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Transfer of an implied incompatible spatial mapping to a Simon task

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ABSTRACT

When location words *left* and *right* are presented in left and right locations and mapped to left and right keypress responses in the Hedge and Marsh (1975) task (Arend & Wandmacher, 1987), a compatible mapping of words to responses yields a benefit for stimulus–response location correspondence (sometimes called the Simon effect), whereas an incompatible mapping yields a benefit for noncorrespondence (called the Hedge and Marsh reversal). Experiment 1 replicated the correspondence benefit and its reversal by using Chinese location words (left) and (right) in the Hedge and Marsh task. Experiments 2 and 3 examined whether the tendency to respond with the noncorresponding response when the mapping is incompatible transfers to the task version in which the mapping is compatible, and Experiment 4 examined whether transfer similarly occurs from the compatible mapping to the task version with incompatible mapping. Transfer of the incompatible relation was apparent in a lack of correspondence benefit when the mapping was changed to compatible, but transfer of the compatible relation to the incompatible mapping did not occur. The results suggest that an association between noncorresponding stimulus–response locations is acquired when the word–response mapping is incompatible, even though this relation is only implicit, regardless of whether through misapplication of a logical recoding rule or spatial representations shared by the locations and words. These associations then continue to affect processing of location when the mapping is compatible.

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1. Introduction

In a typical two-choice spatial reaction task, left and right keypresses are assigned to left and right stimulus locations. Responses are faster and more accurate with a compatible mapping of right stimulus to right response and left stimulus to left response than with an incompatible mapping of right stimulus to left response and left stimulus to right response, which is called the stimulus–response (S–R) compatibility effect (see review by Proctor & Vu, 2006). Moreover, when stimulus location is task-irrelevant and a non-spatial attribute (e.g., color or shape) conveys the task-relevant information, responses are faster and more accurate if the stimulus location and response position correspond than if they do not, a phenomenon called the Simon effect (see reviews of Lu & Proctor, 1995; Simon, 1990; Umiltà & Nicoletti, 1990).

Terminology is less consistent for tasks in which the task-relevant dimension also has spatial meaning (e.g., the task is to respond to the location word *left* or *right*, presented in a task-irrelevant left or right location). Correspondence benefits in such tasks are sometimes called Simon effects (e.g., Georgiou-Karistianis et al., 2012; Toth et al., 1995), based on stimulus location being irrelevant and the responses being keypresses, and sometimes spatial Stroop effects (e.g., Lu & Proctor, 1995), based on the extra overlap of the relevant stimulus dimension with the irrelevant dimension and the responses (Kornblum, Hasbroucq, & Osman, 1990). In the present study, we refer to the location correspondence effect obtained with the words *left* and *right* as the task-relevant stimulus dimension as a Simon effect, consistent with Arend and Wandmacher's (1987) study on which our method is based, but acknowledging that the additional sources of dimensional overlap may play a role.

The Simon effect and its variants have typically been attributed to automatic processing of task-irrelevant spatial information. According to dual-route models (De Jong, Liang, & Lauber, 1994; Kornblum et al., 1990), the task-relevant dimension is processed via a controlled, or conditional, route, by which a response is activated based on instructions. In contrast, the task-irrelevant stimulus location is processed via an automatic, or unconditional, route, by which the response corresponding to the stimulus location is activated. The Simon effect size is a function of the strength of the activation created by the unconditional route relative to that created by the conditional route. Similarly, Zorzi and Umiltà (1995) proposed that the Simon effect arises from two types of S–R links, called short-term memory (STM) and long-term memory (LTM) links. STM links associate stimuli with responses via task instructions, and LTM links connect spatially corresponding stimuli and responses. On incompatible trials the two link types activate different responses, whereas on compatible trials both links activate the same (correct) response, which together create the Simon effect.

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Simon effects are also evident when the irrelevant location information is conveyed by a centrally presented word (*left* or *right*) or arrow (pointing left or right) and stimulus color is task-relevant (Proctor & Vu, 2002). A question of interest is whether words and symbols activate the same shared, mode-independent spatial representations activated by location stimuli or distinct conceptual representations (e.g., verbospatial vs. visuospatial; Miles & Proctor, 2012).

Moreover, although the Simon effect for physical locations is robust, it can be eliminated or even reversed in certain contexts. In the present study, we used two such contexts to examine the relation between processing of location words (Chinese symbols for left and right) and of stimulus locations (left and right): (a) Simon tasks for which the relevant S–R mapping is incompatible, and (b) Simon tasks performed after practice with an incompatible S–R mapping.

1.1. Reversal of the Simon effect with an incompatible relevant S–R mapping

Hedge and Marsh (1975) provided evidence that the task-defined mapping can generalize across different features within the same task. They presented red or green stimuli on the left or right of a display panel and had participants respond by moving an index finger from a start button to one of two response buttons, located to the left or right but also colored red or green. In a compatible-mapping condition the instructions were to respond with the same color (i.e., press the green button for green stimuli and red button for red stimuli), whereas in an incompatible mapping condition the instructions were to respond with the opposite color (i.e., press the green button for red stimuli and the red button for green stimuli). The compatible color mapping showed a typical Simon effect, faster responses when stimulus and response positions corresponded than when they did not, but the incompatible mapping showed a reversed effect, faster responses when stimulus and response positions did not correspond than when they did. This *Hedge and Marsh reversal* with an incompatible color mapping has been replicated in many studies, including ones with keypresses made with left and right index fingers (e.g., De Jong et al., 1994; Hasbroucq & Guiard, 1991; Lu & Proctor, 1994; Wühr & Biebl, 2009), although the color labels for the keys may need to be visible (Proctor & Pick, 2003).

