Transfer effects of incompatible location-relevant mappings on a subsequent visual or auditory Simon task

KIM-PHUONG L. VU, ROBERT W. PROCTOR, and PETER URCUIOLI
Purdue University, West Lafayette, Indiana

Two experiments investigated the influence of practice with an incompatible mapping of left and right stimuli to keypress responses on performance of a subsequent Simon task, for which stimulus location was irrelevant, after a delay of 5 min or 1 week. In Experiment 1, the visual Simon effect was eliminated when the practice modality was auditory and reversed to favor noncorresponding responses when it was visual, and there was no significant effect of delay interval. In Experiment 2, significant auditory Simon effects were obtained that did not vary as a function of practice modality, with delay having only a marginal effect on the magnitude of the Simon effect. The elimination of the visual Simon effect in the transfer session is most likely due to the short-term stimulus–response associations defined for the incompatible spatial mapping remaining active during the transfer session. Because the auditory Simon effect is stronger than the visual one, more practice with the incompatible mapping may be necessary to produce reliable transfer effects for it.

Performance is better when the response assigned to a stimulus corresponds with the stimulus's location than when it does not. This spatial correspondence, or compatibility, effect occurs when responding is based on stimulus location (stimulus–response compatibility [SRC] proper) or on a nonspatial attribute (e.g., color) of the stimulus (Simon effect). Both SRC proper and the Simon effect have been investigated extensively, because they reflect response-selection processes that mediate perception and action (Hommel & Prinz, 1997; Proctor & Reeve, 1990).

Accounts of SRC effects usually emphasize two response-selection processes, automatic activation and intentional translation (see, e.g., De Jong, 1995). Automatic activation of the corresponding response occurs when the stimulus set has dimensional overlap, or similarity, with the response set (Kornblum, Hasbroucq, & Osman, 1990), yielding faster and more accurate responding when this automatically activated response is the one assigned to the stimulus than when it is not. The speed of intentional translation is also affected for stimulus–response (S–R) sets with dimensional overlap by the mapping of stimuli to responses, being fastest when an identity relation exists between stimuli and responses (Duncan, 1977). An alternative way of

characterizing the contributions of automatic activation and intentional translation is to do so in terms of long-term and short-term S–R associations (Barber & O'Leary, 1997; Zorzi & Umiltà, 1995). Automatic activation of the corresponding response occurs by way of the long-term associations between stimulus and response locations, which are innate or established through years of experience. Intentional translation is based on the short-term associations, which reflect the task instructions that assign stimuli to responses. For SRC proper, the incompatible mapping suffers from slower intentional translation and conflict between the automatically activated, but incorrect, response and the correct response that is activated intentionally. The Simon effect is typically attributed solely to the conflict between the automatically activated response and the correct response when they are different.

Both the effect of SRC proper and the Simon effect persist after extensive practice, suggesting that the contribution of the automatic or long-term S–R associations cannot be overridden (Dutta & Proctor, 1992; Prinz, Aschersleben, Hommel, & Vogt, 1995; Proctor & Lu, 1999). However, several recent studies have shown that the Simon effect is influenced by the short-term associations between stimulus and response locations defined for an intermixed location-relevant task. Proctor and Vu (2002) and Proctor, Vu, and Marble (2003) intermixed Simon-task trials, for which stimulus color was the relevant dimension, with compatibly or incompatibly mapped location-relevant trials. Responding was slowed overall, as is typically found when tasks are mixed (see, e.g., Los, 1996), and the SRC effect for location-relevant trials was eliminated. Moreover, the Simon effect was influenced by the location-relevant mapping, being enhanced when the mapping was compatible, but reversed

We thank Rachael Anderson, Abhilasha Bhargav, Amy Smith, Zac Smith, Amelia Sumpter, Kerry Thorne, Leigh Lytle, and Srikanth Ramachandran for their help with testing participants in the experiments. We also thank Bernhard Hommel and Carlo Umiltà for helpful comments on a previous version of the manuscript. Correspondence should be sent to K.-P. L. Vu, Department of Psychological Sciences, Purdue University, 703 Third Street, West Lafayette, IN, 47907-2081 (e-mail: kvu@psych.purdue.edu).

to an advantage for noncorresponding responses when the mapping was incompatible. The effect of the short-term associations for the intermixed location-relevant task on the Simon task can be attributed to the fact that subjects did not know until stimulus presentation whether the location-relevant mapping or the color-response mapping was in effect for the current trial; consequently, they had to maintain the associations for both mappings in an active state.

