THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2009, 62 (4), 746–765

Psychology Press
Taylor & Francis Group

Transfer of orthogonal stimulus–response mappings to an orthogonal Simon task

Gi Yeul Bae and Yang Seok Cho
Korea University, Seoul, Korea

Robert W. Proctor
Purdue University, West Lafayette, IN, USA

When up–down stimulus locations are mapped to left–right keypresses, an overall advantage for the up–right/down–left mapping is often obtained that varies as a function of response eccentricity. This orthogonal stimulus–response compatibility (SRC) effect also occurs when stimulus location is irrelevant, a phenomenon called the orthogonal Simon effect, and has been attributed to correspondence of stimulus and response code polarities. The Simon effect for horizontal stimulus–response (S–R) arrangements has been shown to be affected by short-term S–R associations established through the mapping used for a prior SRC task in which stimulus location was relevant. We examined whether such associations also transfer between orthogonal SRC and Simon tasks and whether correspondence of code polarities continues to contribute to performance in the Simon task. In Experiment 1, the orthogonal Simon effect was larger after practising with an up–right/down–left mapping of visual stimuli to responses than with the alternative mapping, for which the orthogonal Simon effect tended to reverse. Experiment 2 showed similar results when practice was with high (up) and low (down) pitch tones, though the influence of practice mapping was not as large as that in Experiment 1, implying that the short-term S–R associations acquired in practice are at least in part not modality specific. In Experiment 3, response eccentricity and practice mapping were shown to have separate influences on the orthogonal Simon effect, as expected if both code polarity and acquired S–R associations contribute to performance.

Keywords: Orthogonal SRC; Simon effect; Transfer of learning; Polarity correspondence; Stimulus–response compatibility.

In a spatial binary classification task, performance is better when the locations of a stimulus and response are compatible than when they are not. For example, when lateralized responses are made to a horizontally arrayed stimulus set, reaction time (RT) is shorter when the left response is mapped to the left stimulus and the right response to the right stimulus than when the mapping is

Correspondence should be addressed to Yang Seok Cho, Department of Psychology, Korea University, Anamdong, Seongbuk-Gu, Seoul, Korea 136-701. E-mail: yscho_psych@korea.ac.kr

This research was supported in part by the Korea Science and Engineering Foundation (KOSEF) Grant funded by the Korean Government (MOST-2006-05110) and by U.S. Army Research Office Grant W9112NF-05-0153.

http://www.psypress.com/qjep
DOI:10.1080/17470210802303883

opposite. This spatial correspondence effect is called a *stimulus–response compatibility* (SRC) effect (see Proctor & Vu, 2006). The SRC effect also occurs when stimulus location is not relevant to response selection. When participants are instructed to respond to the colour of the stimulus and to ignore its location, performance is faster and more accurate when the stimulus location corresponds to that of the response than when it does not. This phenomenon is called the *Simon effect* (see Hommel & Prinz, 1997).

Kornblum, Hasbroucq, and Osman (1990) proposed a model, called the dimensional overlap model, to explain the SRC and Simon effects. According to this model, response-selection processes consist of two separate response-activation routes, automatic and intentional. The automatic route is activated when there is perceptual, conceptual, or structural overlap (or similarity) between stimulus and response dimensions (Kornblum & Lee, 1995). The intentional route is activated by the participants' purpose of responding to the stimuli as instructed, regardless of whether there is overlap between the stimulus and response dimensions. The model suggests that responses are slower and less accurate when these two routes activate different responses than when they activate the same response because an additional process is required to inhibit the activation of the incorrect response produced by the automatic route.

Barber and O'Leary (1997) explained these two routes in terms of memory associations between stimulus and response locations. According to them, the automatic route is activated by long-term associations between stimulus and response locations, which are innate or created by a lifetime of experiences. The intentional route, however, is activated by short-term associations between stimulus and response locations, as defined by task instructions. Barber and O'Leary attributed both the SRC and Simon effects to conflict between responses activated by the long-term and short-term associations. If these two types of associations activate the same response, performance is fast and accurate. However, if not, the conflict must be resolved, resulting in slower and less accurate responses.

Recently, several studies found that the Simon effect is influenced by the short-term associations created through a brief period of practice with an SRC task for which stimulus location is relevant. Tagliabue, Zorzi, Umiltà, and Bassignani (2000) had participants practise with an incompatible or compatible mapping of stimulus locations to responses for 72 trials and then to perform a Simon task. The Simon effect was nonsignificant or was reversed after practice with the incompatible SRC task, whereas it was positive after practice with the compatible SRC task. Other studies showed that the visual Simon effect in the transfer session is also eliminated following a brief period of practice with an incompatible mapping of left and right tones to left–right keypress responses (Tagliabue, Zorzi, & Umiltà, 2002; Vu, Proctor, & Urcuioli, 2003). Tagliabue et al. (2000) conducted computer simulations of the transfer effect using a computational model developed by Zorzi and Umiltà (1995), which distinguishes short-term and long-term associations, or links (see Figure 1, Panel A). They concluded that the results supported the hypothesis "that the STM [short-term memory] links set up to perform the spatially incompatible task (i.e., a conditional pathway) are still active when the Simon task is later performed" (Tagliabue et al., 2002, p. 19; see Figure 1, Panel B, for a depiction). Because the new S–R associations formed when practising with an incompatible mapping produce activation of the noncorresponding response, this activation counters the activation of the corresponding response through long-term associations that produce the standard Simon effect.

Though SRC effects have been studied most thoroughly for situations in which the stimulus and response sets vary along the same dimension (i.e., their orientations are parallel), SRC effects also occur when the stimulus and response sets vary along orthogonal spatial dimensions. Such effects are called *orthogonal SRC effects*. For "up" and "down" stimuli mapped to left and right responses, two types of orthogonal SRC effect occur (Lippa & Adam, 2001). The first is an up–right/down–left mapping advantage: Performance often is faster and more accurate with the up–right/down–left mapping than with the up–left/

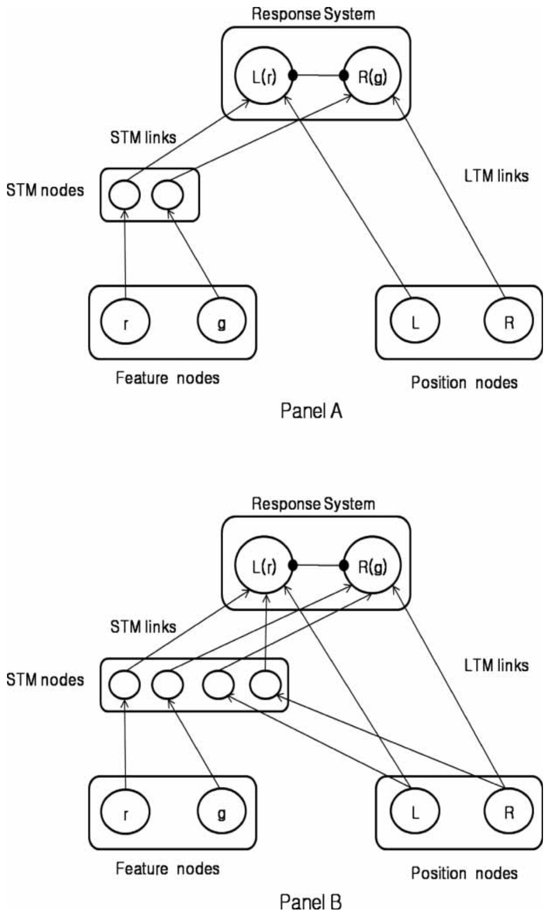

Figure 1. *Zorzi and Umiltà's (1995) connectionist model of the Simon effect (Panel A) and the modified version of the model with additional short-term memory links for stimulus locations proposed by Tagliabue et al. (2000) to characterize the Simon task when performed after practice with an incompatible location mapping (Panel B). L = left; R = right; g = green; r = red; STM = short-term memory; LTM = long-term memory.*

down–right mapping (see Cho & Proctor, 2003). This advantage has been reported within and between various stimulus and response modes (e.g., location words and vocal responses; Weeks & Proctor, 1990). Since orthogonal stimulus and response dimensions do not overlap perceptually or conceptually, the up–right/down–left advantage is most likely due to a form of structural similarity. Cho and Proctor (2003; Proctor & Cho, 2006) have summarized evidence for a multiple asymmetric coding account, according to which this structural similarity arises from the asymmetric nature of categorical spatial codes (e.g., Kosslyn, Thompson, Gitelman, & Alpert, 1998; Logan, 1995). On this account, members of the stimulus and response sets are coded asymmetrically, one as + polarity and the other as − polarity (e.g., Seymour, 1974), with performance being better for the mapping that maintains correspondence of the code polarities. Independent evidence indicates that "up" and "right" are coded as + polarity and "down" and "left" as − polarity in a variety of tasks (e.g., Clark & Chase, 1972; Olson & Laxar, 1973; Seymour, 1974), and thus correspondence of the code polarities exists for the up–right/down–left mapping but not the up–left/down–right mapping.