Hedge and Marsh (1975) offered a logical recoding account of the reversed Simon effect. They proposed that participants apply a logical recoding rule of "respond opposite" to select the response to the relevant color dimension, and this logical recoding rule is misapplied within the task to the irrelevant location dimension as well. De Jong et al. (1994) elaborated this account to incorporate a finding that, whereas the Simon effect decreases across the RT distribution, the Hedge and Marsh reversal increases. They suggested that activation of the spatially corresponding response occurs at stimulus onset via an unconditional route, regardless of whether the color mapping is compatible or incompatible, but diminishes rapidly. The relevant transformation rule is implemented in a conditional route through which "automatic generalization and application of the task-defined transformation of the relevant stimulus attribute to the spatial stimulus code" (p. 737) occurs. The "respond opposite" transformation rule, appropriate when the color mapping is incompatible, is applied at the time of response selection and produces the Hedge and Marsh reversal.

Treccani, Milanese, and Umiltà (2010) showed that logical recoding can generalize across different tasks that share partial similarity. In their study, trials of a Simon task with the task-relevant dimension of stimulus shape were intermixed with those of a color-mapping Simon task similar to that used by Hedge and Marsh (1975). The Simon effect for the shape stimuli showed a nonsignificant reversal when the color mapping was incompatible (e.g., press red key to green stimuli; Experiment 1), indicating that the "respond opposite" rule applicable to the color trials generalized to stimulus location in the shape Simon task. Treccani et al. also reported that the Simon effect was eliminated or reversed for the shape Simon task when the intermixed color stimuli were presented at the center of screen and did not vary in location. This outcome suggested that the logical recoding rule relevant to the color task was misapplied to the irrelevant stimulus-location dimension of the shape-judgment task. However, Baroni, Yamaguchi, Chen, and Proctor (2013) provided evidence that the elimination in the latter case was due to a general slowing of responses and not between-task logical recoding. In contrast, when the color stimuli also varied in location, "respond opposite" recoding for an incompatible color mapping did seem to be the source of the tendency for the shape Simon task to reverse.

The Hedge and Marsh reversal has also been obtained for incompatible mappings in tasks for which the task-relevant stimulus dimension overlaps with the response and task-irrelevant stimulus dimensions. These tasks include ones in which the task-relevant dimension is left or right arrow direction (Arend & Wandmacher, 1987), the German word *links* (left) or *recht* (right; Arend & Wandmacher, 1987), the French word *gauche* (left) or *droite* (right; Hasbroucq & Guiard, 1991, footnote 9) and the English word *left* or *right* (Lu & Proctor, 1994). A benefit of such tasks is that the response keys do not have to be labeled, and the S–R compatibility manipulation is more straightforward because the responses are left and right keypresses. The results obtained when the task-relevant dimension has spatial meaning have also been attributed to logical recoding (e.g., Arend & Wandmacher, 1987; Lu & Proctor, 1994), but an alternative explanation is possible because both the relevant and irrelevant stimulus dimensions involve location. If response activation is mediated at least partially by shared, mode-independent spatial representations that are activated by location words and stimulus locations, then short-term S–R links established for the relevant location-word dimension (e.g., location word *left* to right response) may also be activated by the location in which the stimulus occurs (e.g., left).

Evidence consistent with this latter possibility can be found in studies for which location-relevant trials are intermixed with location-irrelevant Simon-task trials. When the location dimension for both trial types is spatial location, the Simon effect in the location-irrelevant trials is positive if the location-relevant mapping is compatible (i.e., right stimulus–right key, left stimulus–left key) but reverses to favor noncorresponding responses if the mapping is incompatible (i.e., right stimulus–left key, left stimulus–right key; Marble & Proctor, 2000). Of importance, the spatial Simon effect is eliminated when the Simon-task trials are intermixed with trials on which participants respond to the centered words *left* and *right* with incompatibly mapped keypresses (e.g., left/right keypress to word *right*/*left*, respectively; Notebaert, De Moor, Gevers, & Hartsuiker, 2007; Proctor, Marble, & Vu, 2000; Vu, Ngo, Minakata, & Proctor, 2010). This elimination has been interpreted as implying that the location words and spatial locations may activate shared, mode-independent codes. It could also be a consequence of misapplication of a "respond opposite" rule, but the previously cited evidence against misapplication of logical recoding across tasks when the stimuli in the incompatible trials do not vary in location (Baroni et al., 2013) implies that this interpretation is less likely.

1.2. Reversal of the Simon effect in the transfer paradigm

The Simon effect is also eliminated or reversed when a task with incompatible spatial mapping is practiced prior to the Simon task. Proctor and Lu (1999) had participants practice 900 trials responding to the positions of the letters *S* and *H* with incompatible keypresses (i.e., right stimuli–left key, left stimuli–right key). When letter identity was made relevant and stimulus position irrelevant, responses were still faster when stimulus and response positions did not correspond than when they did (a reverse Simon effect). Likewise, Tagliabue, Zorzi, Umiltà, and Bassignani (2000) found that the normal Simon effect was absent following 72 practice trials with an incompatible mapping of left/right positions to left/right keypresses.

Tagliabue et al. (2000) proposed an STM-link account for the transfer paradigm, according to which the transfer is due to acquisition of

STM links that associate the stimulus locations to their assigned response locations. With practice of a spatially incompatible mapping, the links between incompatible stimulus and response locations are strengthened; these strengthened STM links remain in memory for the transfer session, producing activation of the previously associated response (e.g., right) when the particular stimulus feature (e.g., left stimulus) occurs. This activation of the noncorresponding response counters that produced through the LTM links between corresponding stimulus and response locations.

Baroni et al. (2013) examined whether transfer of logical recoding rules can occur from a practice task for which color is relevant to a subsequent Simon task with shape relevant. In the practice phase of their Experiment 1, participants responded to stimuli that occurred at the center of the screen by pressing a key whose color was compatible with the stimulus color (e.g., red–red) or incompatible (e.g., green–red). In the transfer phase, participants responded to the shapes of white stimuli in left or right positions by pressing a left or right key (with no color). Consequently, there was little evidence for transfer of the "respond opposite" recoding rule from the practice task to the Simon task.

