the mapping signal specified location as relevant. Thus, conflict about which response to make to a particular stimulus position should be much less

than when spatial mappings are mixed. For the location-irrelevant trials there also was only a single mapping of the stimulus color to the responses in effect. If conflict of the mapped response codes is in part responsible for the difficulties experienced by the older adults with the mixed mappings of Experiment 1, then older adults should have relatively less difficulty performing a location-relevant task mixed with a location-irrelevant task.

The methodology used in Experiment 2 necessitated inclusion of a pure location-irrelevant condition as a baseline measure of the Simon effect. This condition was conducted first for all participants because prior experience with incompatible location-relevant mappings is known to reverse the Simon effect (e.g., Vu, Proctor, & Urcuioli, 2003). Another difference from Experiment 1 is that two mixed conditions were tested, one for which the location-relevant mapping was compatible and one for which it was not.

3.1. Method

3.1.1. Participants—Sixteen older adults (range: 55–88 years; $M = 68.38$, $SD = 10.32$; 7 females and 9 males) and 16 younger adults (range: 18–20 years; $M = 18.56$, $SD = 0.73$; 11 females and 5 males) were recruited and compensated as in Experiment 1. All older adults had at least a high school education, were in good health, and had normal or corrected-to-normal vision.

3.1.2. Apparatus, stimuli, and procedure—These were the same as in Experiment 1, except as noted. Each participant performed five trial blocks consisting of three separate tasks. In the first block of 240 trials, all participants performed the Simon task to measure the effect of irrelevant-location information on performance. Participants were to respond to stimulus color, red or green, and ignore its left-right location. Half performed with a color-response mapping of red-to-left and green-to right, and half with the opposite mapping.

For the second and third blocks, participants performed a location-relevant task in which the stimuli were white, red, or green, and responses were to be based on stimulus location regardless of color. The mapping was compatible for one block of 120 trials and incompatible for the other, with order counterbalanced between subjects.

For the fourth and fifth blocks, participants performed mixed location-relevant and Simon tasks. Each block consisted of 240 trials, 80 for each stimulus color. Participants were to respond with a right or left keypress to the red or green color (with the same color-response mapping used in the pure Simon-task block). They were to respond to the location of the white stimuli with a compatible mapping in one block and an incompatible mapping in the other, counterbalanced for order between participants.

3.2. Results

3.2.1. Location-relevant trials—Mean correct RT and PE were submitted to separate Condition (pure/mixed) $\times$ Mapping (compatible/incompatible) $\times$ Age (younger/older) ANOVAs, with age as a between-subjects factor (see Table 3 and Table 4).

3.2.1.1. Reaction time: For RT, all effects were significant. Older adults' RT was 132 ms longer than that of younger adults. Overall, the mixing cost was 339 ms, and the SRC effect was 35 ms. The mixing cost was 70 ms larger for older (373 ms) than younger adults (303 ms). Older adults also showed a larger SRC effect (63 ms) than younger adults (7 ms). A large positive SRC effect was obtained in the pure condition (108 ms), but it reversed to favor the incompatible mapping in the mixed condition (−38 ms).

The three-way interaction of condition, mapping, and age reflects the following. Under pure conditions, the SRC effect was larger for older (149 ms) than younger (54 ms) adults, $F(1,30) = 28.61, p < .001$. For mixed conditions, however, there was no difference between the reversed SRC effect for younger (−42 ms) and older (−34 ms) adults, $F < 1.0$.

As in Experiment 1, the Condition $\times$ Age interaction was no longer significant for log-transformed RT, $F < 1.0$. However, the three-way interaction of Age $\times$ Mapping $\times$ Condition remained significant, indicating a tendency for mixing to slow RT with the compatible mapping proportionally more for older adults (123%) than for younger adults (110%), with the reverse tendency for the incompatible mapping (older adults: 53%; younger adults: 68%).