The second type of orthogonal SRC effect is one that varies with hand or response location (Lippa & Adam, 2001), changes of which we call the *response eccentricity effect*: When lateralized responses are made at different response positions (centred at body midline, to the left of centre, or to the right of centre), the up–right/down–left advantage obtained at body midline increases when responses are made at the right position and tends to reverse to an up–left/down–right advantage when they are made at the left position (Cho & Proctor, 2002; Michaels, 1989; Weeks, Proctor, & Beyak, 1995). According to the multiple asymmetric codes account, the response position is represented as left or right relative to one or more reference frames (e.g., stimulus set location, body midline, etc.; Cho & Proctor, 2005), with the response consistent with the response position receiving a + polarity code and the response inconsistent with the position receiving a − polarity code for each reference frame (see Cho & Proctor, 2003, for details). The overall polarities of the left and right responses are determined by the combined contributions of these polarity codes and the polarity codes that produce the up–right/down–left advantage when the response position is neutral (e.g., centred at body midline). When the response position is right, the right response receives additional + polarity codes because it is consistent with the response position, and the up–right/down–left advantage increases. When the response position is left, the left response receives the + polarity codes because it is consistent with the response position, and correspondence of the up stimulus with these + polarity codes for the left response counters the up–right/down–left advantage, eliminating or reversing it.

Both kinds of orthogonal SRC effect have been obtained when stimulus location is task irrelevant (Cho, Proctor, & Yamaguchi, 2008; Nishimura & Yokosawa, 2006), a phenomenon called the orthogonal Simon effect. Nishimura and Yokosawa's Experiment 1 showed a 12-ms up–right/down–left advantage when participants were to respond to stimulus colour with left–right bimanual keypresses and to ignore whether the stimulus appeared above or below a fixation cross. Their Experiment 2 showed the response eccentricity effect: A nonsignificant 4-ms up–right/down–left advantage at the centre response position increased to a significant 16-ms up–right/down–left advantage at the right response position and reversed to a significant 9-ms up–left/down–right advantage at the left response position. Cho et al. (2008) replicated Nishimura and Yokosawa's (2006) results with unimanual left–right toggle-switch responses instead of bimanual keypresses. In line with the results of Nishimura and Yokosawa, the up–right/down–left advantage was −4 ms, 6 ms, and 18 ms at the left, middle, and right response positions. As evident in these experiments and others, although when stimulus location is irrelevant there is typically an RT advantage for the up–right/down–left relation when responding at a centred position, this advantage is small and often nonsignificant (averaging 6 ms across the three experiments in Cho et al.'s and Nishimura and Yokosawa's studies for which the responses were keypresses; see Cho et al., 2008, for discussion).

Simon effects obtained when there is perceptual or conceptual overlap of stimulus and response sets on any dimension, spatial or nonspatial, are usually attributed to activation produced through the long-term associations of the automatic route (Proctor & Vu, 2006). Assuming that the same principle applies to structural overlap, the results of Nishimura and Yokosawa (2006) and Cho et al. (2008) showing an orthogonal Simon effect imply that activation is produced automatically through long-term associations between stimulus and response codes of the same polarity. That is, the associations of stimulus and response codes of corresponding polarity are "hard wired". In the Simon task, the intentional route is activated by short-term, task-defined associations between the relevant stimulus attribute (e.g., colour) and responses. Response selection is delayed when the activation produced by these two types of association conflicts compared to when it does not, causing the orthogonal Simon effect.

No prior studies have been conducted examining transfer of practice with an orthogonal S–R mapping to performance of a subsequent orthogonal Simon task. The closest study is that of Vu (2007), which examined conditions in which the orientation of parallel stimulus and response dimensions was vertical for the practice trials and horizontal for the transfer Simon trials, or vice versa, such that the S–R dimensions were parallel with practice and transfer tasks but orthogonal between the tasks. She found no transfer from an SRC task in one dimension to a Simon task in the other after 72 practice trials, although some transfer became evident after more extended practice of several hundred trials. It should be noted, though, that when stimulus and response dimensions are parallel within a task, as in Vu's study, there is perceptual and conceptual overlap between the stimulus and response dimensions for each task, and not just the structural overlap of code polarity that is present when the stimulus and response dimensions are orthogonal.

For an orthogonal SRC task, the instructions map the up and down stimulus locations to the left and right response locations, and these short-term associations provide the basis for task performance. If the orthogonal Simon effect in a subsequent transfer session is a consequence of the combined activation produced by short-term and long-term S–R associations, as is the case for the more typical parallel Simon effect, then the orthogonal Simon effect should also be affected systematically by the prior short-term

S−R associations established by practice with an orthogonal mapping. Specifically, if practice with an orthogonal S−R mapping creates new short-term associations between stimulus and response locations that remain active during the subsequent orthogonal Simon task, then the stimulus should automatically activate the previously assigned response. Consequently, the orthogonal Simon effect should be larger following practice with the up−right/down−left mapping than with the up−left/down−right mapping. Note that short-term associations would not be expected to be established between the polarity codes that underlie the base orthogonal SRC and Simon effects because the practice task is defined with respect to mappings of specific stimuli to specific responses.

One implication of the multiple-codes view is that performance of a single task can be influenced by both polarity correspondence and other forms of correspondence. Because the response activation of the previously assigned response produced by way of the short-term S−R location associations established through practice is separate from that produced by polarity correspondence through long-term associations, polarity correspondence should still contribute to the Simon effect in the transfer session. Since polarity correspondence tends to produce an advantage for the up−right/down−left relation that would contribute to performance regardless of practice mapping, a contribution of polarity correspondence should be evident in an overall up−right/down−left advantage when averaging across practice mappings.

The purpose of the present study thus was to test whether new short-term associations between vertical stimulus locations and horizontally arrayed responses formed from practice of a task with an orthogonal S−R mapping modulate the orthogonal Simon effect in a subsequent transfer task and, if so, whether the Simon effect reflects joint contributions of those associations and polarity correspondence. Experiment 1 was designed to establish the basic transfer effect from an orthogonal visual SRC task to an orthogonal visual Simon task: Participants practised for 72 trials with one of the two mappings of up and down visual stimulus locations to left and right responses and then performed a visual Simon task. The purpose of Experiment 2 was to determine whether the associations underlying transfer between orthogonal tasks, for which there is no perceptual and conceptual S−R overlap, are mode independent, as for parallel tasks that have both of those types of overlap. That experiment was similar to Experiment 1 except that the visual orthogonal SRC practice task was replaced with an auditory orthogonal SRC practice task in which high (up) and low (down) pitch tones were mapped to the left and right keypresses. Experiment 3 was conducted to provide a strong demonstration of the contribution of polarity correspondence to the orthogonal Simon effect in the transfer session: Response position for the orthogonal Simon task was manipulated, and the prediction was that a typical response eccentricity effect would be observed following performance with either practice mapping.

EXPERIMENT 1

In Experiment 1 participants practised an orthogonal SRC task with up−right/down−left or up−left/down−right mapping, and then they performed an orthogonal Simon task for which stimulus colour was relevant and stimulus location irrelevant. If the orthogonal Simon effect is affected by short-term associations between the stimulus and response locations acquired in the preceding orthogonal SRC task, then the overall up−right/down−left advantage should be larger after practice with the up−right/down−left mapping than with the up−left/down−right mapping.