The previously discussed studies demonstrating transfer from a location-relevant task to the Simon task used physical-location stimuli for both tasks. Location words yield mapping effects when the signified location information is relevant (Wang & Proctor, 1996) and, as noted, Simon effects when it is irrelevant (Proctor & Vu, 2002). Proctor, Yamaguchi, Zhang, and Vu (2009) found that transfer occurs from a relevant, incompatible mapping of centered location words (to keypress responses) to a word version of the Simon task (centered word *left* or *right* in red or green color), although many practice trials with the incompatible mapping were necessary (see also Yamaguchi, Chen, & Proctor, 2015). However, the incompatible word mapping had no influence on a location Simon task (responding to a red or green circle), even after 600 practice trials. This result implies that even when a centered stimulus conveys location information, it does not produce transfer of an incompatible mapping to a subsequent spatial Simon task, in agreement with what Baroni et al. found for centered color stimuli.

1.3. Purpose of the present study

To summarize, Arend and Wandmacher (1987) and others observed a reversed Simon effect when participants responded with an incompatible S–R mapping to keypresses of words signifying left and right. With mixed tasks, an incompatible mapping of location words to responses eliminates or reverses the spatial Simon effect (e.g., Proctor et al., 2000; Vu et al., 2010), implying that the words and spatial locations activate share spatial representations. However, when the task with incompatible mapping of location words is performed prior to a Simon task, the Simon effect is not reduced (Proctor et al., 2009; Yamaguchi et al., 2015), suggesting that the representations activated by the spatial locations in the Simon task are independent from those activated by the words in the practice task.

In the present study, we used Chinese location words (left) and (right) as the relevant stimuli (for Chinese speakers) in the Hedge and Marsh task (Arend & Wandmacher, 1987; Lu & Proctor, 1994) because of their more straightforward incompatible mapping to the ultimate responses (e.g., press the left key to the word *right*) than that of stimulus colors (e.g., press the key, left or right, labeled with red color to the red stimulus). We examined whether practice with a prior incompatible word–response mapping influenced the Simon effect in a subsequent task and whether practice with a prior compatible word–response mapping influenced the reversed Simon effect in a subsequent task. The prior task differed from the subsequent task only in the mapping rule being compatible or incompatible.

Because the experiments were conducted in China with Chinese speakers, a first step was to reproduce the pattern of results obtained with location words in prior studies. Consequently, Experiments 1A and 1B were replications of the conditions of Arend and Wandmacher's Experiment 2, with compatible and incompatible word–response mappings, respectively, but using Chinese location words. We anticipated obtaining similar results, but this needed to be verified because prior studies have shown that (a) languages are likely to have an influence on the Simon effect (Notebaert et al., 2007; Vu et al., 2010), (b) spelled location words may be processed differently than location symbols (Proctor et al., 2000), and (c) logographic characteristics of stimuli affect the magnitude of the closely-related spatial Stroop effect (for which the word and nonword stimulus dimensions involve vertical orientations and the responses are left and right keypresses; e.g., Luo & Proctor, 2013; Shimamura, 1987).

Having replicated the Simon and reverse Simon effects in Experiment 1, in Experiment 2 we examined whether practice with a prior incompatible word–response mapping influenced the Simon effect in a subsequent task that differed from the practice task only in the mapping being compatible. Any such influence could be attributed to the locations words being eccentrically presented in practice, since previous studies have shown that practice with an incompatible mapping of centered location words does not transfer to a subsequent Simon task (Proctor et al., 2009; Yamaguchi et al., 2015). Experiment 3 was a control experiment in which two blocks of trials were performed with the compatible word–response mapping, to ensure that a reduction in the Simon effect observed in the transfer session of Experiment 2 was not due to a general change in performance with practice. This reduction likely reflects continued effects during performance of the transfer task of STM links between incompatible S–R locations that either are a consequence of spatial representations shared by physical locations and location words or were created by logical recoding.

Experiment 4 tested implications of these two possibilities; it was similar to Experiment 2 but with the compatible mapping practiced prior to a trial block with the incompatible mapping. At variance with incompatible mappings, which require an S-R logical recoding (i.e., reverse transformation), no transformation is required to respond with a compatible response (Laird, Rosenbloom, & Newell, 1986). Accordingly, the logical recoding account does not provide for transfer effects from a compatible task to an incompatible task. Therefore, evidence of transfer in Experiment 4 would tend to favor the shared representations account whereas an absence of such evidence would tend to favor the logical recoding account.

2. Experiments 1A and 1B

Considerable emphasis has been placed in the past few years on replication and generalizability of findings (e.g., Schmidt, 2009). Consequently, Experiments 1A and 1B were designed to establish that results similar to those of Arend and Wandmacher (1987) and Lu and Proctor (1994) could be obtained with Chinese location words for native Chinese speakers. We utilized a paradigm similar to that of Arend and Wandmacher's Experiment 2, except that in the present study two Chinese location words (left) and (right) were used as stimuli.

In Experiment 1A, the mapping of words to response locations was compatible. Specifically, a Chinese word *left* or *right* was presented to the left or right of center fixation cross, and participants were to make left and right responses to the words *left* and *right*, respectively. We expected that the Simon effect would be observed, manifesting as faster responses when stimulus and response locations corresponded than when they did not. Experiment 1B was the same as Experiment 1A, except that the mapping of words to response locations was incompatible: Participants responded with the right response to the word *left* and the left response to the word *right*. We anticipated that this incompatible mapping would yield a reversed Simon effect for which responses are faster when stimulus and response locations do not correspond than when they do. The reversal would confirm this finding with a logographic language. Similarity of the reversal obtained with the location words to that found with stimulus and response colors would imply that the reversal is due to application of a "respond opposite" rule, although the reversal in this case could be due to stimulus location activating the STM links relevant to the location words via shared representations.