3.2.1.2. Percent error: The mixing cost was 4.1%, and the SRC effect was −1.8%. The two-way interactions of Age $\times$ Condition and Condition $\times$ Compatibility were significant. Mixing increased PE more for younger adults than older adults, and reversed the SRC effect from a lower PE for compatible than incompatible trials in the pure condition to a higher PE for the compatible trials in the mixed condition. The three-way interaction of all factors was also significant. For the pure condition, there was no difference between the SRC effect for older (0.9%) and younger (1.2%) adults, $F < 1.0$, but for the mixed condition, younger adults (−6.1%) showed a larger reverse SRC effect than older adults (−3.2%), $F(1,30) = 4.37, p < .045$.

3.2.1.3. RT distribution analysis: As in Experiment 1, RT for each participant in each condition was ranked from shortest to longest, divided into 10 RT bins, and the SRC effect for each bin was obtained. These data were submitted to a 2 (Condition: pure versus mixed) $\times$ 10 (Bin: 1–10) $\times$ 2 (Age: young versus old) ANOVA. The main effect of bin was significant, $F(9, 270) = 8.07, MSE = 5,503, p < .001$, indicating that the SRC effect increased across bins (see Figure 3). Bin interacted with age, $F(9, 270) = 1.94, p = .046$, and condition, $F(9, 270) = 16.76, MSE = 4,622, p < .001$. The increase in the SRC effect across bins was larger for older than younger adults and evident only for the pure condition. The three-way interaction of all variables was also significant, $F(9, 270) = 2.33, p = .016$. This increase in SRC effects across RT bins in the pure condition was larger for older than younger adults, but the lack of an increase in the SRC effect across RT bins for the mixed conditions was similar for both younger and older adults.

3.2.1.4. Sequential analysis: An analysis was performed on RT with age group (younger, older) as a between-subjects factor and condition (mixed-compatible, mixed-incompatible), task transition (repeat, switch), and stimulus-position transition (repeat, switch) as factors. Both of task transition and stimulus-position transition showed main effects, $F_s(1,30) > 100.78, p_s < .001$, and, more important, a two-way interaction, $F(1,30) = 90.51, MSE = 5,018, p < .001$ (see Figure 4). A benefit of stimulus-position repetition was evident only when the location-relevant task repeated (156 ms), with a slight cost when the task switched (−12 ms).

As in Experiment 1, the three-way interaction of these variables with age was also significant, $F(1,30) = 12.41, MSE = 4,041, p < .001$: The benefit of stimulus-position repetition when the task repeated was larger for older than younger adults (209 ms vs. 103 ms), $F(1,30) = 8.43, p < .007$, whereas the tendency toward a cost of stimulus repetition when the task switched was of similar magnitude for older and younger adults (−22 ms vs. −3 ms), $F(1,30) = 1.31, p > .25$. This three-way interaction was still significant for logRT, $F(1,30) = 6.05, MSE = .002, p < .020$. The three-way interaction of Task Transition, Stimulus-Location Transition, and Condition was also significant, $F(1,30) = 7.22, MSE = 4,041, p < .022$. When the task switched, the SRC effect reversed regardless of whether stimulus location changed (−37 ms) or not (−34 ms). However, when the task remained the same as on the preceding trial, the SRC effect was smaller when the location repeated (29 ms) than when it changed (60 ms). Importantly, this

pattern did not differ significantly for younger and older adults, as indicated by the absence of four-way interaction of those variables with age, $F < 1.0$.

3.2.2. Location-Irrelevant Trials—Mean RT and PE were submitted to separate Condition (pure/mixed-compatible/mixed-incompatible) $\times$ Correspondence (corresponding/noncorresponding) $\times$ Age (younger/older) ANOVAs, with age as a between-subjects factor (see Table 5 and Table 6).