The design of this experiment and the others was not optimal for showing a statistically significant up−right/down−left mapping advantage in the practice session because mapping was a between-subject variable. With keypress responses made at locations centred about body midline, the up−right/down−left advantage is sometimes nonsignificant in between-subject designs due to high error variability (e.g., Weeks & Proctor, 1990, Exp. 2). However, demonstrating a reliable mapping advantage in the practice session is not crucial to the purpose of the present study because the transfer effects to the Simon task are presumed to be due to the practised mapping of stimulus locations to response locations, regardless of which mapping that was. Evidence in support of this point is provided in the Discussion section.

Method

Participants

A total of 40 undergraduates (17 male and 23 female) who were enrolled in the course Art Psychology or Brain and Human Society at Korea University participated in partial fulfilment of a course requirement. All were right-handed and had normal colour vision and normal or corrected-to-normal visual acuity as determined by self-report. They were randomly assigned to the two different mapping practice groups: up−right/down−left mapping (7 male and 13 female) and up−left/down−right mapping (10 male and 10 female).

Apparatus and stimuli

E-prime software (Schneider, Eschman, & Zuccolotto, 2002) was used to programme the experiment. Stimuli were presented on the display screen of a microcomputer. Responses were made by pressing the leftmost or rightmost key among five keys on a Micro Experimental Laboratory 2.0 response box with the left and right index fingers. Viewing distance was approximately 60 cm.

In the practice session, the imperative stimulus for the orthogonal SRC task was a white square (0.8 cm × 0.8 cm, $0.7^\circ \times 0.7^\circ$), which was randomly presented 2.2 cm (2.1°) above or below a white fixation row "XXX" (0.5 cm × 0.5 cm, $0.4^\circ \times 0.4^\circ$ for each X) on a dark background. In the transfer session, stimuli for the orthogonal Simon task were red and blue squares that were the same size as the white stimuli presented at practice session. Each colour square was presented randomly 2.2 cm above or below the fixation row.

Procedure

The experiment took place in a soundproof room with dim light. Participants were instructed to align body midline with the centre of the screen and to put the left and right index fingers on the left and right keys of the response box. The experiment consisted of two sessions: an orthogonal SRC practice session and orthogonal Simon-task transfer session. In the practice session, participants were divided into two groups: One group performed the orthogonal SRC task with the up−right/down−left mapping, whereas the other performed with the up−left/down−right mapping. Each participant received 12 warm-up trials and 72 main trials for the practice session. After finishing the practice session, participants took a 5-min break and then performed the orthogonal Simon task session, which was composed of 12 warm-up trials and 144 main trials. For the orthogonal Simon task, half of the participants in each group pressed the left key for the blue square and the right key for the red square, and the other half performed with the opposite colour−response mapping.

At the beginning of both tasks, the fixation row was presented at the centre of the screen. Participants were instructed to stare at it. After 500 ms, the imperative stimulus was presented above or below the fixation row. The stimulus remained on until the response was made. A 500-Hz tone was given for 500 ms as feedback through the exterior speaker when an incorrect response was made. The fixation row for the next trial came on 1,000 ms after the response or the error feedback.

Results

RTs shorter than 125 ms and longer than 1,250 ms were excluded from data analysis as outliers (<1.0%). For the practice session, mean correct reaction time (RT) and percentage error (PE) were 303 ms and 0.34% for the up−right/down−left mapping and 316 ms and 0.83% for the up−left/down−right mapping, Fs(1, 39) = 1.71 and 1.87, ps = .19 and .17.

For the transfer session, mean correct RT and PE were calculated for each participant as a function of correspondence (up–right and down–left as corresponding; up–left and down–right as noncorresponding). Analyses of variance (ANOVAs) were conducted on the RT and PE data, with correspondence as a within-subject factor and practice mapping (up–right/down–left; up–left/down–right) as a between-subject factor. Of most concern was the interaction of correspondence and practice mapping.

Reaction time

A significant overall orthogonal Simon effect was obtained, $F(1, 38) = 5.11$, $p = .0297$, $MSE = 194$: Responses were 7 ms faster for the up–right/down–left trials ($M = 375$ ms) than for the up–left/down–right trials ($M = 382$ ms). The main effect of practice mapping was not significant, $F(1, 38) < 1.0$, but the interaction with correspondence was, $F(1, 38) = 35.47$, $p < .0001$, $MSE = 194$ (see Table 1). Participants who practised the orthogonal SRC task with the up–right/down–left mapping showed a significant 26-ms orthogonal Simon effect, $F(1, 38) = 24.60$, $p < .0001$, $MSE = 194$, whereas those who practised it with the up–left/down–right mapping showed a significant −11-ms reversed orthogonal Simon effect, $F(1, 38) = 12.01$, $p = .001$, $MSE = 194$. Thus, practice with the mapping consistent with the up–right/down–left relation produced a larger orthogonal Simon effect than practice with the mapping that was inconsistent with that relation, and the positive Simon effect following practice with the consistent mapping was larger than the negative Simon effect following practice with the inconsistent mapping, as indicated by the significant positive correspondence main effect.

Percentage error

Overall PE was 1.52%. Practice mapping was not significant, $F(1, 38) < 1.0$. However, a significant overall orthogonal Simon effect was obtained, $F(1, 38) = 4.97$, $p = .0317$, $MSE = 3.21$: PE was less for the up–right/down–left trials ($M = 0.99\%$) than for the up–left/down–right trials ($M = 1.89\%$). Practice mapping and correspondence interacted, $F(1, 38) = 11.81$, $p = .0014$, $MSE = 3.21$. For participants who practised with the up–right/down–left mapping responses were more accurate on up–right/down–left trials than on up–left/down–right trials (Ms = 0.53% and 2.80%, respectively), $F(1, 38) = 16.05$, $p < .001$, $MSE = 3.21$. However, for those who practised with the up–left/down–right mapping, there was no significant difference between the up–right/down–left and up–left/down–right trials (Ms = 1.46% and 0.97%, respectively), $F < 1$. The PE results are thus in agreement with the RT results.

Discussion

The results confirm that the orthogonal Simon effect in the transfer session was influenced by the S–R associations between vertical stimulus positions and horizontal response locations acquired in the practised orthogonal SRC task. An orthogonal Simon effect of 26 ms, favouring

Table 1. *Experiment 1: Mean reaction time and percentage of error for the visual orthogonal Simon task after visual practice, as a function of practice mapping and correspondence*

	Correspondence					
	Corresponding		*Noncorresponding*		*Orthogonal Simon effect*	
Practice mapping	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Up–right/down–left	364	0.53	390	2.80	26	2.27
Up–left/down–right	386	1.46	375	0.97	− 11	− 0.49

Note: RT = mean reaction time (in ms). PE = percentage of error.

the up–right/down–left relation, was found when participants practised with the up–right/down–left mapping. However, the orthogonal Simon effect reversed to a significant −11 ms, favouring the up–left/down–right relation, when participants practised with the up–left/down–right mapping. Without prior practice of an orthogonal SRC task, previous studies have reported orthogonal Simon effects with keypress responses ranging from 3 to 12 ms (Cho et al., 2008; Nishimura & Yokosawa, 2006), suggesting approximately equal influences of practice with the two mappings of vertical stimulus locations to horizontal response locations.

To verify that practice with the up–right/down–left mapping increases the subsequent orthogonal Simon effect but practice with the up–left/down–right mapping decreases it, we tested 20 additional participants who performed the orthogonal Simon task as in Experiment 1, but without prior performance of the SRC task. The participants in this no-practice control condition showed a nonsignificant orthogonal Simon effect of 11 ms, $F(1, 38) = 1.17$, $p = .2854$, $MSE = 1,066$. An ANOVA including all three practice conditions (up–left/down–right mapping; no orthogonal SRC practice; up–right/down–left mapping) and correspondence as independent variables showed a significant interaction, $F(2, 57) = 17.82$, $p < .0001$, $MSE = 196$, indicating that the orthogonal Simon effect differed reliably across conditions. Separate ANOVAs comparing the no-practice control with each practice condition showed significant two-way interactions of practice mapping and correspondence for the up–right/down–left mapping, $F(1, 38) = 6.00$, $p = .0190$, $MSE = 173$, and the up–left/down–right mapping, $F(1, 38) = 11.60$, $p = .0016$, $MSE = 222$. Thus, both the larger orthogonal Simon effect after practice with the up–right/down–left mapping and the negative orthogonal Simon effect after practice with the up–left/down–right mapping differed from the effect in the no-practice control condition.