2.1. Method

2.1.1. Participants

Eighteen participants (8 males) took part in Experiment 1A, and 18 participants (10 males) in Experiment 1B, all age 19 to 22 years, recruited from universities near the Institute of Psychology, Chinese Academy of Sciences. All had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

2.1.2. Apparatus, stimuli, procedure, design

Stimuli were presented in white on a super VGA high-resolution color monitor with gray background. A personal computer, running E-Prime 1.1 software, controlled the presentation of stimuli, timing operations, and data collection. Participants placed their heads on a chinrest and viewed the monitor from a distance of 57 cm in a dimly lit room.

The stimuli were created by presenting a Chinese character (left) or (right) to the left or right of the center of the screen. The two positions were symmetric to the vertical middle line of the screen, separated by 8 cm. The visual angle for each Chinese character was 0.85° × 0.85°.

Each participant took part in a block of 16 practice trials followed by 128 test trials. Each trial began with onset of a red central fixation cross (0.4° × 0.4°). After 1 s, a word in white appeared for 150 ms. After that, the gray screen became blank, during which the trial terminated when the participant responded or after 1.5 ms if no response had been made. After the response, a 1-s inter-trial interval occurred, during which the screen remained blank.

Responses were made by pressing a left key (C) for the character *left* or right key (M) for the character *right* on the computer keyboard with the left or right index finger in Experiment 1A. The mapping of characters to responses was reversed in Experiment 1B. The response keys and computer screen were aligned such that the fixation point and the midway point between the two response keys were on the participant's sagittal midline. Participants were instructed to maintain fixation and to respond to the targets as quickly and accurately as possible. Experiments 1A and 1B had a 2 (response position: left, right) × 2 (stimulus position: left, right) design, with 32 observations per experimental condition.

2.2. Results

Mean correct response times (RTs) and percent errors (PEs) are presented in Table 1. An analysis of variance (ANOVA) was performed separately on RT and PE for each sub-experiment, with stimulus position (left vs. right) and response position (left vs. right) as within-subject variables.

2.2.1. Experiment 1A

The analysis of RT revealed a main effect of response position, $F(1, 17) = 20.67$, $p < .001$, $MSE = 340$, $\eta_p^2 = .549$, with the right response being faster than the left one, and an interaction between stimulus position and response position, $F(1, 17) = 8.55$, $p = .009$, $MSE = 905$, $\eta_p^2 = .335$. This interaction reflects a Simon effect of 21 ms (faster responding when stimulus and response positions corresponded than when they did not). The main effect of stimulus position was not significant, $F(1, 17) = 3.44$, $p = .081$, $MSE = 825$, $\eta_p^2 = .168$.

The analysis of PE revealed a significant main effect of stimulus position, $F(1, 17) = 5.17$, $p = .036$, $MSE = .001$, $\eta_p^2 = .233$, with more correct responses when the stimulus was in the right position than in the left position. The interaction between stimulus position and response position was significant, $F(1, 17) = 4.93$, $p = .040$, $MSE = .001$, $\eta_p^2 = .225$, showing a Simon effect of 1.8%. The main effect of response position was not reliable, $F < 1$.

Table 1
Experiments 1 to 4: Mean reaction time (in ms) and mean percentage of error (%, in parentheses) as a function of experimental task, stimulus position and response position.

	Stimulus position	Left		Right	
	Response position	Left	Right	Left	Right
Exp. 1a	Compatible	369 (4.3)	370 (7.1)	377 (4.3)	337 (3.5)
Exp.1b	Incompatible	494 (6.4)	464 (6.2)	465 (3.1)	481 (6.2)
Exp. 2	Practice: incompatible	426 (8.3)	423 (5.0)	398 (4.3)	440 (9.9)
	Transfer: compatible	329 (4.5)	315 (4.3)	325 (4.0)	305 (3.3)
Exp. 3	1st block: compatible	357 (3.6)	363 (5.2)	373 (2.3)	341 (3.3)
	2nd block: compatible	345 (3.1)	362 (6.2)	364 (3.3)	334 (2.4)
Exp. 4	Practice: compatible	351 (3.8)	345 (2.6)	352 (3.5)	313 (1.4)
	Transfer: incompatible	430 (6.1)	409 (5.9)	423 (4.5)	445 (8.5)

2.2.2. Experiment 1B

The ANOVA of RT revealed an interaction between stimulus position and response position, $F(1, 17) = 8.69$, $p = .009$, $MSE = 1061$, $\eta_p^2 = .338$. In this case, though, the interaction was due to a reverse Simon effect of 23 ms (faster responding when stimulus and response positions did not correspond than when they did). The main effects were not significant, $Fs < 1$.

The analysis of PE revealed a main effect of stimulus position, $F(1, 17) = 5.42$, $p = .033$, $MSE = .001$, $\eta_p^2 = .242$, with more correct responses when the stimulus was in the right position. The interaction between stimulus position and response position was not significant, $F(1, 17) = 2.97$, $p = .103$, $MSE = .002$, $\eta_p^2 = .149$, nor was the main effect of response position, $F(1, 17) = 1.12$, $p = .304$, $MSE = .003$, $\eta_p^2 = .062$.

2.3. Discussion

When the word meaning and response position were compatible, the Simon effect was observed, with RT being shorter when stimulus and response positions corresponded than when they did not. In contrast, when the word meaning and response position were incompatible, a reversed Simon effect was observed, manifesting as faster responses when stimulus position and response position did not correspond than when they did. These results replicate those of Arend and Wandmacher (1987) and Lu and Proctor (1994), and establish that people fluent in the logographic Chinese language show the reversal with an incompatible mapping of characters to responses just as people fluent in phonetic languages do. The reversed Simon effect with the incompatible word–response mapping could be due to misapplication of a "respond opposite" rule to the irrelevant stimulus-position attribute, as suggested in the earlier studies, or possibly to activation of responses via STM links established for the location words that share representations with physical locations.