3.2.2.1. Reaction time: Older adults were 125-ms slower than younger adults, and the overall mixing cost was 174 ms. Age interacted with correspondence, with the Simon effect being larger for older (29 ms) than younger (−12 ms) adults. Condition interacted with correspondence: The Simon effect was largest in the mixed-compatible condition (56 ms), intermediate in the pure condition (30 ms), and reversed in the mixed-incompatible condition (−60 ms). The three-way interaction was not significant, indicating that the effects of the mixed location-relevant trials on the Simon effect were similar for older and younger adults.

In agreement with the findings for location-relevant trials, the Correspondence $\times$ Age interaction remained significant for logRT. This finding suggests that the larger Simon effect for older adults is not due to proportional slowing (see Proctor, Pick, Vu, & Anderson, 2005).

3.2.2.2. Percent error: The main effects of age and condition were significant. PE was higher for younger (3.8%) than older (2.3%) adults and in the mixed-incompatible condition (3.6%) than in the mixed-compatible (2.8%) and pure (2.7%) conditions. The two-way interactions of Age $\times$ Condition and Condition $\times$ Correspondence were significant, but they were modified by a three-way interaction of all factors. For the pure and mixed-compatible conditions, there was no difference between the Simon effect for older adults (1.9% and 2.9%, respectively) and younger adults (1.0% and 2.6%, respectively), $F(1,30) < 1.33$, $ps > .25$, but for the mixed-incompatible condition, younger adults (−8.3%) showed a larger reverse Simon effect than did older adults (−3.2%), $F(1,30) = 13.85$, $p = .001$.

3.2.2.3. RT distribution analysis: As with the location-relevant trials, RTs on location-irrelevant trials for each participant in each condition were ranked from shortest to longest and divided into 10 RT bins. The Simon effect for each bin was obtained by subtracting RT for the corresponding trials from RT for the noncorresponding trials. These data were submitted to a 3 (Condition: pure, mixed-compatible, or mixed-incompatible) $\times$ 10 (Bin: 1 – 10) $\times$ 2 (Age: young versus old) ANOVA. The main effect of bin was significant, $F(9, 270) = 4.04$, $MSE = 2,687$, $p < .001$, indicating that the Simon effect decreased across bins (see Figure 5). Bin interacted with age, $F(9, 270) = 4.02$, $p < .001$, and condition, $F(9, 270) = 5.17$, $MSE = 3,180$, $p < .001$. Regarding the interaction with age, for younger adults the Simon effect decreased across bins, whereas for older adults the Simon effect was relatively constant across RT bins. However, for the pure condition alone, the Simon effect decreased 13 ms from the first to the ninth RT bin for older adults (before increasing at the last one), and this pattern did not differ significantly from the 23 ms decrease shown by the younger adults, $F < 1.0$. Regarding the interaction with condition, the mixed-compatible condition showed an increasing tendency across RT bins for both younger and older adults, and the mixed-incompatible condition showed a tendency toward a more negative Simon effect across RT bins. These patterns were similar for younger and older adults, as indicated by the three-way interaction of all variables being nonsignificant, $F < 1.0$.

3.2.2.4. Sequential analysis: Because the Simon effect is known to be modulated by the correspondence relationship of the previous trial, an analysis was performed for task-repetition trials (for which the previous trial was also a Simon task) as a function of previous correspondence in all three conditions (see Figure 6). Mean RT was submitted to a 3 (Condition:

pure, mixed-compatible, mixed-incompatible) $\times$ 2 (Previous Correspondence) $\times$ 2 (Current Correspondence) $\times$ 2 (Age group) ANOVA. The only significant effect involving previous correspondence was its two-way interaction with current correspondence, $F(2,60) = 163.61$, $MSE = 1,858$, $p < .001$. As typically found, a large positive 66-ms Simon effect was obtained only following corresponding trials; the effect was reversed to -47 ms following noncorresponding trials. Note that this sequential effect pattern did not enter into three-way interactions with condition or age, or their four-way interaction, $F_s < 1.20$. Thus, although the Simon effect was larger when the location-relevant mapping was compatible and reversed when the mapping was incompatible, the sequential effect patterns did not differ from those in the pure Simon condition, indicating that this modulation in overall Simon effect was not achieved through different patterns of sequential effects.