For each practice mapping, we also compared performance for the two trial types, corresponding and noncorresponding, to that for the no-practice condition. For the up–right/down–left practice condition, on noncorresponding trials, the mean RT of 390 ms was longer than that of 369 ms for the no-practice condition, $F(1, 38) = 24.08$, $p < .0001$, $MSE = 173$; on corresponding trials, though, there was no significant difference (up–right/down–left practice, 364 ms; no practice, 358 ms), $F(1, 38) = 2.08$, $p < .1573$, $MSE = 173$. In contrast, for the up–left/down–right practice condition, on noncorresponding trials there was no difference in RT (up–left/down–right practice, 375 ms; no practice, 369 ms), $F(1, 38) = 1.18$, $p = .2823$, $MSE = 222$; but, on corresponding trials, the mean RT of 386 ms was longer following the up–left/down–right practice than that of 358 ms with no practice, $F(1, 38) = 34.94$, $p < .0001$, $MSE = 222$. These results suggest that the main consequence of practice with a prior orthogonal location mapping is to lengthen RT on those trials for which the response consistent with that mapping is not the one that is to be made. However, this conclusion rests on an assumption that overall RT is not lengthened much by the prior practice with a particular mapping, which seems questionable since the practised mapping adds another source of noise to the response-selection process.

That both the compatible up–right/down–left mapping and less compatible up–left/down–right mapping influenced the orthogonal Simon effect in the transfer session is in contrast to results obtained by Tagliabue et al. (2000) with the SRC and Simon tasks for parallel dimensions. Although they found the Simon effect for left and right locations to be eliminated or reversed after 72 practice trials with an incompatible spatial mapping, practice with a compatible mapping had no influence on the Simon effect in the transfer session. The results of the present experiment suggest that the critical factor is spatial correspondence in terms of perceptual or conceptual similarity. When a stimulus tends to automatically activate its spatially corresponding response, prior practice with a spatially compatible mapping does not provide any additional tendency to automatically activate the corresponding response. In contrast, when the only relation between stimuli and responses is the structural similarity of polarity codes, then establishing associations between specific stimulus and response locations affects response activation regardless of the mapping.

Finally, it is important to note that there was an overall positive orthogonal Simon effect of 7 ms, which is in the range obtained without prior performance of the orthogonal SRC task. Another way of describing this result is that the negative Simon effect after practice with the up–left/down–right mapping (−11 ms) was not as large as the positive Simon effect after practice with the up–right/down–left mapping (26 ms). This finding provides evidence that the orthogonal Simon effect was also influenced by the long-term polarity associations. These associations would contribute an advantage for the up–right/down–left mapping in both practice conditions, resulting in the asymmetry of results that yielded the overall up–right/down–left advantage. In sum, the results indicate that the activation produced by the short-term S–R location associations established through practice makes a contribution to the orthogonal Simon effect in the transfer session that is separate from the contribution produced by polarity correspondence through long-term associations.

EXPERIMENT 2

For Simon tasks in which the stimulus and response dimensions are parallel, practice with a spatially incompatible S–R mapping of left–right tones to keypresses influences the Simon effect in a transfer task for which the stimuli are left–right visual locations. Tagliabue et al. (2002) had participants perform the visual Simon task 5 minutes, 24 hours, or 7 days after practising an auditory compatible or incompatible SRC task for 72 trials. For all three delays, a positive Simon effect was evident after practice with the compatible mapping but not after practice with the incompatible mapping. Vu et al. (2003) replicated these results of auditory to visual transfer, although the transfer to the visual Simon effect was smaller when the stimuli for the practice stimuli were auditory than when they were visual. The transfer from auditory to visual tasks when the S–R dimensions are parallel implies that the associations underlying the transfer effect involve spatial codes that are to at least some extent supramodal—that is, not specific to a stimulus modality.

As noted earlier, for parallel S–R sets, the stimuli and responses overlap both conceptually and perceptually. For orthogonal S–R sets, however, the stimuli and responses have neither conceptual nor perceptual overlap because they are arrayed along different dimensions. If associations between supramodal spatial codes are formed only when conceptual and/or physical overlap exists between stimulus and response sets, then transfer from an auditory orthogonal SRC task to a visual orthogonal Simon task should not occur. However, if supramodal associations are formed and transferred even when the dimensions lack conceptual and physical overlap, then practice with auditory stimuli should transfer to the visual Simon task with orthogonal arrangements.

Experiment 2 thus used a procedure similar to that of Experiment 1, but with the stimuli for the practice task being auditory rather than visual. The purpose was to determine whether the transfer effect across orthogonal SRC and Simon tasks observed in Experiment 1 was due to associations between supramodal stimulus and response codes. In the auditory orthogonal SRC task, participants were instructed to press a left or right key to a high or low pitch tone presented through a headphone. Parallel SRC effects are obtained for high and low pitches mapped to up–down responses (Rusconi, Kwan, Giordano, Umiltà, & Butterworth, 2006; Walker & Ehrenstein, 2000), which can be interpreted as "indicating that pitch is treated spatially" (e.g., Walker & Ehrenstein, 2000, p. 15). Moreover, Rusconi et al. (2006) found a 16.5-ms advantage for the mapping of high pitch (up) to right and low pitch (down) to left, which fell just short of the .05 level ($p = .054$). However, previous studies showing transfer from auditory SRC to visual Simon tasks with parallel mappings have used physical locations for the auditory dimension (Tagliabue et al., 2002; Vu et al., 2003). Thus, a transfer effect in the present study would provide the additional information that cross-modal transfer can occur even when the vertical spatial dimension for the auditory practice task is implicit rather than explicit. Failure to obtain a transfer effect would still leave open the possibility, though, that one could occur across modalities if auditory location were explicitly varied.

Method

Participants

A total of 40 undergraduates (3 male and 37 female) who were enrolled in the course Introductory Psychology at Duksung Women's University or Brain and Human Society at Korea University participated in partial fulfilment of a course requirement. All were right-handed and reported having normal colour vision and normal or corrected-to-normal visual acuity. They were randomly assigned to the two mapping practice groups (3 male and 17 female for the high-right/low-left mapping and 20 female for the high-left/low-right mapping).

Apparatus, stimuli, and procedure

Apparatus and procedure were identical to those of Experiment 1. The only exception was that brief tones, instead of visual stimuli, were used in the practice session. The tones were presented bilaterally through headphones. A middle-pitch tone of 500 Hz was presented for 500 ms as a referent. After another 500 ms, a high (1,000-Hz) or low (250-Hz) pitch tone was presented for 500 ms. For the high-right/low-left mapping group, participants were instructed to press the right key to the high pitch tone and the left key to the low pitch tone. For the high-left/low-right mapping group, the instructions were the opposite. The word "Incorrect" in red was presented for 500 ms following an incorrect response. After finishing 72 auditory practice trials, a 5-min break was given, and participants then performed the visual orthogonal Simon task, which was identical to that in Experiment 1.

Results

For the practice task, RT tended to be shorter for the high-right/low-left mapping ($M = 363$ ms; PE = 0.27%) than for the high-left/low-right mapping ($M = 382$ ms; PE = 0.41%), but this difference, as well as that for errors, was not significant, $F\text{s} \leq 1.21$, $p\text{s} > .27$.

For the Simon task, with the same exclusion criteria as those in Experiment 1, 0.16% of the trials were excluded from analysis. Mean RT and PE were calculated for each participant and were analysed as in that experiment.

Reaction time

The main effect of practice mapping was not significant, $F < 1$. Although the overall orthogonal Simon effect did not quite attain the .05 level, $F(1, 38) = 3.61$, $p = .06$, $MSE = 219$, the up−right/down−left trials tended to show shorter mean RT than the up−left/down−right trials (368 vs. 374 ms), as in Experiment 1. Of importance, the interaction of practice mapping and correspondence was significant, $F(1, 38) = 6.82$, $p = .01$, $MSE = 219$ (see Table 2). When participants practised the orthogonal SRC task with the high-right/low-left mapping, an orthogonal Simon effect of 15 ms was evident, $F(1, 38) = 10.21$, $p = .003$, $MSE = 219$. However, when they practised with the high-left/low-right mapping, the Simon effect was a nonsignificant −2 ms, $F < 1$.