3. Experiment 2

Experiment 2 was designed to determine whether the incompatible relation between stimulus and response locations evident with an incompatible word–response mapping transfers to the same task performed with a compatible word–response mapping in a subsequent trial block. Participants first performed the incompatible mapping task of Experiment 1B, after which they performed the compatible task of Experiment 1A. Of concern was whether a typical Simon effect would or would not be evident for the latter task.

Previous experiments have found that an incompatible color mapping does not transfer to a Simon task with a different relevant dimension unless the color stimuli also vary in left and right location (Baroni et al., 2013). Moreover, an incompatible mapping of location words presented at a centered location does not transfer to a subsequent color Simon task (Proctor et al., 2009; Yamaguchi et al., 2015). Thus, any transfer observed in the present experiment should be attributable to the influence of the prior incompatible mapping of the eccentrically presented word to response position in the practice phase. Elimination or reversal of the Simon effect in the transfer phase would imply that activation of the incompatible location-response relation in the practice phase, whether through misapplication of the "respond opposite" rule or activation by way of shared representations, yielded short-term S–R links analogous to those produced by an explicit incompatible spatial S–R mapping in the practice phase.

3.1. Method

3.1.1. Participants

Eighteen new participants (7 males), age 19 to 22 years and from the same subject pool as in Experiment 1, took part in this experiment. All had normal or corrected-to-normal vision and were not aware of the purpose of the experiment.

3.1.2. Apparatus, stimuli, procedure, design

They were identical to those in Experiment 1, except that each participant first performed the incompatible task, and then transferred to the compatible task. Therefore, this experiment included two phases, one practice phase for the incompatible task and one transfer phase for the compatible task. Each phase had a 2 (response position: left, right) × 2 (stimulus position: left, right) design, with 32 observations per experimental condition.

3.2. Results

Mean correct RTs and PEs are shown in Table 1. For each phase, an ANOVA was performed separately on RT and PE, with stimulus position (left vs. right) and response position (left vs. right) as within-participant variables.

3.2.1. Practice phase

The analyses of RT for the incompatible practice mapping showed that the main effect of stimulus position was not significant, $F < 1$, but the main effect of response position was significant, $F(1, 17) = 4.72$, $p = .044$, $MSE = 1{,}502$, $\eta_p^2 = .235$, with faster left than right responses. Most important, the interaction between stimulus position and response position was significant, $F(1, 17) = 6.24$, $p = .023$, $MSE = 1{,}465$, $\eta_p^2 = .268$: RT was shorter when stimulus and response positions were noncorresponding than when they were corresponding, yielding a reverse Simon effect of 23 ms.

The analysis of PE for the incompatible task showed that the main effects were not reliable, $Fs < 1$, but the interaction between stimulus position and response position was significant, $F(1, 17) = 8.02$, $p = .012$, $MSE = .004$, $\eta_p^2 = .320$. More responses were correct when stimulus position and response position did not correspond than when they did, showing a reverse Simon effect of 4.3%.

3.2.2. Transfer phase

The analysis for the compatible transfer task showed that the main effects of stimulus position and response position on RT were not significant, $F(1, 17) = 3.04$, $p = .099$, $MSE = 239$, $\eta_p^2 = .152$, and $F(1, 17) = 3.02$, $p = .100$, $MSE = 1{,}695$, $\eta_p^2 = .151$. More important, neither was their interaction, $F < 1$, with an unreliable Simon effect of 3 ms. Analysis of PE for the compatible task showed no reliable main effects or interaction, $Fs < 1$, although the descriptive statistics showed a Simon effect tendency of 0.3%.

3.2.3. Comparison to Experiment 1A

The Simon effect in the transfer phase of this experiment (3 ms) was smaller than that in Experiment 1A (21 ms), $t(34) = -2.11$, $p = .042$, which differed only in not having prior practice with the incompatible word–response mapping. The PE Simon effect in this experiment (0.3%) was numerically smaller than that in Experiment 1A (1.8%), but this difference did not approach statistical significance, $t(34) = -0.17$, $p = .869$.

3.3. Discussion

For the incompatible task performed in the practice phase, the reverse Simon effect was again observed. For the subsequent compatible task in the transfer phase, there was no significant Simon effect in the RT or PE data. This absence of Simon effect implies that activation of the response opposite the irrelevant stimulus location continued to occur in the transfer phase, offsetting the typical activation of the corresponding response.

4. Experiment 3

The Simon effect is reduced by practice in some cases (e.g., Proctor & Lu, 1999; Simon, 1990). Consequently, the absence of Simon effect in the transfer phase of Experiment 2 could be due solely to having practiced responding to the word stimuli (appearing in left and right locations). To evaluate this possibility, in Experiment 3 participants performed two trial blocks, with the number of trials in each block being identical to Experiment 2. If transfer of the incompatible relation established in practice was responsible for the absence of the Simon effect in Experiment 2, then the Simon effect should be evident in the second session of the present experiment.

4.1. Method

4.1.1. Participants

Eighteen new participants (7 males), aged from 19 to 22 years, were recruited from the same subject pool. All had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

4.1.2. Apparatus, stimuli, procedure, design

They were identical to those in Experiment 2, except that each participant performed two blocks of trials with the compatible task. This experiment had a 2 (block: first, second) × 2 (response position: left, right) × 2 (stimulus position: left, right) design, with 32 observations per experimental condition.

4.2. Results

Mean correct RTs and PEs are presented in Table 1. An ANOVA was performed separately on RT and PE, with block (first, second), stimulus position (left vs. right) and response position (left vs. right) as within-participant variables.

4.2.1. Analyses of RT and PE

The analysis of RT showed no significant main effect of stimulus position, $F < 1$, block order, $F(1, 17) = 1.23$, $p = .284$, $MSE = 1{,}541$, $\eta_p^2 = .067$, or response position, $F(1, 17) = 3.33$, $p = .086$, $MSE = 772$, $\eta_p^2 = .164$. Stimulus position interacted with response position, $F(1, 17) = 14.39$, $p = .001$, $MSE = 1{,}122$, $\eta_p^2 = .458$, with 21 ms faster responses when stimulus and response positions corresponded than when they did not. The only three-way interaction, $F < 1$, and the other two-way interactions, $ps > .324$, were not reliable.