We also performed an analysis of sequential effects for the mixed conditions only, with RT analyzed as a function of task transition (repeated/switched), stimulus-position transition (repeated/switched), condition (mixed-compatible/mixed-incompatible), correspondence (corresponding/noncorresponding), and age (younger/older). This analysis showed an interaction of Task Transition $\times$ Stimulus-Position Transition, $F(1,30) = 33.97$, $MSE = 3,004$, $p < .001$, and a three-way interaction of those variables with condition, $F(1,30) = 5.06$, $MSE = 5,168$, $p = .032$. A benefit for stimulus-position repetition was evident when the location-irrelevant task repeated compared to a slight cost when it did not (51 ms vs. -5 ms); the benefit of stimulus and task repetition was similar when the location-relevant trials were incompatible and compatible (49 ms and 55 ms), but the cost of stimulus repetition when the task switched was evident when the location-relevant mapping was incompatible but not when it was compatible (-36 ms and $+27$ ms). Age did not interact with Stimulus-Location Transition $\times$ Task Transition nor with the combination of those variables with condition, and the 5-way interaction was also not significant, $F_s < 1.0$.

Unlike the repetition analysis for location-relevant trials, the trials for which both task and stimulus location repeated were not all complete repetitions. That is, the color of the stimulus could change, indicating a different response. To evaluate whether older adults showed any greater benefit for complete repetitions in the Simon task, only trials in the mixed conditions for which the task repeated (i.e., the previous trial was location-irrelevant) were analyzed, with stimulus-color transition as an additional factor. This analysis showed an interaction of stimulus-color transition and stimulus-location transition, $F(1,30) = 93.99$, $MSE = 4,364$, $p < .001$, but no three-way or four-way interactions of these variables with age and condition, $F_s(1,30) \leq 1.13$, $p_s > .25$. Both older and younger adults benefited more from color repetition when stimulus location also repeated than when it did not (152 ms vs. 38 ms).

3.3. Discussion

For the pure SRC task, RT was longer for older than younger adults, and the older adults showed an SRC effect approximately three times the size of that for the younger adults. In the mixed condition, RT for the location-relevant task was increased by 368 ms for the older adults and 303 ms for the younger adults, with the SRC effect reversed for both age groups to favor the incompatible mapping. Thus, mixing had a larger influence on the SRC effect for older than younger adults, as in Experiment 1, although in this case the reverse SRC effect in the mixed condition was of similar size for the two age groups. Also as in Experiment 1, for both age groups the SRC effect increased across RT bins in the pure mapping condition and showed flatter, but U-shaped, functions in the mixed condition, which went more negative than in Experiment 1.

Previous experiments using the mixed-task procedure with younger adults also found a tendency for the SRC effect to reverse. Across four experiments using that procedure [Marble & Proctor (2000), Experiments 1 and 4; Proctor & Vu (2002) Experiment 1; Proctor et al

(2003), Experiment 1], the SRC effect for the location-relevant task was -9 ms and -1.4% . Though these values favor the incompatible mapping, they are smaller than those of -42 ms and -6.1% for younger adults observed in the present experiment. The location-relevant task occurred on 50% of the trials in the earlier experiments but only 33% in the present one, but there is no obvious reason why reducing the percentage of location-relevant trials would lead to a greater benefit for the incompatible mapping. Another distinction is that participants in the mixed-task condition of the earlier studies used a single location mapping and received no prior practice with pure Simon and SRC tasks, unlike the present study. This distinction seems more likely to be responsible for the stronger reversal of the SRC effect in Experiment 2 because the influence of prior practice with an incompatible mapping is stronger than that with a compatible mapping (e.g., Tagliabue, Zorzi, Umiltà, & Bassignani, 2000).