Percentage error

There was no significant difference in PE as a function of practice mapping, $F < 1$. The main effect of correspondence was significant, $F(1, 38) = 10.11$, $p = .002$, $MSE = 2.92$. PE was less for the up−right/down−left trials (1.14%) than for the up−left/down−right trials (2.36%). Finally, though the interaction of practice mapping and correspondence was not significant, $F(1, 38) = 2.39$, $p = .13$, $MSE = 2.92$, it showed a numerical trend consistent with the RT data

Table 2. *Experiment 2: Mean reaction time and percentage of error for the visual orthogonal Simon task after auditory practice, as a function of practice mapping and correspondence*

	Correspondence					
	Corresponding		*Noncorresponding*		*Orthogonal Simon effect*	
Practice mapping	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Up−right/down−left	354	1.04	369	2.84	15	1.8
Up−left/down−right	381	1.25	379	1.87	−2	0.6

Note: RT = mean reaction time (in ms). PE = percentage of error.

(see Table 2). There was a 1.80% orthogonal Simon effect after practice with the high-right/low-left mapping compared to 0.6% after practice with the high-left/low-right mapping.

Discussion

The results of Experiment 2 were similar to those of Experiment 1. The mapping used for the auditory orthogonal SRC task in the practice session affected performance on the visual orthogonal Simon task in the transfer session: The orthogonal Simon effect was 15 ms and 1.8% when the practice mapping was high-right/low-left and −2 ms and 0.6% when the practice mapping was high-left/low-right. This result indicates that the short-term S−R associations established with the auditory stimuli transferred to the subsequent visual Simon task, providing evidence that these associations are not modality specific. When compared to the no-practice control condition described in the Discussion of Experiment 1, the orthogonal Simon effect for the up−right/down−left practice condition did not differ reliably from that for the no-practice condition, $F(1, 38) < 1$, whereas the difference in orthogonal Simon effects for the up−left/down−right practice and no-practice conditions approached statistical significance, $F(1,\ 38) = 3.94$, $p = .0545$, $MSE = 233$. Not much can be made of these comparisons, though, since the range of the practice effects was smaller than that in Experiment 1, and, as noted previously, the orthogonal Simon effect for the no-practice control condition is to the high end of those reported previously in the literature, which average 6 ms.

In prior studies showing transfer of an incompatible auditory mapping to a visual Simon task, not only have the dimensions for the practice and transfer tasks been parallel (left and right stimulus locations for both tasks) but also the stimuli for the auditory practice task have varied in physical location. Thus, the present results are unique in demonstrating that transfer of the short-term associations acquired in practice with auditory stimuli can occur both when the dimensions are orthogonal and when the spatial dimension for the stimuli is implicit (high versus low pitch) rather than explicit. In this experiment, practice with the auditory orthogonal SRC task apparently linked the "high" (or "up") and "low" (or "down") stimulus codes with the "right" and "left" response codes. The up and down stimulus codes activated their linked response codes when a visual stimulus was present in the orthogonal Simon task. This activation was consistent with the natural tendency for an up−right/down−left advantage when the practice mapping associated up with right and down with left and counter to it when the practice mapping associated up with left and down with right. Although the F ratio for the overall up−right/down−left advantage did not quite attain the .05 level in the RT data, it was evident in the means (6 ms) and significant in the PE data (1.2%), consistent with the conclusion from Experiment 1 that polarity correspondence continues to make a contribution to performance that is separate from that of the short-term associations acquired in the practice task.

To compare the influences of the visual and auditory practice modalities on the orthogonal Simon transfer task, mean RT and PE of Experiments 1 and 2 were submitted to 2 (practice modality: visual or auditory) × 2 (practice mapping) × 2 (correspondence) ANOVAs. As expected, for both RT and PE, practice mapping had no significant main effect, but the main effect of correspondence and interaction of correspondence with practice mapping were significant. Of most concern was the influence of practice modality, for which all F ratios were less than 1.0 except that for the three-way interaction of practice modality, practice mapping, and correspondence for RT, which was significant, $F(1, 76) = 4.74$, $p = .03$, $MSE = 206$. This interaction indicates that the effect of practice mapping on the orthogonal Simon effect was larger when the stimuli were visual in Experiment 1 (26 ms minus −11 ms = 37 ms) than when they were auditory in Experiment 2 (15 ms minus −2 ms = 17 ms). This between-experiment comparison suggests that there may be a modality-specific component for the visual practice stimuli in Experiment 1 in addition to the supramodal component that affects performance in both experiments. Alternatively, the smaller transfer effect in Experiment 2 could be due to the vertical spatial dimension for the auditory practice stimuli being implicit rather than explicit.

EXPERIMENT 3

The results of Experiments 1 and 2 imply that the long-term polarity associations continued to affect performance in the transfer sessions because an overall up−right/down−left advantage was evident for RT (significantly in Experiment 1 but not Experiment 2) and PE (significant in both experiments) in the transfer Simon task. Another signature of polarity correspondence is the influence of response eccentricity on the orthogonal Simon effect: A small, often nonsignificant, advantage for the up−right/down−left pairing at the centre response position increases when responding is to the right of body midline and tends to reverse to favour the up−left/down−right pairing when responding is to the left of midline (Cho et al., 2008; Nishimura & Yokosawa, 2006). Considerable evidence indicates that this response eccentricity effect for orthogonal SRC and Simon effects is also due to correspondence of stimulus and response code polarities. Representation of the response position as left or right introduces polarity codes for the respective response alternatives, with the response that is consistent with the response position being coded as + polarity and the other response as − polarity (Cho & Proctor, 2003; Cho et al., 2008; Proctor & Cho, 2006). That an overall up−right/down−left advantage is often present suggests that the code polarities causing the response eccentricity effect contribute to performance separately from the code polarities causing the up−right/down−left advantage.

In Experiment 3, participants performed the orthogonal Simon task at three different response positions (left, body midline, and right) 5 minutes after practising the orthogonal SRC task for 72 trials at the body midline with either orthogonal S−R mapping. This method allowed measurement of the response eccentricity effect in the transfer session. If polarity correspondence continues to contribute a separate effect on performance in the transfer session after practice with the orthogonal SRC task, the response eccentricity effect should be present to a similar extent following practice with either of the orthogonal mappings since it is a separate contributor to performance.

Method

Participants

A total of 32 new undergraduate students (12 male and 20 female) who were enrolled in introductory psychology courses at Korea University participated in partial fulfilment of a course requirement. All were right-handed, had normal or corrected vision, and were naive as to this experiment. A total of 16 participants (6 male and 10 female) used the up−right/down−left mapping in the practice session, and 16 (6 male and 10 female) used the other mapping.

Apparatus and stimuli

The apparatus and stimuli were identical to those of Experiment 1, except that the participants made responses at three different response positions (see Figure 2).

Procedure

The practice session was conducted in the same manner as that in Experiment 1. After finishing the practice session, participants took a 5-minute break and then entered into the orthogonal Simon task session. In the practice session, responses were made only at the body midline location. However, in the orthogonal Simon task session, responses were made at three different locations: response box centred 20 cm left of midline, at body midline, and 20 cm right of midline. All participants performed the orthogonal Simon task at all three locations, and the sequence of response locations was counterbalanced. Half of the participants began at the left response location and progressed to right response location; the other half began at the right response location and progressed to the opposite position.

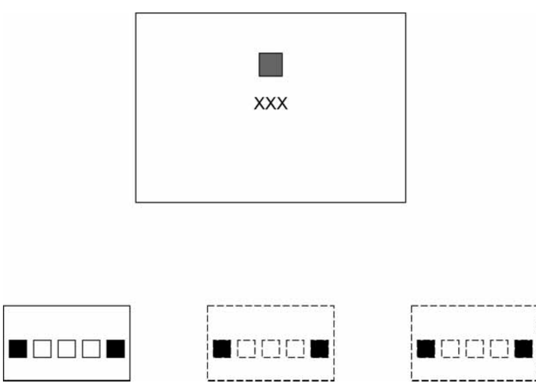

Figure 2. *The physical arrangement for the stimulus display and the three response positions in Experiment 3. The solid box to the left indicates the condition in which the response box was to the left of the screen, and the dashed boxes in the centre and to the right indicate the other two positions at which responses were made.*

Each participant practised the orthogonal SRC mapping for 72 trials plus 12 warm-up trials at practice session. At orthogonal Simon task session, they performed 12 warm-up trials only at the body middle line location, and then they moved to left or right response location for 100 main trials. The warm-up trials were excluded from data analysis.