The analysis of PE showed a main effect of stimulus position, $F(1, 17) = 4.99$, $p = .039$, $MSE = .002$, $\eta_p^2 = .227$, whereas the main effects of block, $F < 1$, and response position, $F(1, 17) = 1.64$, $p = .218$, $MSE = .003$, $\eta_p^2 = .088$, were not reliable. The interaction between stimulus position and response position was not significant, $F(1, 17) = 1.56$, $p = .229$, $MSE = .003$, $\eta_p^2 = .084$, nor were the only three-way interaction, $F(1, 17) = 2.34$, $p = .145$, $MSE = .001$, $\eta_p^2 = .121$, and the other two-way interactions, $Fs < 1$.

4.2.2. Comparison to Experiment 2

The Simon effect (24 ms) in the second block of this experiment was larger than that of Experiment 2 (3 ms), $t(34) = 2.33$, $p = .026$, in which the first block used an incompatible word–response mapping. The PE

Simon effect (2%) in the second block of this experiment was also larger in value than that in Experiment 2 (0.3%), though this difference was not significant, $t(34) = 1.25$, $p = .218$. Note also that the overall mean RT in the second block was shorter in Experiment 2 (319 ms; PE = 4.02) then in Experiment 3 (351 ms; PE = 3.75), rather than longer, showing no evidence of a cost in responding to the relevant location words in the second session when the mapping was changed from incompatible to compatible.

4.3. Discussion

When participants performed two blocks of trials in the compatible task, the Simon effect was observed, and it was not reduced in the second trial block. This result provides evidence against the possibility that the absence of the Simon effect in the transfer phase of Experiment 2 was due to general effects of practice responding to location words in left and right positions. Instead, the absence apparently was due to the incompatible mapping used for the practice phase: The irrelevant stimulus location attribute continued to produce activation of the noncorresponding response in the transfer phase, although the incompatible mapping was no longer in force for the word–response choices. This result implies that STM links between noncorresponding stimulus and response locations were acquired, via application of a "respond opposite" rule or through shared representations, when the word-location mapping was incompatible in the practice phase.

That the Simon effect was not even reduced in the second trial block of this experiment differs from reductions with practice shown in other studies (Proctor & Lu, 1999; Simon, 1990). This discrepancy may be due to the relatively small number of test and practice trials that were experienced prior to the second trial block (160). Alternatively, the lack of reduction could be because in the current task not only stimulus position and response position corresponded; they both also corresponded with location-word meaning.

5. Experiment 4

Given that transfer from a task with incompatible word–response mapping to one with compatible word–response mapping occurred in Experiment 2, an interesting empirical question is whether transfer in the opposite direction occurs. In Experiment 4, therefore, we had participants practice with the compatible word–response mapping and then transfer to the task with the incompatible mapping. The shared representations account implies that transfer should occur much as it did in Experiment 2. That is, links to shared representations should be strengthened during the practice phase like in Experiment 2, only in this case between corresponding locations. These links between corresponding locations should remain active during the transfer session, countering the activation produced via the STM links for the newly defined incompatible word–response mapping and opposing the reversed Simon effect.

If it is assumed that logical recoding applies only to an incompatible mapping rule, then the logical recoding account predicts no transfer effect in Experiment 4. Hedge and Marsh (1975) suggested that participants use a "respond same" rule when performing with a compatible relevant S–R mapping, but tests of logical recoding have focused almost exclusively on the incompatible mapping. For example, Simon, Sly, and Vilapakkam (1981) interpreted a lack of Hedge and Marsh reversal for irrelevant left-right tone location when responding with an incompatible red-green color mapping to a centered visual stimulus as evidence against logical recoding, even though a large Simon effect was evident with a compatible color mapping. The reason why the compatible mapping has tended to be ignored is that logical recoding implies a transformation, and no transformation is needed when the stimulus and required response are compatible (e.g., Laird, Rosenbloom, & Newell, 1986). Moreover, the standard Simon effect is obtained when stimulus color is relevant but the response keys are not labeled by colors, and it therefore could not be due to application of a "respond same" rule. The only study of which we are aware that considered whether logical recoding applies to both compatible and incompatible color mappings is that of Zhang (2000), which used an atypical 3-choice task. He came to the conclusion that his results not only do not support logical recoding but "lead to the conclusion that the Simon effect and its reversal result from different factors" (Zhang, 2000, p. 1028). In sum, if the transfer effect in Experiment 2 was due to application of a logical recoding rule (in that case, "respond opposite"), and participants do not make a similar "respond same" transformation when performing the task with the compatible word–response mapping, then no transfer is predicted in Experiment 4, in contrast to the prediction of transfer from the shared representations account.

5.1. Method

5.1.1. Participants

Eighteen new participants (8 males), aged from 19 to 22 years, from the same pool took part. All had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

5.1.2. Apparatus, stimuli, procedure, design

They were identical to that in Experiment 2, except for the following: Each participant performed two blocks of trials, the first was for the compatible task as in Experiment 1A and the second was for the incompatible task as in Experiment 1B. Therefore, this experiment included two phases, a practice phase for the compatible task and a transfer phase for the incompatible task. Each phase had a 2 (response position: left, right) × 2 (stimulus position: left, right) design, with 32 observations per experimental condition.

5.2. Results

Mean correct RTs and PEs are presented in Table 1. For each phase, an ANOVA was performed separately on RT and PE, with stimulus position (left vs. right) and response position (left vs. right) as within-participant variables.

5.2.1. Practice phase

The analysis for the compatible task showed significant main effects of stimulus position and response position, $F(1, 17) = 12.25$, $p = .003$, $MSE = 367$, $\eta_p^2 = .419$, and $F(1, 17) = 7.81$, $p = .012$, $MSE = 1{,}159$, $\eta_p^2 = .\ 315$, as well as an interaction between them, $F(1, 17) = 9.48$, $p = .007$, $MSE = 521$, $\eta_p^2 = .358$. Responses were 17 ms faster when stimulus position and response position corresponded than when they did not.