For the pure Simon task, RT was 102 ms longer for older than younger adults, and the older adults showed a Simon effect of 41 ms compared to 20 ms for the younger adults. For this task, mixing increased RT in the compatible block by 166 ms for the younger adults and 179 ms for the older adults, and it increased RT in the incompatible block by 161 ms for the younger adults and 186 ms for the older adults. When intermixed with compatibly mapped location-relevant trials, the Simon effect increased to 33 ms for younger adults and to 80 ms for older adults; when intermixed with incompatibly mapped location-relevant trials, the Simon effect reversed to -89 ms for younger adults and -31 ms for older adults. The RT distribution functions showed the Simon effect in the pure condition to decrease as RT increased for the younger adults, as is often found; the decrease was not as evident for older adults, but their distribution function did not differ significantly from that for the younger adults. For both age groups, the primary influence of intermixed location-relevant trials on the RT distribution was for the compatible or incompatible mapping to exert a stronger influence on the Simon effect as RT increased, exception for the last point of the distribution function for younger adults in the mixed-compatible condition.

The sequential effect pattern for the location-relevant trials in the mixed conditions was similar to that for Experiment 1, with the major difference being that there was no benefit for repetition of stimulus location when the task switched. Otherwise, like Experiment 1, older adults showed a larger RT reduction than did younger adults for complete repetition. For the location-irrelevant trials, again, there was a benefit for complete repetition of stimulus location and task but not for partial repetition. The benefit of complete repetition was of similar magnitude regardless of whether the location-relevant mapping was compatible or incompatible, but a cost of stimulus repetition when the task switched was evident only when the location-relevant mapping was incompatible. These effects did not interact with age, indicating that the sequential effects are not the source of the overall effects of age.

4. General Discussion

Dual-route models of response selection postulate two processes that contribute to SRC effects: automatic activation of the corresponding response via the direct route and efficiency of translation to the assigned response via the indirect route (e.g., De Jong et al., 1994; Proctor & Vu, 2006). If it is assumed that automatic activation of the corresponding response becomes stronger with experience, in this case with age, then older adults should show larger SRC and Simon effects in the pure conditions, as typically found (Proctor et al., 2005). Similarly, if it is assumed that S-R translation becomes more efficient for particular S-R pairings as a function of experience, then the translation benefit for the compatible location mapping in the indirect route should also increase with age. Consequently, the benefit for corresponding responses should be relatively larger with age when location is relevant than when it is irrelevant because the compatible location mapping gains in both translation efficiency and stronger automatic

activation. In other words, compared to the effects shown by younger adults, the SRC effect for older adults should be relatively larger than the Simon effect.

In Experiments 1 and 2, with pure compatible mappings of stimulus locations to responses, older adults were slower than younger adults, but with pure incompatible mappings the difference between the two age groups was much larger. For the pure Simon task, older adults were also slower than younger adults when stimulus and response locations corresponded but only slightly more so when they did not. Thus, as predicted from dual-route models, the cost of noncorrespondence between S-R locations for older adults was larger when stimulus location was relevant than when it was not.

When compatible and incompatible mappings are mixed, or when a location-relevant task is mixed with a location-irrelevant task, younger adults typically show elimination of the SRC effect for location-relevant trials (see Vu & Proctor, 2004). This elimination is often attributed to suppression of the direct response-selection route. If older adults are less able than younger adults to suppress this route, then mixing should not result in as much reduction of the SRC effect for older adults. Yet, in Experiment 1, the SRC effect was reduced more for older than younger adults when compatible and incompatible spatial mappings were mixed. Similarly, in Experiment 2, the SRC effect was reduced by a mixed location-irrelevant task as much for older adults as for younger adults. These results suggest that the decrement in performance with a pure incompatible mapping for older adults is not due primarily to a deficiency in overcoming automatic response tendencies.