In other studies, it has been found that the associations defined for the SRC task can affect performance even in a subsequent block of trials in which the Simon task is performed alone (Proctor & Lu, 1999; Tagliabue, Zorzi, & Umiltà, 2002; Tagliabue, Zorzi, Umiltà, & Bassignani, 2000). In Proctor and Lu's (1999) study, subjects performed a two-choice SRC task for 3 days (310 trials per day) using an incompatible spatial mapping, and then transferred to a Simon task on the 4th day. The incompatible mapping from the SRC task continued to exert an influence on response selection for the Simon task, resulting in a reversed Simon effect. Consistent with the notion that the incompatible mapping still exerts an effect when it is no longer relevant to the task, Tagliabue et al. (2000) showed that practice with an incompatible mapping for a single session of 72 trials eliminated the Simon effect when a Simon task was performed 5-min after the practice session or after a 24-hour delay. On the basis of simulations run with a computational model of the Simon effect developed by Zorzi and Umiltà (1995), Tagliabue et al. (2000) concluded that the transfer effects were attributable to the short-term associations for the previous SRC task remaining active during performance of the Simon task. The most likely reason why the effect reversed in Proctor and Lu's study, with its 24-h delay between the last practice session and the transfer session, but was only eliminated in Tagliabue et al.'s (2000) study, is that the subjects' more extended practice in Proctor and Lu's study enhanced the short-term (incompatible) associations.

Although Tagliabue et al. (2000) did not find a reverse Simon effect after a 5-min or 24-h delay, they did find this pattern when subjects performed the Simon task 1 week after practice with the SRC proper task. Tagliabue et al. (2000) attributed this rather remarkable finding—that 72 trials of practice with an incompatible mapping produced a reverse Simon effect 7 days later but not 5 min or 1 day later—to consolidation of the short-term associations over the week delay. Tagliabue et al. (2002) also concluded that these short-term S–R associations are not modality specific. They had subjects practice with an incompatible mapping of auditory stimuli to keypress responses and transfer to a visual Simon task after delays of 5 min, 1 day, or 1 week. The Simon effect was eliminated at all delays. Even though the Simon effect did not reverse significantly after a week delay, a comparison of this condition (Tagliabue et al., 2002, Experiment 3) with the visual practice condition of their earlier study (Tagliabue et al., 2000, Experiment 5) yielded no significant effect of practice modality. Consequently, Tagliabue et al. (2002) concluded that practice with an incompatible mapping apparently pro-

duces similar effects on the subsequent Simon task regardless of whether the practice stimuli are visual or auditory, indicating that the spatial associations formed during practice are not modality specific.

Two aspects of Tagliabue et al.'s (2002; Tagliabue et al., 2000) conclusions are particularly important, but both can be questioned. The first is that consolidation of the short-term S–R associations defined for the incompatible spatial mapping takes place during the week after practice, resulting in a greater influence of those associations on the Simon effect. This conclusion is significant, because there is not much evidence in support of consolidation in the memory literature (Neath & Surprenant, 2003). Moreover, the evidence for consolidation reported by Tagliabue et al. (2000) for the visual practice condition was obtained in only one experiment and was not replicated for the auditory practice condition. The second important aspect is that the short-term associations of stimulus and response locations acquired through practice with the incompatible mapping are independent of stimulus modality. Although Tagliabue et al.'s (2002) between-study comparison showed no difference in the magnitude of the visual Simon effect 1 week after practice with visual or auditory stimuli, as previously mentioned, the reverse Simon effect was evident only for the visual practice modality. The lack of a significant interaction may reflect the fact that the analysis was based on a between-study comparison of two conditions that had unequal numbers of subjects in each condition (i.e., 5 in the visual practice condition vs. 16 in the auditory practice condition) and hence was of low power. In addition, a strong case that the associations acquired through practice are not modality specific requires that the practice modality also have no influence when the stimuli for the Simon task are auditory.