The analysis of PE revealed a reliable main effect of response position, $F(1, 17) = 7.94$, $p = .012$, $MSE = .001$, $\eta_p^2 = .318$, with more correct responses (1.6%) for the right responses. The main effect of stimulus position was not significant, $F(1, 17) = 1.65$, $p = .217$, $MSE = .001$, $\eta_p^2 = .088$, nor was the interaction ($F < 1$).

5.2.2. Transfer phase

The analyses for the incompatible task showed that the main effects of response position and stimulus position were not significant, $F < 1$ and $F(1, 17) = 3.44$, $p = .081$, $MSE = 1{,}134$, $\eta_p^2 = .168$, but their interaction was, $F(1, 17) = 8.32$, $p = .010$, $MSE = 995$, $\eta_p^2 = .329$. Responses were faster when stimulus position and response position did not correspond than when they did, manifesting as a reverse Simon effect of 23 ms.

The analysis of PE revealed neither reliable main effects of stimulus position and response position, $F < 1$ and $F(1, 17) = 1.36$, $p = .260$, $MSE = .005$, $\eta_p^2 = .074$, nor a significant interaction, $F(1, 17) = 1.70$, $p = .210$, $MSE = .005$, $\eta_p^2 = .091$.

5.2.3. Comparison to Experiment 1B

The reverse Simon effect in the transfer phase (23 ms) was equivalent to that of Experiment 1B (23 ms), for which participants had no prior practice with an incompatible word-location mapping. Also, the Simon effect for PE (2.1%) in this experiment was not significantly smaller than that in Experiment 1B (3.0%), $t(34) = -0.38$, $p = .705$.

5.3. Discussion

When the compatible word–response task was performed in the practice phase, the Simon effect occurred as an RT benefit for correspondence of stimulus and response positions. For the incompatible task performed in the transfer phase, the reversed Simon effect was evident, showing an RT benefit for non-correspondence of stimulus and response positions. The similarity of results in the transfer phase for the incompatible task after practice with the compatible task to those of Experiment 1B with no prior practice indicates that prior practice with the compatible mapping did not influence the subsequent reverse Simon effect obtained with an incompatible word–response mapping. This outcome implies that STM links between stimulus locations and the corresponding responses were not acquired. Based on the logic outlined in the introduction to Experiment 4, the most likely reason for this difference from Experiment 2 is that participants applied a "respond opposite" recoding rule in the practice phase of the earlier experiment, which created the links between incompatible locations, but did not apply a recoding rule in the practice phase of the current experiment.

It is possible that acquisition of short-term associations between compatible stimulus and response locations did occur during practice in Experiment 4, but the incompatible mapping in the transfer session was too dominant to allow those associations to influence performance. However, Miles and Proctor (2008) found that an "implementation intention" to make one particular response to a specific stimulus in a particular location (e.g., respond quickly to a red stimulus in the left location) was just as evident when that implementation was spatially corresponding (e.g., the left response) as when it was noncorresponding (e.g., make the right response). Thus, the most straightforward interpretation of the results is that no associations were established in the practice session, which suggests that STM kinks established as a consequence of logical recoding were the basis for the transfer effect obtained in Experiment 2.

6. General discussion

A benefit for noncorresponding stimulus and response locations has previously been found when location words from an alphabetic language signifying *left* and *right* are mapped incompatibly to left and right keypresses and presented in left and right locations. We replicated this result in Experiment 1 with a logographic language, Chinese, as well as a benefit of correspondence when the mapping was compatible. Thus, the results obtained by Arend and Wandmacher (1987) more than 25 years ago with the German words signifying *left* and *right*, and by Lu and Proctor (1994) more than 20 years ago with the English words, extend to the Chinese language, showing that the results generalize to a non-alphabetic language. The reversal in the practice task could be accomplished by employing a "respond opposite" rule that was inadvertently applied to the physical locations in which the words appeared or by the locations activating representations shared with the words through STM links established for the task.

In Experiment 2, the incompatible-mapping task in the practice phase yielded a reverse Simon effect of −22 ms, as in Experiment 1. In the transfer phase with a compatible word–response task, the Simon effect was a nonsignificant 3 ms. The absence of Simon effect implies occurrence of transfer of the spatially incompatible relation from the practice phase, which counteracted the activation of the corresponding response that typically yields a Simon effect. Experiment 3 showed that the reduced Simon effect in Experiment 2 was not a general consequence of practice responding to location words: The Simon effect was fully apparent in the second trial block when the first block was also performed with a compatible mapping.

These results suggest that the incompatible word–response mapping not only generalizes to the irrelevant stimulus-location dimension of that task but also yields transfer to the processing of that dimension when the word–response mapping is changed to compatible. Our results may seem on the surface to be inconsistent with those obtained by Proctor et al. (2009) and Yamaguchi et al. (2015), in which practicing a task of responding incompatibly to centered location words *left* and *right* did not transfer to a red/green Simon task in which the stimuli appeared in left and right locations. A crucial difference is that by presenting the location words in left and right locations during practice in Experiment 2, the locations themselves were being processed as part of the practice task. Regardless of whether through misapplying a "respond opposite" rule to the physical locations of the words or by activating shared representations through STM links, the combined results of Experiment 2 and those of Proctor et al. and Yamaguchi et al. imply that participants acquired associations between noncorresponding stimulus and response locations in the practice session that continued to produce activation of the noncorresponding response even though the word–response mapping was compatible in the transfer session.

Note that this conclusion is similar to that from Baroni et al.'s (2013) Experiments 3 and 4 in which an incompatible color-mapping task preceded a shape-judgment Simon task: Transfer of the "respond-opposite rule" was evident when the colored stimuli appeared in left and right locations but not when they were presented in a constant, centered location. Having the stimuli vary in left and right locations when responding with either an incompatible color mapping or an incompatible location-word mapping seems to be essential to obtaining transfer to a Simon task, which implies that the transfer occurs by way of acquired associations between spatial locations and responses.