The Simon effect is typically attributed to activation of the corresponding response through the direct response-selection route. As mentioned above, the Simon effect for the pure condition was larger for older than younger adults. Mixing showed a qualitatively similar pattern of influence on the Simon effect for younger and older adults. When the intermixed location-relevant trials were compatibly mapped, the Simon effect increased for both RT and PE, with the increase in the Simon effect for RT being slightly larger for older than younger adults. When the intermixed location-relevant trials were incompatibly mapped, the Simon effect reversed in both RT and PE, with the reversal being larger for the younger adults only in the PE data. Moreover, if older adults had more difficulty in suppressing automatic activation, then they should show qualitative differences in the RT distribution functions from those shown by younger adults. Yet, for both the pure and mixed conditions of Experiment 2, the RT distributions for the Simon task were mainly shifted to longer times for the older adults. These data for the Simon effect thus also show relatively little indication that older adults are deficient in suppressing the long-term associations of the direct route under mixed task conditions, in agreement with the results for the location-relevant trials.

The cost of mixing spatial tasks is also usually greater for older than younger adults (e.g., Meiran et al., 2001). In Experiment 1, the cost on RT of mixing compatible and incompatible spatial mappings was 204 ms larger for older than younger adults. In Experiment 2, when a location-relevant task with a single mapping was mixed with a location-irrelevant task, the additional mixing cost for older adults compared to younger adults was only 65 ms, and this additional cost was even less for the location-irrelevant task (20 ms). Thus, the additional mixing cost for older adults was much larger when the mixed tasks were both spatial and their S-R mappings conflicted. In Experiment 1, the color of the stimulus had to be identified when compatible and incompatible mappings were mixed but not when they were presented in pure blocks. Thus, the greater mixing cost for older adults could be attributed to this difference in identification requirements rather than to additional difficulty in response selection. If such were the case, though, then in Experiment 2 older adults should have shown a similar additional mixing cost for the location-relevant task because identification of stimulus color was required only for the mixed-tasks condition. That the additional age-related mixing cost was

considerably smaller in Experiment 2 than in Experiment 1 therefore provides evidence that majority of the additional cost in Experiment 1 was not due to the difference in color-processing requirements for the pure and mixed mapping conditions.

Previous studies have found that older adults do not show a deficit in specific switch costs when the task on the current trial differs from that on the previous trial. Examples include studies by Reimers and Maylor (2005) for tasks requiring categorization of faces by gender or emotion and Eppinger et al. (2007) for switching between meaning of color word or ink color in a Stroop color task. Consistent with the prior findings, the sequential analyses of the mixed conditions in the present study showed similar patterns of repetition benefits and switch costs for younger and older adults. The main difference was that older adults benefited more than younger adults from complete repetition of the prior trial for the location-relevant task in both Experiments 1 and 2. For the location-irrelevant task of Experiment 2, the older adults showed no statistically reliable difference from the younger adults in sequential-effect magnitudes. Thus, the main additional decrement in performance for older adults when tasks were mixed was in the overall mixing costs and not the specific switch costs. These results imply that the deficiency shown by older adults is primarily in the ability to maintain spatial task sets with conflicting response mappings in working memory rather than in the ability to reconfigure the S-R mapping, or suppress/release the direct route, on a trial-to-trial basis.

Our results imply that activation of a left/right response code through the direct route is not particularly problematic for older adults. Although the Simon effect was larger for older than younger adults, the absolute increase in effect size and the costs of mixing Simon trials with location-relevant trials were relatively small. Thus, the processes involved in preventing irrelevant information from having much influence on performance do not seem to be as impaired in older adults as those involved in intentional response selection. This conclusion is consistent with the finding that although older adults' show little deficiency in the ability to prepare subsets of responses, they are slowed in doing so for subsets that require effortful selection (Proctor et al., 2006).