In the present study, we examined whether the short-term S–R associations consolidate over time and are modality independent, as Tagliabue et al. (2002; Tagliabue et al., 2000) proposed, by evaluating the influence of a visual or auditory incompatible location-relevant mapping on a subsequent visual or auditory Simon task at 5-min and 1-week delay intervals. Although Tagliabue et al. (2002; Tagliabue et al., 2000) also used a delay of 24 h, we used only the shortest and longest delays, because the 24-h delay yielded similar results to those for the 5-min delay in their studies. Furthermore, because elimination and reversal of the Simon effect in their studies was restricted to the incompatible mapping, we used only that mapping for the practice session. In Experiment 1, subjects performed with an incompatible mapping of visual or auditory stimuli and were transferred to a visual Simon task 5 min or a week later. This experiment allowed determination of whether the influence of practice with the incompatible mapping on the visual Simon task (1) increases at the week delay as opposed to the 5-min delay, as the consolidation hypothesis predicts, and (2) is independent of the modality of the practice stimuli. In Experiment 2, subjects performed with an incompatible mapping of visual or auditory stimuli and were transferred to an auditory Simon task

after a 5-min or a week delay. If the associations developed from practice with an incompatible spatial mapping are truly independent of stimulus modality, as Tagliabue et al. (2002) suggested, then the auditory Simon task should yield results similar to the visual Simon task, and practice modality should be of no consequence.

EXPERIMENT 1

In Experiment 1, we attempted to confirm Tagliabue et al.'s (2002; Tagliabue et al., 2000) conclusions that the influence of practice with an incompatible mapping on the visual Simon task (1) is independent of practice modality, and (2) increases with a week delay. We followed their method closely, adding a control condition in which subjects performed the Simon task without prior practice with the incompatible S–R mapping to provide a baseline.

Method

Subjects. One hundred and twenty subjects were recruited from Purdue University's introductory psychology courses to participate for partial course credit. All subjects reported having normal or corrected-to-normal vision and normal hearing. Twenty-four were assigned to the control condition. Of the 96 assigned to the transfer conditions, 48 performed the practice task with visual stimuli and 48 with auditory stimuli. Within each of the practice modalities, 24 of the subjects were transferred to the Simon task 5 min after the practice session and 24 were transferred a week later.

Apparatus and Stimuli. The stimuli were presented on personal computers, with 14-in. VGA color monitors. Micro Experimental Laboratory (MEL 2.01) was used to control the experiment. The subjects sat directly in front of the monitor, at a viewing distance of approximately 60 cm. A crosshair located in the center of the screen served as a fixation point. The visual stimuli for the practice session were white circles (MEL color code 15; approximately 1.2 cm or 1.1° diameter, presented in left and right physical locations approximately 11 cm or 10.4° from center). The auditory stimuli for the practice session were administered through headphones. The frequency of the tone was 1800 Hz, and its intensity was 83 dB. Sounds were delivered to the left channel or the right channel. For the Simon transfer session, the stimuli were red or green circles (MEL color codes 4 and 2, respectively) of the same size and presented in the same locations as in the visual practice session.

The crosshair appeared for 1,800 msec simultaneously with a 400-Hz warning tone (which lasted 400 msec), presented by the computer's centered speakers. After the offset of the crosshair, the imperative stimulus was presented and it remained on the screen until a response was made or 1,500 msec had passed. For all conditions, responses were made by pressing the "z" and "f" keys on the computer keyboard, with the index finger of each hand.

Procedure. For the practice task, subjects were instructed to respond to the left stimulus by pressing the right key and the right stimulus by pressing the left key. For the Simon task, subjects were instructed to respond on the basis of stimulus color while ignoring the location of the stimulus when selecting the correct response. The red stimulus was assigned to the left response and the green stimulus to the right response for half the subjects, and vice versa for the other half. Subjects in the control condition performed only the Simon task.