Results

For the practice task, RT showed a nonsignificant tendency to be shorter for the up–right/down–left mapping (284 ms) than for the up–left/down–right mapping (313 ms), $F(1, 30) = 3.15$, $p = .09$. PE was low but showed a slight tendency in the opposite direction (up–right/down–left mapping, 0.78%; up–left/down–right mapping, 0.35%), $F(1, 30) = 1.58$, $p = .22$.

For the transfer session, with the same exclusion criteria as those in Experiments 1 and 2, only one trial among 9,600 trials was excluded from analysis. Mean RT and PE were calculated for each participant as a function of practice rule (up–right/down–left or up–left/down–right), response position (left, centre, right), and correspondence (up–right/down–left and up–left/down–right). ANOVAs were conducted on the mean RT and PE data, with response position and correspondence as within-subject factors and practice mapping (up–right/down–left; up–left/down–right) as a between-subject factor (see Table 3).

Reaction time

Neither the main effect of practice mapping, $F(1, 30) = 2.67$, $p = .11$, $MSE = 8{,}713$, nor the main effect of correspondence, $F < 1$, was significant. Importantly, as in Experiments 1 and 2, the interaction of correspondence and practice mapping was significant, $F(1, 30) = 15.35$, $p < .001$, $MSE = 447$. For participants who practised with the up–right/down–left mapping, a 14-ms orthogonal Simon effect was obtained, $F(1, 30) = 9.91$, $p = .003$, $MSE = 447$, whereas for participants who practised with the up–left/down–right mapping, a −9-ms reversed

Table 3. *Experiment 3: Mean reaction time and percentage of error for the visual orthogonal Simon task after visual practice, as a function of practice mapping, correspondence, and response position*

	Practice mapping/response position											
	Left				*Middle*				*Right*			
	UR/DL		*UL/DR*		*UR/DL*		*UL/DR*		*UR/DL*		*UL/DR*	
Correspondence	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Corresponding	345	0.37	386	2.12	345	0.75	378	1.37	343	0.87	372	0.87
Noncorresponding	348	3.00	369	0.75	364	3.37	368	1.12	363	4.50	367	1.00
Orthogonal Simon effect	3	2.63	−17	−1.37	19	2.62	−10	−0.25	20	3.63	−5	0.13

Note: RT = mean reaction time (in ms). PE = percentage of error. UR/DL = up−right/down−left mapping; UL/DR = up−left/down−right mapping.

orthogonal Simon effect was obtained, $F(1, 30) = 5.72$, $p = .02$, $MSE = 447$.

Neither the main effect of response position, $F(2, 60) = 0.25$, $p = .78$, $MSE = 466$, nor the interaction between response position and practice mapping, $F = 2.03$, $p = .14$, $MSE = 466$, was significant. However, the two-way interaction of response position and correspondence was significant, $F(2, 60) = 5.82$, $p = .005$, $MSE = 148$ (see Figure 3). A nonsignificant 4-ms up−right/down−left advantage at the middle response position, $F(1, 60) = 1.76$, $p = .19$, $MSE = 148$, reversed to a significant 7-ms up−left/down−right advantage at the left response position, $F(1, 60) = 4.72$, $p = .03$, $MSE = 148$, and increased to a significant 8-ms up−right/down−left advantage at the right response position, $F(1, 60) = 6.02$, $p < .01$, $MSE = 148$. Of importance, the three-way interaction of practice mapping, response position, and correspondence was not significant, $F < 1$.

Percentage error

The main effect of response position was not significant, $F < 1$. The main effect of practice mapping, $F(1, 30) = 5.03$, $p = .03$, $MSE = 8.4$, was, and the interaction between practice mapping and response position approached the .05 level, $F(2, 60) = 2.94$, $p = .06$, $MSE = 3.12$.

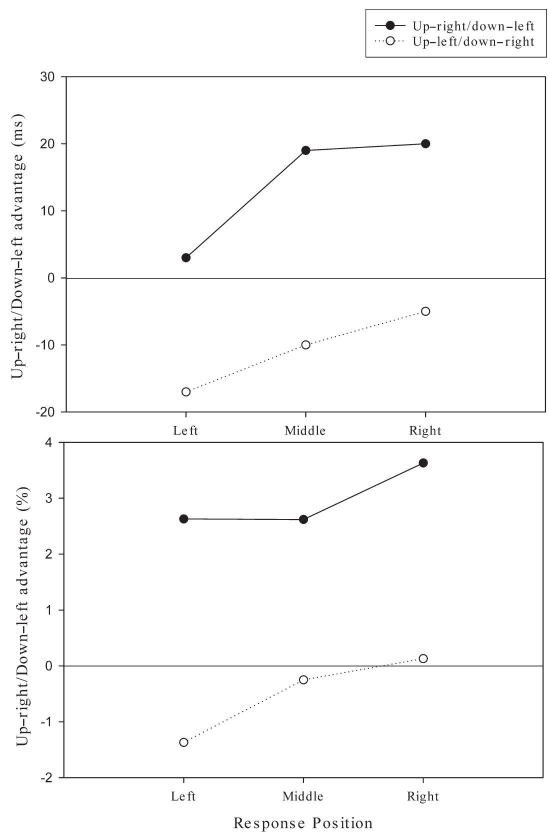

Figure 3. *The orthogonal Simon effect as a function of practice mapping (up−right/down−left; up−left/down−right) and response position in Experiment 3.*

PE was higher for the up–right/down–left practice condition (2.14%) than for the up–left/down–right practice condition (1.20%). This effect was most evident at the right response position (2.68% vs. 0.93%), $F(2, 60) = 15.67$, $p < .001$, $MSE = 3.12$, not significant at the left response position (1.68% vs. 1.43%), $F < 1$, and close to significant at the middle response position (2.06% vs. 1.25%), $F(2, 60) = 3.37$, $p = .07$, $MSE = 3.12$. The main effect of correspondence was significant, $F(1, 30) = 13.66$, $p < .001$, $MSE = 5.3$, showing a 1.2% overall orthogonal Simon effect. Correspondence interacted with practice mapping, $F(1, 30) = 27.03$, $p < .0001$, $MSE = 5.3$. A significant 3% orthogonal Simon effect for the up–right/down–left mapping, $F(1, 30) = 39.55$, $p < .0001$, $MSE = 5.3$, reversed to a nonsignificant − 0.5% orthogonal Simon effect for the up–left/down–right mapping, $F(1, 30) = 1.13$, $p = .29$, $MSE = 5.3$. Neither the two-way interaction of response location and correspondence, $F(1, 30) = 1.37$, $p = 0.26$, $MSE = 4.6$, nor the three way interaction of response location, correspondence, and practice mapping, $F < 1$, was significant.

Discussion

As in Experiments 1 and 2, after practising the orthogonal SRC task with the up–right/down–left mapping, a significant orthogonal Simon effect (14 ms and 3%) was obtained, whereas after practising with the up–left/down–right mapping, the orthogonal Simon effect (−9 ms and −0.5%) was reversed. These results once again show that the orthogonal Simon effect was influenced by the short-term S–R location associations from the practice session. Comparisons to the no-practice control condition described in the Discussion section of Experiment 1 showed that the orthogonal Simon effect for the up–right/down–left practice condition did not differ significantly from the 11-ms effect of the no-practice condition, $F(1, 34) < 1.0$, whereas that for the up–left/down–right practice condition did, $F(1, 34) = 12.07$, $p = .0014$, $MSE = 169$. This outcome, along with that of Experiment 2, suggests that the transfer effect may be stronger for the less compatible up–left/down–right mapping, which would be consistent with Tagliabue et al.'s (2000) findings for parallel S–R dimensions, but, for reasons noted in the Discussion section of Experiment 2, caution is warranted in reaching that conclusion.