That the cost of noncorrespondence becomes relatively greater for older adults as the need to attend to location increases is in agreement with our earlier findings comparing the standard Simon task with the accessory Simon task (Proctor et al., 2005). For this latter task, the irrelevant location information is usually conveyed by a left or right auditory tone separate from the visual stimulus that conveys the relevant color information. Older adults showed a Simon effect of larger absolute size than that of younger adults for the standard Simon task in which the location information was integrated with the color information, but they did not in accessory stimulus versions of the task, including one in which the accessory was a left or right visual stimulus. Thus, when there is no need to attend to a stimulus's location, its influence on performance is similar for older and younger adults. When location must be attended to evaluate a relevant stimulus dimension other than location, as in the Simon task, the irrelevant location information is more problematic for older than younger adults. Older adults have still more difficulty when stimulus location not only must be attended but also is relevant and mapped incompatibly to responses, and the difficulty becomes extreme when competing responses are mapped to each stimulus location. These results suggest that automatic processing of the location information is not the cause of the additional difficulty for older adults. When attention is directed to the location information for processing of the relevant dimension, older adults experience more difficulty when the activated location code conflicts with that of the assigned response.

The difficulty that older adults experienced in our Experiment 1 with mixed mappings that applied to the same set of stimulus locations is in agreement with results of Meiran et al. (2001). In their Experiment 1, stimuli could occur in one of four quadrants of a square, and

two response keys were arrayed along one diagonal. A cue indicated whether subjects were to respond based on the horizontal or vertical location of the stimulus. The irrelevant dimension could be congruent or incongruent with the cued dimension. Their results showed that age had a larger influence on the overall mixing cost than on the congruency effects, and they concluded that the selective aspect of attention reflected in the congruency effects was less affected by aging than were the intentional response-selection processes. Taken together, the results with spatial tasks converge on Mayr and Liebscher's (2001) conclusion that global mixing costs "seem to be particularly large when demands in terms of 'keeping competing mental sets apart' are high" (p. 47).

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Figure 1. Mean SRC effect for younger (top panel) and older (bottom panel) adults as a function of RT bin for the pure and mixed mapping conditions of Experiment 1.

Exp 1: Younger Adults

Exp 1: Older Adults

Figure 2. Mean reaction time (in ms) for Experiment 1 as a function of mapping and stimulus repetition for younger (top panel) and older (bottom panel) adults.

Figure 3. Mean SRC effect for younger (top panel) and older (bottom panel) adults as a function of RT bin for the pure and mixed location-relevant trials of Experiment 2.

Figure 4.

Mean reaction time (in ms) for location-relevant trials in Experiment 2 as a function of mapping and stimulus repetition for younger (top panel) and older (bottom panel) adults.

Figure 5. Mean Simon effect for younger (top panel) and older (bottom panel) adults as a function of RT bin for the pure, mixed-compatible, and mixed-incompatible location-irrelevant trials of Experiment 2.

Figure 6.

Mean Simon effect for younger and older adults for task repetition trials as a function of correspondence on the previous trial for the pure, mixed-compatible, and mixed-incompatible location-irrelevant trials of Experiment 2.

Table 1
Mean Reaction Time (RT), Percent Error (PE), and Log-transformed RT (logRT) as a Function of Condition, Mapping, and Age in Experiment 1

Condition	RT	Compatible logRT	Mapping		RT	Incompatible logRT	PE
			PE				
Pure	296	2.47	0.84%	Younger Adults	348	2.54	2.51%
Mixed	546	2.73	6.43%		540	2.73	2.67%
Pure	412	2.61	0.63%	Older Adults	659	2.81	2.10%
Mixed	926	2.96	6.17%		996	2.98	7.27%

Table 2
Analyses of Variance for Reaction Time (RT), log Reaction Time (logRT), and Percent Error (PE) in Experiment 1