The practice session consisted of 72 trials plus 12 warm-up trials, and the transfer session consisted of 144 trials plus 12 warm-up trials. The warm-up trials were not included in any of the data analyses. For all conditions, the order in which the stimuli appeared was randomized. The subjects were instructed to respond as quickly and accurately as possible. Reaction time (RT) was measured from stimulus onset to the depression of a response key. The stimulus remained present for 1,500 msec or until a response was made, and the intertrial interval was 1 sec. For the visual conditions, a 400-Hz error tone was presented for 500 msec following incorrect responses. For the auditory conditions, the word "INCORRECT" was presented for 500 msec following incorrect responses.

Results

Trials in which RT was less than 200 msec (anticipations) and over 1,500 msec (terminated trials) were excluded from the analyses in this and the subsequent experiment (less than 1.5% of all trials).

For the practice task, responses were slower and less accurate when the stimuli were auditory ($M_s = 442$ msec and 6.32%) than when they were visual ($M_s = 406$ msec and 1.51%) [$F_s(1,94) > 4.43, p_s \leq .038$]. For the control Simon task, both RT and percentage error (PE) showed effects of correspondence [$F_s(1,23) = 12.06$ and 7.70, $MS_e s = 254$ and 4.97, $p_s = .002$ and .011, respectively], yielding Simon effects of 16 msec and 1.8%, as can be seen in Table 1.

For the transfer Simon task, mean RT and PE were submitted to 2 (correspondence) $\times$ 2 (practice modality): vi-

Table 1
Experiment 1: Mean Reaction Time (RT, in Milliseconds) and Percentage Error (PE) for the Visual Simon Task in the Control and Transfer Conditions, as a Function of Correspondence, Practice Modality, and Delay

Practice Modality, and Delay						
Practice Modality	Correspondence				Simon Effect	
	Corresponding		Noncorresponding			
	RT	PE	RT	PE	RT	PE
Control Condition						
	482	2.41	498	4.19	16	1.78
5-min Delay						
Auditory practice	476	2.43	476	1.96	0	−0.47
Visual practice	538	4.40	526	2.56	−12	−1.84
Week Delay						
Auditory practice	482	3.57	490	2.89	8	−0.68
Visual practice	510	2.43	488	1.52	−22	−0.91

sual or auditory) $\times$ 2 (delay: 5 min or a week) ANOVAs. Table 1 shows mean RT and PE for each condition. For RT, the main effect of correspondence was not significant [$F(1,92) = 2.85, MS_e = 735, p = .095$], showing no overall Simon effect. However, correspondence interacted with practice modality [$F(1,92) = 7.03, MS_e = 735, p = .009$]. For the auditory practice modality, the Simon effect was a nonsignificant 4 msec ($F < 1.0$), whereas for the visual practice modality, the Simon effect reversed to -17 msec [$F(1,47) = 7.76, p = .008$]. Comparisons with the control condition showed the Simon effect to be significantly different for both practice modalities [$F_s(1,94) > 4.37, ps < .039$]. Of importance, no term involving delay was significant [$F_s(1,92) < 1.41, ps > .24$].

For PE, the main effect of correspondence was significant [$F(1,92) = 8.55, MS_e = 5.36, p = .004$], with an overall reverse Simon effect of -0.98% . The correspondence $\times$ practice modality interaction was not significant [$F(1,92) = 1.44, p = .233$], but similar to the RT data, the incompatible mapping showed a larger effect for the visual (mean difference [MD] = -1.38%) than for the auditory ($MD = -0.58\%$) practice modality. All terms involving delay were nonsignificant ($F_s < 1.0$), except for the delay $\times$ practice modality interaction [$F(1,92) = 9.44, MS_e = 8.173, p = .003$]. PE was larger at the longer delay than at the shorter delay for the auditory practice modality, but the relation was opposite for the visual practice modality.