Most important, the response eccentricity effect was observed, and this effect did not interact with that of practice mapping. The orthogonal Simon effect (4 ms) obtained at the body midline increased to an 8-ms effect at the right response position and reversed to a −7-ms difference favouring the up–left/down–right relation at the left response position. Regardless of which mapping participants practised with, the orthogonal Simon effect was more evident at the right response position than at the body midline, and it tended to reverse at the left response position.

These results imply that the polarity correspondence caused by the long-term associations, or overlap, of codes of the same polarity was still contributing to performance of the orthogonal Simon task in addition to the short-term location associations established by practising the orthogonal SRC task. The influence of the polarity associations was independent of the influence of the short-term location associations. When the orthogonal Simon task is performed at the centre position without prior practice of the orthogonal SRC task, as in the no-practice control experiment, correspondence of the + polarity codes for up stimulus and right response and − polarity codes for down stimulus and left response produces an orthogonal Simon effect favouring the up–right/down–left relation. When the orthogonal Simon task is performed at the centre position after practice of the orthogonal SRC task, the short-term location associations established through practice are consistent with the polarity correspondence relations when the practice mapping was up–right/down–left but counter to them when the practice mapping was up–left/down–right, which acts to increase and oppose, respectively, the basic orthogonal Simon effect. Finally, placing the response box to the right adds another + polarity code for the right response and − code for the left response, whereas placing the response box to the left adds a − polarity code for the right response and + code for the right response, and the correspondence of these codes with the + polarity of the up stimulus and − polarity of the down stimulus modulates the orthogonal Simon effect accordingly.

GENERAL DISCUSSION

Summary of main results

In the present study, participants practised with one of the two possible mappings of vertically oriented stimuli to horizontally oriented responses in the visual (Experiments 1 and 3), or auditory (Experiment 2) modality. The between-subject mapping manipulation in the practice session was of relatively low power for detecting the RT advantage for the up–right/down–left mapping, and all experiments showed a nonsignificant trend toward this advantage. The up–right/down–left advantage was significant, though, in an ANOVA with increased power that included experiment as a factor, $F(1, 106) = 5.32$, $p = .023$, $MSE = 2{,}053$, and it did not interact with experiment, $F < 1.0$. It was also statistically significant across just Experiments 1 and 3, which both used the same visual stimulus condition, $F(1, 68) = 4.87$, $p = .031$, $MSE = 1{,}479$.

The primary concern was how the practice mapping affected the orthogonal Simon effect when stimulus location was subsequently made irrelevant in the transfer session. In Experiment 1, the orthogonal Simon effect showed the usual advantage for the up–right/down–left relation when the short-term S–R associations created in practice were up → right and down → left, but it reversed to a nonsignificant advantage for the up–left/down–right relation when the associations created in practice were up → left and down → right. A similar pattern of results was evident in Experiment 2 when participants practised with a mapping of high and low pitch tones to left and right responses before performing the visual Simon task. This outcome implies that the short-term S–R associations are between spatial codes that are at least in part supramodal and not specific to the practised stimulus modality. Experiment 3 showed that a response eccentricity effect was obtained independent of the transfer effect of the location mapping used in practice, providing evidence that the long-term polarity associations still influenced the orthogonal Simon effect independently of the short-term associations between stimulus and response locations formed during practice.

Short-term S–R associations and long-term polarity associations

The mechanism that causes the Simon effect is response activation produced by short-term and long-term memory associations (Barber & O'Leary, 1997). The short-term associations are created by task instructions in order to perform the assigned task, and the long-term associations are the preexisting associations that do not depend on the task instructions. In the typical Simon task for which the stimuli and responses vary along parallel dimensions, the long-term associations are those between stimulus locations and corresponding response locations. The short-term associations are links between the relevant nonspatial stimulus values (often colours) and their assigned response locations.

This distinction between short-term and long-term associations is also applicable to the orthogonal Simon effect. In the orthogonal Simon task, the long-term associations are the links between corresponding code polarities for stimulus and response locations. The short-term associations, as in the Simon task for parallel dimensions, are created to perform the instructed task, which in the present experiments was to respond to stimulus colours with keypress responses. Practice with a location-relevant mapping introduces an additional set of short-term associations: those between stimulus and response locations that were previously defined as relevant for performance of the practice task. So, it is plausible to interpret the orthogonal Simon effect obtained after

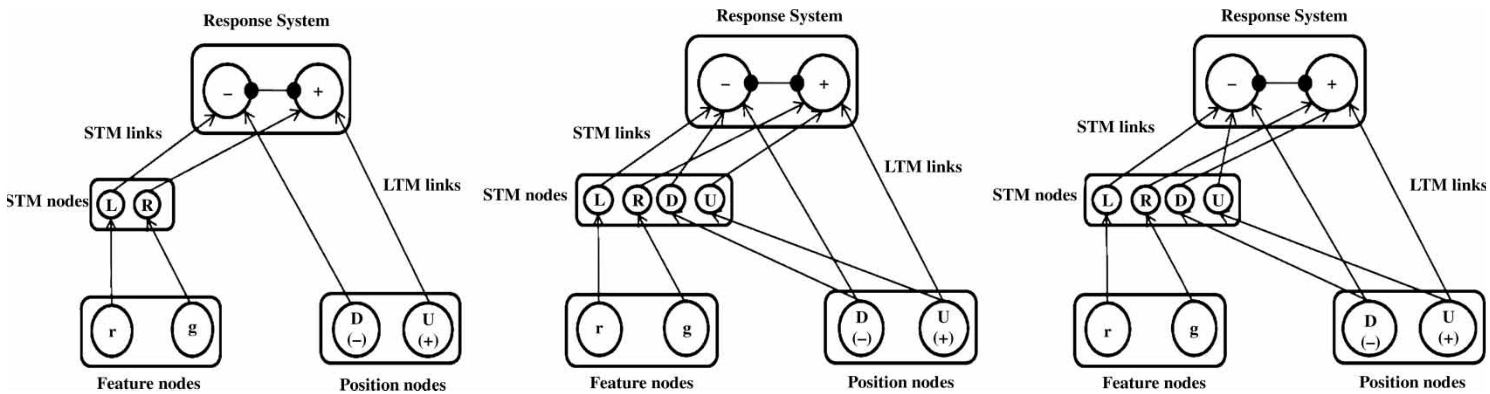

Figure 4. *Depiction of short-term and long-term memory links for the orthogonal Simon task with no prior practice (left panel), prior practice with the up−right/down−left mapping (centre panel), and prior practice with the up−left/down−right mapping (right panel).*

72 trials of practice with an orthogonal S−R mapping as reflecting the combined effects of correspondence of the long-term polarity codes and the short-term associations between stimulus and response locations established for the previous task.

This account is consistent with the short-term-memory-association-based model (STM-based account) provided by Tagliabue et al. (2000), which supposes two different types of STM links (see Figure 1): One type of links is between stimulus features (e.g., green or red) and response locations (e.g., left or right) needed to perform the Simon task, and the other is between stimulus locations and response locations created by prior practice (called spatial compatibility, SC, STM links in their model). So, there are two different response activation links that are triggered by irrelevant stimulus location: long-term memory (LTM) and SC-STM links.

Within this model, the results of the present study can be characterized as follows. With orthogonal orientations of the stimulus and response sets, the polarity codes for the stimuli have LTM links to the responses of corresponding polarity (see Figure 4, left panel). SC-STM links between specific stimulus and response locations are created when participants perform the orthogonal SRC task, with those associations being specific to the mapping used for that task: up−right/down−left or up−left/down−right. These SC-STM links contribute to performance of the subsequent orthogonal Simon task (see Figure 4, centre and right panels for the model depiction after practice with the up−right/down−left and up−right/down−left mappings, respectively), though stimulus location is no longer relevant. So, the task-irrelevant stimulus location activates responses through two different pathways. For example, when a stimulus appears above the fixation row, the positive stimulus polarity code activates the response code of corresponding polarity (the right response) through LTM polarity links. At the same time, the upper stimulus activates the response to which it was assigned in the practice task through the SC-STM links: For the up stimulus, this would be the right response when the practice mapping was up−right/down−left and the left response when the practice mapping was up−left/down−right.