Term	RT			logRT			PE		
	F (1,30)	MSE	p ≤	F (1,30)	MSE	p ≤	F (1,30)	MSE	p ≤
Condition	198.03	16,896	.001	504.15	.004	.001	25.03	21.66	.001
Mapping	53.70	4,915	.001	108.71	.002	.001		Not Significant	
Age Group	51.50	62,018	.001	87.46	.018	.001		Not Significant	
Condition × Mapping	54.83	2,015	.001	126.58	.001	.001	13.08	5.16	.001
Condition × Age Group	19.76	16,896	.001		Not Significant			Not Significant	
Mapping × Age Group	29.79	4,915	.001	33.73	.002	.001	6.05	7.17	.020
Condition × Mapping × Age Group	13.95	2,015	.001	19.10	.001	.001	9.89	5.16	.004

Table 3
Mean Reaction Time (RT), Percent Error (PE), and Log-transformed RT (logRT) as a Function of Condition, Mapping, and Age for Location-Relevant Trials of Experiment 2

Condition	Compatible		Mapping		Incompatible	
	RT	logRT	PE	RT	logRT	PE
Pure	320	2.50	0.57%	374	2.57	1.76%
Mixed	671	2.82	9.50%	629	2.79	3.37%
Pure	374	2.55	0.88%	523	2.71	1.75%
Mixed	834	2.91	5.82%	800	2.90	2.58%

Analyses of Variance for Reaction Time (RT), log Reaction Time (logRT), and Percent Error (PE) for the Location-Relevant Trials in Experiment 2

Term	RT			logRT			PE		
	F (1,22)	MSE	p ≤	F (1,22)	MSE	p ≤	F (1,22)	MSE	p ≤
Condition	513.11	7.138	.001	759.82	.003	.001	49.95	10.62	.001
Mapping	12.95	2.957	.001	60.35	.001	.001	27.22	3.92	.001
Age Group	15.82	35.244	.001	16.46	.018	.001	Not Significant		
Condition × Mapping	48.39	3.493	.001	100.23	.001	.001	59.58	4.38	.001
Condition × Age Group	5.46	7.138	.026	Not Significant			4.28	10.62	.032
Mapping × Age Group	8.56	2.956	.006	19.11	.001	.001	Not Significant		
Condition × Mapping × Age Group	5.54	3.493	.025	8.27	.001	.007	4.65	4.38	.045

Table 5
Mean Reaction Time (RT), Percent Error (PE), and Log-transformed RT (logRT) as a Function of Condition, Correspondence, and Age for Location-Irrelevant Trials of Experiment 2

Condition	Corresponding		Correspondence		Noncorresponding	
	RT	logRT	PE	RT	logRT	PE
Pure Mixed-Compatible Mixed-Incompatible	434	2.64	3.00%	454	2.65	3.96%
	593	2.77	1.54%	626	2.79	4.19%
	649	2.81	9.25%	560	2.74	0.94%
Pure Mixed-Compatible Mixed-Incompatible	525	2.71	1.03%	566	2.75	2.96%
	685	2.83	1.36%	765	2.88	4.23%
	747	2.87	3.70%	716	2.85	0.54%

Table 6
Analyses of Variance for Reaction Time (RT), log Reaction Time (logRT), and Percent Error (PE) for the Location-Irrelevant Trials in Experiment 2

Term	RT			logRT			PE		
	F (1,30)	MSE	p ≤	F (1,30)	MSE	p ≤	F (1,30)	MSE	p ≤
Condition	142.59	4.483	.001	196.34	.002	.001	3.61	4.06	.035
Correspondence		Not Significant			Not Significant			Not Significant	
Age Group	12.78	49.308	.001	13.75	.023	.001	7.71	14.22	.009
Condition × Correspondence	62.35	953	.001	63.69	.001	.001	64.81	5.16	.001
Condition × Age Group		Not Significant			Not Significant		8.37	4.06	.001
Correspondence × Age Group	19.64	1,077	.001	20.76	.001	.001	10.70	5.01	.003
Condition × Correspondence × Age Group		Not Significant			Not Significant		5.48	5.16	.008