Discussion

In agreement with previous studies (Proctor & Lu, 1999; Tagliabue et al., 2002; Tagliabue et al., 2000), practice with an incompatible spatial mapping eliminated or reversed the visual Simon effect. Following practice with auditory stimuli, the Simon effect was eliminated, whereas following practice with visual stimuli, the Simon effect was reversed to favor the noncorresponding response. Tagliabue et al. (2002) concluded from a nonsignificant, between-study interaction of correspondence and practice modality that the two modalities yielded similar effects. However, our results indicate that the influence on the Simon effect of prior practice with an incompatible mapping is smaller when the practice modality is auditory than when it is visual. Thus, there is a modality-specific component to the transfer effect, as well as a component that is modality independent. The fact that the magnitude of the transfer effect is larger when both the practice and Simon tasks are visual than when only the transfer task is visual can be attributed to the greater dimensional overlap, or similarity, of the stimuli for the two tasks when they are in the same modality (Kornblum et al., 1990; Proctor & Wang, 1997). That is, the short-term S-R associations from the prior task produce stronger response activation in the Simon task when the stimuli are perceptually similar (i.e., similar visual stimuli in the same locations) than when they are not (i.e., auditory tones rather than visual stimuli).

Experiment 1 also showed that the Simon effect did not vary overall as a function of delay. None of the interactions involving both correspondence and delay were sig-

nificant. However, in agreement with Tagliabue et al.'s (2000) findings, the reverse Simon effect after practice with the incompatible visual mapping was at least as evident at the week delay as at the 5-min delay. In fact, for RT, the reversal of the Simon effect was significant only at the week delay [Simon effects of -12 msec, $F(1,23) = 1.61, p = .217$, at the 5-min delay and -22 msec, $F(1,23) = 7.69, p = .008$, at the week delay]. Even for the visual practice modality alone, though, correspondence did not interact significantly with delay ($F < 1.0$), and the PE data showed an opposite nonsignificant tendency for a larger reverse Simon effect at the 5-min delay ($MD = -1.84\%$) than at the week delay ($MD = -.91\%$) ($F < 1.0$). Thus, the results provide little evidence that the reverse Simon effect following practice with visual stimuli is larger after a week delay than it is after a 5-min delay, although the influence of the incompatible mapping does not seem to decrease across a week delay.

EXPERIMENT 2

In Experiment 2, we examined whether the Simon effect for auditory stimuli is affected by previous experience with an incompatible mapping of visual or auditory stimuli after a 5-min or a week delay. The previous experiment provided evidence that the influence of practice on the visual Simon effect was larger when the practice modality was also visual than when it was auditory. If the transfer effect has the general property of being stronger within stimulus modalities than between stimulus modalities, then the auditory Simon effect should show a larger influence of prior practice with auditory rather than visual stimuli.

Auditory Simon effects are usually larger than visual Simon effects (see, e.g., Proctor & Pick, 1998), indicating that activation of the spatially corresponding response is stronger with auditory stimuli than with visual stimuli. As a consequence, 72 trials of practice may not be sufficient to eliminate the auditory Simon effect. However, if the short-term associations defined in the practice session influence performance in the transfer session, the Simon effect should at least be reduced relative to baseline.

Method

Subjects. One hundred twenty new undergraduates from the same subject pool as that for the previous experiments participated. Twenty-four were assigned to the control condition and 24 to each of the four transfer-delay conditions.

Apparatus, Stimuli, and Procedure. The practice sessions were conducted in the same manner as in Experiment 1. For the Simon transfer session, subjects were instructed to respond to the tone's pitch and ignore its location. The high-pitched tone was 880 Hz, and the low-pitched tone was 220 Hz. The high-pitched tone was assigned to the left response and the low-pitched tone to the right response for half the subjects, and vice versa for the other half. Following incorrect responses, the word "INCORRECT" appeared for 500 msec. A 1-sec intertrial interval was used throughout.

Results

For the practice task, responses were slower and less accurate when the stimuli were auditory ($M_s = 456$ msec

and 8.13%) than when they were visual ($M_s = 404$ msec and 1.89%) [$F_s(1,94) > 12.10$, $p_s < .001$]. For the control Simon task, both RT and PE showed effects of correspondence [$F_s(1,23) = 62.34$ and 10.47 , $MS_e = 483$ and 3.15 , $p_s < .001$ and $.005$, respectively], with Simon effects of 50 msec and 1.65% being evident, as can be seen in Table 2.