The orthogonal Simon effect at the centre response position is typically smaller than the parallel Simon effect, which suggests that the LTM links of polarity codes in the orthogonal Simon task are not as strong as the LTM links of corresponding locations in the parallel Simon task. Consistent with the relative weakness of the LTM links between codes of corresponding polarity, in Experiment 1, the orthogonal Simon effect reversed to −11 ms, favouring the up−left/down−right relation, after participants practised with the up−left/down−right mapping. This reversal, which produces an effect that is consistent with the SC-STM links established in practice, indicates that those links were stronger than the LTM links between codes of + polarity (up and right) and − polarity (down and left).

Though not depicted in Figure 4, the response eccentricity effect can be characterized by additional polarity codes for the responses when both responses are made to the left or right of body midline. At the right response position, these polarity codes are + polarity for the right response and − polarity for the left response. They thus add to the already positive right response code and negative left response code, increasing the overall polarity difference between the responses. At the left response position, the additional polarity codes are + polarity for the left response and − polarity for the right response, which counters the positive right and negative left response codes. This tends to yield an overall + code for the left response and − code for the right response, which acts to reverse the up−right/down−left advantage. Thus, all of the major results can be explained in a straightforward manner within the model of Tagliabue et al. (2000) that was developed originally to explain the transfer effects for parallel stimulus and response dimensions.

Short-term S−R associations between supramodal spatial codes

Tagliabue et al. (2002) concluded that the new spatial S−R associations, or links, created from practice with an incompatible mapping are between supramodal spatial codes that are independent of stimulus modality: When their participants practised with an incompatible auditory S–R mapping, the visual Simon effect was not evident in a subsequent transfer task. As noted, however, Vu et al. (2003) provided evidence of a modality-specific component in the short-term S–R associations. In their Experiment 1, the Simon effect reversed when the practice modality was visual, whereas it was only eliminated when the practice modality was auditory, and this difference was significant. In line with Vu et al.'s findings, comparison of Experiments 1 and 2 of the present study showed that the effect of the short-term spatial S–R associations on the subsequent orthogonal visual Simon task was less when the stimuli for the practice task were auditory than when they were visual. The orthogonal Simon effect reversed after participants practised the orthogonal SRC task with an up–left/down–right mapping when the practice stimuli were visual but was just eliminated when they were auditory. This result also suggests that a modality-specific component may contribute to the transfer effects with orthogonal S–R orientations. However, because the vertical dimension for the auditory stimuli in Experiment 2 was not explicit, we cannot rule out the possibility that the smaller transfer effect from prior auditory practice in Experiment 2 was due to the implicit spatial nature of the practised dimension.

CONCLUSION

The implications of the present findings can be summarized as follows. First, fewer than 100 trials of practice with a mapping of up and down stimulus locations to left and right responses are sufficient to produce a difference in orthogonal Simon effects in a transfer task for which stimulus location is irrelevant. Practice with an up–right/down–left mapping increases the base orthogonal Simon effect, which shows an advantage for the up–right/down–left relation, whereas practice with an up–left/down–right mapping tends to reverse the orthogonal Simon effect to favour the up–left/down–right relation. Both practice mappings affect performance of the transfer task, though the influence of the incompatible up–left/down–right mapping may be somewhat greater. The impact of the practice mapping on the subsequent orthogonal Simon effect may arise from conflict created when the response activated by that mapping is different from the correct response for the trial. Second, these short-term S–R associations involve spatial codes that are at least in part supramodal, though there may be a modality-specific component as well. Third, the influence of the short-term S–R associations on the orthogonal Simon effect is separate from that of polarity correspondence, as evidenced by the continued presence of an overall up–right/down–left Simon effect when averaged across practice mappings and the finding of a distinct response eccentricity effect. On the whole, the results conform to the view that relative performance in various conditions of choice-reaction tasks is influenced concurrently by multiple correspondence relations.

Original manuscript received 11 January 2008
Accepted revision received 27 April 2008
First published online 8 September 2008

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.

Cho, Y. S., & Proctor, R. W. (2002). Influences of hand posture and hand position on compatibility effects for up-down stimuli mapped to left-right responses: Evidence for a hand referent hypothesis. *Perception & Psychophysics*, *64*, 1301–1315.

Cho, Y. S., & Proctor, R. W. (2003). Stimulus and response representation underlying orthogonal stimulus–response compatibility effects. *Psychonomic Bulletin & Review*, *10*, 45–73.

Cho, Y. S., & Proctor, R. W. (2005). Representing response position relative to display location:

Influence on orthogonal stimulus–response compatibility. *Quarterly Journal of Experimental Psychology*, *58A*, 839–864.

Cho, Y. S., Proctor, R. W., & Yamaguchi, M. (2008). Influence of response position and hand posture on the orthogonal Simon effect. *Quarterly Journal of Experimental Psychology, 61,* 1020–1035.

Clark, H. H., & Chase, W. G. (1972). On the process of comparing sentences against pictures. *Cognitive Psychology*, *3*, 472–517.

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.

Kornblum, S., & Lee, J.-W. (1995). Stimulus–response compatibility with relevant and irrelevant stimulus dimensions that do and do not overlap with the response. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 855–875.

Kosslyn, S. M., Thompson, W. L., Gitelman, D. R., & Alpert, N. M. (1998). Neural systems that encode categorical versus coordinate spatial relations: PET investigations. *Psychobiology*, *26*, 333–347.

Lippa, Y., & Adam, J. J. (2001). Orthogonal stimulus–response compatibility resulting from spatial transformations. *Perception & Psychophysics*, *63*, 156–174.

Logan, G. D. (1995). Linguistic and conceptual control of visual spatial attention. *Cognitive Psychology*, *28*, 103–174.

Michaels, C. F. (1989). S–R compatibilities depend on eccentricity of responding hand. *Quarterly Journal of Experimental Psychology*, *41A*, 262–272.

Nishimura, A., & Yokosawa, K. (2006). Orthogonal stimulus–response compatibility effects emerge even when the stimulus position is task-irrelevant. *Quarterly Journal of Experimental Psychology*, *59*, 1021–1032.

Olson, G. M., & Laxar, K. (1973). Asymmetries in processing the terms "right" and "left". *Journal of Experimental Psychology*, *100*, 284–290.

Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological Bulletin*, *132*, 416–442.

Proctor, R. W., & Vu, K. P. L. (2006). *Stimulus–response compatibility principles: Data, theory, and application.* Boca Raton, FL: CRC Press.

Rusconi, E., Kwan, B., Giordano, B. L., Umiltà, C., & Butterworth, B. (2006). Spatial representation of pitch height: The SMARC effect. *Cognition*, *99*, 113–129.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime user's guide*. Pittsburgh: Psychology Software Tools.

Seymour, P. H. K. (1974). Asymmetries in judgments of verticality. *Journal of Experimental Psychology*, *102*, 447–455.

Tagliabue, M., Zorzi, M., & Umiltà, C. (2002). Cross-modal re-mapping 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 and Performance*, *26*, 648–670.

Vu, K. P. L. (2007). Influence on the Simon effect of prior practice with spatially incompatible mappings: Transfer within and between horizontal and vertical dimensions. *Memory & Cognition*, *35*, 1463–1471.

Vu, K. P. L., Proctor, R. W., & Urcuioli, P. (2003). Transfer effects of incompatible location-relevant mappings of a subsequent visual or auditory Simon task. *Memory & Cognition*, *31*, 1146–1152.

Walker, B. N., & Ehrenstein, A. (2000). Pitch and pitch change interact in auditory displays. *Journal of Experimental Psychology: Applied*, *6*, 15–30.

Weeks, D. J., & Proctor, R. W. (1990). Salient-features coding in the translation between orthogonal stimulus–response dimensions. *Journal of Experimental Psychology: General*, *119*, 335–366.

Weeks, D. J., Proctor, R. W., & Beyak, B. (1995). Stimulus–response compatibility for vertically oriented stimuli and horizontally oriented responses: Evidence for spatial coding. *Quarterly Journal of Experimental Psychology*, *48A*, 367–383.

Zorzi, M., & Umiltà, C. (1995). A computational model of the Simon effect. *Psychological Research*, *58*, 193–205.