Experiment 4 showed no indication of similar transfer occurring from a prior compatible-mapping task to the incompatible-mapping task: A reverse Simon effect was observed in the transfer session of similar magnitude to that found in Experiment 1B. These results are consistent with the hypothesis that application of a "respond opposite" recoding rule is responsible for the reversal of the Simon effect and to the associations between noncorresponding locations that transfer in Experiment 2. As noted, there does not seem to be much reason to think that a "respond same" recoding rule would be applied when performing the compatible-mapping task in the practice phase, since no transformation is needed. Hence, if application of a recoding rule during the practice tasks is essential, there would be no strengthening of relations between the irrelevant stimulus locations and their corresponding responses. As described in the Discussion of Experiment 4, an alternative is that such relations were acquired for the compatible mapping but were not evident in the transfer task for which the word–response mapping was incompatible. However, given that implementation intentions emphasizing the corresponding response show an effect just as large as that for those emphasizing noncorresponding responses (Miles & Proctor, 2008) and that an intermixed trials with spatially compatible mapping can increase the Simon effect (Marble & Proctor, 2000), this alternative interpretation seems unlikely.

The logical recoding account (Hedge & Marsh, 1975) assumes that response selection is based on abstract translation rules. This account can explain the reverse Simon effect observed in Experiment 1B through generalization of a "respond opposite" rule from relevant location word dimension to the irrelevant stimulus position dimension. Also, this account can explain the finding that the prior incompatible task influenced the Simon effect for the subsequent compatible task in Experiment 2. Application of "respond opposite" to the location dimension results in associations between locations and noncorresponding responses that are then carried forward to the following compatible-mapping task. If it is assumed that no recoding transformation is applied when the word–response mapping is compatible, then the account can also explain why a prior compatible task did not influence the reverse Simon effect for the subsequent incompatible task in Experiment 4.

The STM-link account proposed by Tagliabue et al. (2000) for the transfer paradigm provides an alternative account, according to which the reverse Simon effect with location word stimuli is not due to logical recoding but to left and right stimulus locations activating representations that are shared with the location words *left* and *right*. This activation would strengthen the STM links between noncorresponding S–R locations, which would then continue to produce activation in the transfer session, countering the contribution of the LTM links that produce the standard Simon effect. The STM-link account implies that response selection is performed based on associations between specific stimuli and responses. After the incompatible associations are learned between specific stimulus and response features, these associations remain in memory and affect performance on subsequent trials or tasks if those particular stimulus features occur and retrieve the learned associations. The shared representation account can explain elimination of the Simon effect in Experiment 2 after practicing with an incompatible location-word mapping, but it seems to predict a similar influence of practice with a compatible location-word mapping on the reverse Simon effect in the transfer phase of Experiment 4. This prediction is because STM links should be activated similarly when performing a task, regardless of whether they are compatible or incompatible. We emphasize, though, that regardless of whether the shared representation account or the logical recoding account is correct, they agree that associations between stimulus and response locations are acquired with an incompatible word-location mapping and differ primarily in whether this learning is an automatic consequence of shared representations or due to application of a "respond opposite" rule.

In the current study, we presented the location words in left and right locations to allow stimulus location to vary in the context of compatible and incompatible word–response mappings. This manipulation added another factor that might have affected the results, congruency between the relevant and irrelevant stimulus dimensions (i.e., S–S congruency, the location-word meaning and its physical position). For the compatible mapping task, the S–R corresponding trials were also S–S congruent (e.g., word *left* on the left) and the S–R noncorresponding trials were S–S incongruent (e.g., word *left* on the right). The opposite was true for the incompatible mapping task, in which the S–R noncorresponding trials were S–S congruent and the S–R corresponding trials were S–S incongruent. Thus, the incompatible mapping differs from the compatible one not only in the word–response mapping, but whether the trials with S–S congruence were responded to incompatibly or compatibly.

Hasbroucq and Guiard (1991) proposed that S–S congruence in stimulus-identification processes is the source of the Simon effect in the basic Simon task and in the Hedge and Marsh task with compatible mapping, as well as the reversal with incompatible mapping. But compelling evidence against this stimulus-identification account has been provided (e.g., Hommel, 1995; Lu & Proctor, 1994). Treccani, Cubelli, Della Sala, and Umiltà (2009) provided evidence from a flanker Simon task (in which a target red or green stimulus was flanked to the left or right by an irrelevant stimulus of the same or different color) that S–S congruity of the color interacted with S–R correspondence of location. But it is unclear that similar factors would be involved in the present experiments in which only a single stimulus, albeit with two location attributes, was presented on each trial.

In conclusion, the demonstration that Simon and reverse Simon effects similar to those for German and English location-word stimuli (Arend & Wandmacher, 1987; Lu & Proctor, 1994) are obtained with Chinese location words establishes the reliability of the results and that the results are not restricted to alphabetic languages. Performing an incompatible task in a practice phase not only reversed the Simon effect in that phase but also eliminated the Simon effect when performing a compatible task in the transfer phase, similar to transfer effects obtained from practice with an incompatible color mapping (Baroni et al., 2013). In contrast, performing the compatible task for practice did not influence the reversed Simon effect for the incompatible task in the transfer phase. These results imply that associations between noncorresponding stimulus and response locations are acquired from practice with an incompatible task-relevant mapping that transfer to a task that follows. On the whole, the results tend to favor the view that misapplication of a "respond opposite" rule to stimulus locations in the practice task results in the associations between the noncorresponding locations. Transfer to a subsequent Simon task of noncorresponding S–R associations acquired implicitly during practice of an incompatible word–response mapping seems to occur much as when the associations are acquired explicitly by responding directly to stimulus location with an incompatible mapping.

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