Mean RT and PE for the Simon task as a function of practice modality, delay, and correspondence are also shown in Table 2. For RT, the main effect of correspondence was significant [$F(1,92) = 116.32$, $MS_e = 586$, $p_s < .001$], with an overall Simon effect of 38 msec. The only other F ratio to exceed 1.0 was that for correspondence $\times$ delay [$F(1,92) = 3.19$, $p = .078$]. The Simon effect tended to be smaller at the 5-min delay ($MD = 31$ msec) than at the week delay ($MD = 44$ msec). The 31-msec effect at the 5-min delay was significantly smaller than the 50-msec effect obtained in the control condition [$F(1,94) = 7.49$, $p = .007$], but the 44-msec effect at the week delay was not ($F < 1.0$).

For the PE data, the main effect of correspondence was also significant [$F(1,92) = 53.76$, $MS_e = 5.896$, $p < .001$], yielding a 2.57% Simon effect. This overall effect was significantly larger than the 1.65% Simon effect for the control condition [$F(1,190) = 4.54$, $p = .034$]. The only other significant effect was the main effect of practice modality [$F(1,92) = 4.38$, $MS_e = 7.574$, $p = .039$]. The error rate was higher after practice with auditory stimuli ($M = 2.86\%$) than with visual stimuli ($M = 2.03\%$).

Discussion

Unlike the findings in Experiment 1 with visual stimuli, positive Simon effects remained evident at both delays. Moreover, practice modality did not interact significantly with the Simon effect for either RT or PE, indicating that any influence of practice was similar for the two stimulus modalities. For RT, the Simon effect was smaller after practice with an incompatible mapping than for the control condition, but for PE, it was larger. Thus, the evidence suggests at most a small influence of the prior practice on

the magnitude of the auditory Simon effect. The RT data showed a significantly reduced Simon effect at the 5-min delay, this changed to a slightly larger Simon effect at the week delay that did not differ from the control condition, but the interaction of the Simon effect with delay did not attain the .05 level. In summary, the influence of the incompatible mapping on the Simon effect was minimal, regardless of whether the practice modality was auditory or visual.

GENERAL DISCUSSION

In Experiment 1, prior practice with an incompatible spatial mapping influenced the visual Simon effect in two important ways. First, the Simon effect was eliminated when the practice modality was auditory, and it was reversed when the practice modality was visual. This effect of practice modality was statistically reliable, and it suggests, contrary to Tagliabue et al. (2002), that the mechanisms influencing performance of the subsequent Simon task involve both modality-specific and modality-independent (or cross-modal) components. Second, there was no significant effect of delay on the visual Simon effect. In Experiment 2, in which we used an auditory Simon task, the auditory Simon effect was not eliminated or reversed following practice with an incompatible spatial mapping for either practice modality. There also was a tendency in the RT data for the Simon effect to be smaller at the 5-min delay than at the week delay, for which the impact of the prior practice with an incompatible mapping was negligible. Thus, if anything, practice with an incompatible mapping influences the auditory Simon effect less as delay increases. Finally, practice modality had no significant influence on the auditory Simon effect. This outcome differs from that of Experiment 1, in which the visual Simon effect was affected more when the practice modality was visual than when it was auditory.

Tagliabue et al. (2000) reported that, when subjects practiced with an incompatible mapping of visual stimuli, the visual Simon effect showed a larger reversal after a

Table 2
Experiment 2: Mean Reaction Time (RT, in Milliseconds) and Percentage Error (PE) for the Auditory Simon Task in the Control and Transfer Sessions, as a Function of Correspondence, Practice Modality, and Delay

Practice Modality	Correspondence				Simon Effect	
	Corresponding		Noncorresponding		RT	PE
	RT	PE	RT	PE		
Control Condition						
	478	0.57	528	2.23	50	1.65
5-min Delay						
Auditory practice	442	1.80	476	4.70	34	2.90
Visual practice	447	1.16	476	3.17	29	2.01
Week Delay						
Auditory practice	424	1.17	466	3.79	42	2.62
Visual practice	420	0.53	466	3.27	46	2.74

week delay than after a 5-min delay. They attributed this larger effect to the time needed for consolidation of the short-term associations mapping left–right stimulus locations to responses. However, our experiments did not show a larger influence of the prior incompatible mapping on the Simon effect at the week delay than at the 5-min delay. Not only did the influence of the prior incompatible mapping not increase at the long delay in Experiment 1, it tended to decrease in Experiment 2. Thus, our study does not provide evidence for consolidation, a process for which there is little support in other research paradigms (Neath & Surprenant, 2003).

Tagliabue et al. (2002) also concluded that the associations of S–R locations acquired from practice with an incompatible mapping are independent of stimulus modality. However, the results for the visual Simon task in Experiment 1 showed evidence of a modality-specific component in addition to a modality-independent component: The Simon effect reversed when the practice modality was visual but was only eliminated when it was auditory. The results for the auditory Simon task in Experiment 2 did not show any evidence of a modality-specific component: There was no reliable difference in magnitude of the Simon effect as a function of practice modality. However, in that experiment, any effect of the prior practice was minimal, thus allowing little possibility of showing a modality-specific component. Perhaps more extended practice with the incompatible mapping prior to transfer to the auditory Simon task would yield stronger transfer effects and show evidence of modality specificity.

Simon's (1990) original explanation of the Simon effect attributed it to a tendency to respond toward the source of stimulation, primarily on the basis of the large effects that he obtained with auditory stimuli. Several findings indicate that this tendency to respond toward the source of stimulation is stronger for auditory than for visual stimuli. First, outside of the SRC literature, considerable evidence suggests that visual stimuli are less automatically alerting than auditory ones (Posner, Nissen, & Klein, 1976). Second, within the SRC literature, the Simon effect is typically larger for auditory than for visual stimuli (e.g., Pick & Proctor, 1999; Proctor & Pick, 1998), as in the present experiments, implying that activation of the corresponding response is stronger.

The present experiments provided two additional findings consistent with the view that there is a stronger tendency to respond in the direction of auditory stimuli rather than visual stimuli. One is that even at the 5-min delay, the prior practice with an incompatible mapping of S–R locations did not eliminate the auditory Simon effect, although it did eliminate the visual Simon effect. Another is that an incompatible S–R mapping is relatively more difficult when the stimuli are auditory than when they are visual. In both Experiments 1 and 2, responses were slower and less accurate when the practice modality was auditory than when it was visual, a result also obtained by Tagliabue et al. (2002; Tagliabue et al., 2000). Tagliabue and colleagues' studies also included practice conditions for which the lo-

cation mapping was compatible. Whereas Tagliabue et al.'s (2000, Experiments 4 and 5) visual practice conditions yielded an average SRC effect of 97 msec, Tagliabue et al.'s (2002, Experiments 1 and 3) auditory practice conditions yielded an average SRC effect of 146 msec. Thus, an incompatible mapping is particularly problematic with auditory stimuli, which implies that it is more difficult to respond on the basis of short-term associations that are counter to the long-term associations when the stimuli are auditory than when they are visual.

In summary, the present experiments confirm that 72 practice trials with an incompatible mapping of stimulus and response locations is sufficient to eliminate or reverse the visual Simon effect. This elimination is most likely due to the short-term spatial S–R associations defined for the practice task remaining active during the subsequent Simon task. In other words, although these associations are no longer relevant to the current task, they cannot be inhibited completely. Contrary to the prediction of the consolidation hypothesis, there was little evidence of an increase in the influence of these associations over a week delay. However, for the visual Simon task, the influence of the prior incompatible mapping did not diminish across the week. Thus, although the short-term spatial S–R associations do not appear to consolidate over the delay, they do not lose strength. These associations produce activation that is sufficiently strong to eliminate the visual Simon effect even when they have been established for auditory location stimuli and to reverse the effect when they have been established for visual stimuli. The 72 trials of practice with a spatial incompatible mapping did not eliminate the auditory Simon effect, which typically is larger than the visual Simon effect. However, it is likely that the auditory Simon effect can be eliminated or reversed if more extended practice with the incompatible location mapping is given to increase the strength of the short-term spatial associations. If so, a modality-specific component will likely be found for transfer to the auditory Simon task as well.

REFERENCES

- BARBER, P., & O'LEARY, M. (1997). The relevance of salience: Towards an activation account of irrelevant stimulus–response compatibility effects. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus–response compatibility* (pp. 135–172). Amsterdam: North-Holland.
- DE JONG, R. (1995). Strategic determinants of compatibility effects with task uncertainty. *Acta Psychologica*, **88**, 187–207.
- DUNCAN, J. (1977). Response selection rules in spatial choice reaction tasks. In S. Dornic (Ed.), *Attention and performance VI* (pp. 49–61). Hillsdale, NJ: Erlbaum.
- DUTTA, A., & PROCTOR, R. W. (1992). Persistence of stimulus–response compatibility effects with extended practice. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **18**, 801–809.
- HOMMEL, B., & PRINZ, W. (Eds.) (1997). *Theoretical issues in stimulus–response compatibility*. Amsterdam: North-Holland.
- KORNBLUM, S., HASBROUCQ, T., & OSMAN, A. (1990). Dimensional overlap: Cognitive basis for stimulus–response compatibility—A model and taxonomy. *Psychological Review*, **97**, 253–270.
- LOS, S. A. (1996). On the origin of mixing costs: Exploring information processing in pure and mixed blocks of trials. *Acta Psychologica*, **94**, 145–188.

- NEATH, I., & SURPRENANT, A. M. (2003). *Human memory: An introduction to research, data, and theory* (2nd ed.). Belmont, CA: Wadsworth.
- PICK, D. F., & PROCTOR, R. W. (1999). Age differences in the effects of irrelevant location information. In M. Scerbo & M. W. Mouloua (Eds.), *Automation technology and human performance* (pp. 258-261). Mahwah, NJ: Erlbaum.
- POSNER, M. I., NISSEN, M. J., & KLEIN, R. M. (1976). Visual dominance: An information-processing account of its origins and significance. *Psychological Review*, **83**, 157-171.
- PRINZ, W., ASCHERSLEBEN, G., HOMMEL, B., & VÖGT, S. (1995). Handlungen als Ereignisse [Actions as events]. In D. Dörner & E. van der Meer (Eds.), *Das Gedächtnis: Probleme, Trends, Perspektiven* (pp. 129-168). Göttingen: Hogrefe.
- PROCTOR, R. W., & LU, C.-H. (1999). Processing irrelevant location information: Practice and transfer effects in choice-reaction tasks. *Memory & Cognition*, **27**, 63-77.
- PROCTOR, R. W., & PICK, D. F. (1998). Lateralized warning tones produce typical irrelevant-location effects on choice reactions. *Psychonomic Bulletin & Review*, **5**, 124-129.
- PROCTOR, R. W., & REEVE, T. G. (Eds.) (1990). *Stimulus-response compatibility: An integrated perspective*. Amsterdam: North-Holland.
- PROCTOR, R. W., & VU, K.-P. L. (2002). Eliminating, magnifying, and reversing spatial compatibility effects with mixed location-relevant and irrelevant trials. In W. Prinz & B. Hommel (Eds.), *Common mechanisms in perception and action: Attention and performance XIX* (pp. 443-473). Oxford: Oxford University Press.
- PROCTOR, R. W., VU, K.-P. L., & MARBLE, J. G. (2003). Eliminating spatial compatibility effects for location-relevant trials by intermixing location-irrelevant trials. *Visual Cognition*, **10**, 15-50.
- PROCTOR, R. W., & WANG, H. (1997). Differentiating types of set-level compatibility. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus-response compatibility* (pp. 11-37). Amsterdam: North-Holland.
- SIMON, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus-response compatibility: An integrated perspective* (pp. 31-86). Amsterdam: North-Holland.
- TAGLIABUE, M., ZORZI, M., & UMILTÀ, C. (2002). Cross-modal remapping influences the Simon effect. *Memory & Cognition*, **30**, 18-23.
- TAGLIABUE, M., ZORZI, M., UMILTÀ, C., & BASSIGNANI, F. (2000). The role of LTM links and STM links in the Simon effect. *Journal of Experimental Psychology: Human Perception & Performance*, **26**, 648-670.
- ZORZI, M. & UMILTÀ, C. (1995). A computational model of the Simon effect. *Psychological Research*, **58**, 193-205.

(Manuscript received January 15, 2003;
revision accepted for publication May 30, 2003.)