Reversing the Simon Effect with Prior Practice of Noncorresponding Location Words

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Abstract. A benefit for spatial correspondence, called the Simon effect, is typically obtained in choice-reaction time tasks when the stimulus location is irrelevant to the task. Reversal of the Simon effect to favor noncorresponding stimulus-response locations has been obtained for physical-location stimuli after minimal practice (84 trials) with an incompatible spatial mapping. After practice with location-word stimuli, the Simon effect for physical locations is not reduced. The present study evaluated whether practice with "incompatibly" mapped location words can reverse the Simon effect when the practice session emphasizes color-to-response mappings rather than spatial mappings. Two conditions were tested in which the proportion of noncorresponding to corresponding trials was manipulated in the practice session. A full reversal was evident when all trials in the practice session were noncorresponding. Implications for interface design are discussed.

Keywords: Simon effect, stimulus–response compatibility, practice-transfer paradigm.

1 Introduction

One goal of designers is to make products easy to use. For example, when using a stove to cook food, users expect to be able to turn on a specific burner without having to receive any instructions. This expectation is satisfied with well-designed stoves that set the burners and control knobs in layouts that spatially correspond. That is, users can expect a top left burner to be turned on with the knob located in the top left position, top-right burner with the knob in the top-right position, and so on. In addition, to the stimulus-response compatibility effects brought about by mapping of display and control elements, population stereotypes regarding operation of individual controls could also be included in the design to make the product more usable. With the stove example, a right/clockwise rotation of the control knob is expected to turn the burner on and a left/counterclockwise rotation of the knob control is expected to turn the burner off. Both natural response tendencies brought about by stimulus-response compatibility and population stereotypes come from our experience interacting with display and controls in our daily lives.

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1.1 SRC and Simon Tasks

Stimulus-response compatibility (SRC) refers to better performance for compatible than incompatible mappings of stimulus locations to response locations [1]. In a two-choice task where the stimulus could occur in a left or right location and the response is a left or right keypress, the compatible mapping of left stimulus to left response and right stimulus to right response yields better performance than the incompatible mapping of left stimulus to right response and right stimulus to left response. Spatial compatibility effects not only apply to physical locations, but they are also obtained with conceptually similar stimuli and responses. For example, compatibility effects occur when the meaning of the stimulus (e.g., the word “left”) is compatible with the meaning of the response (e.g., turn left). In general, compatibility effects occur when there is similarity, or dimensional overlap, between the stimulus and response set [2]. Thus, compatibility effects are obtained with arrow stimuli that point in left-right directions and “left”-“right” location-word stimuli. Similarly, compatibility effects occur when the responses are verbal (e.g., saying the words “left”/”right”) as well as when they are manual (left-right keypresses; joystick movements; steering wheel rotations) [1].

Compatibility effects also occur when stimulus location is nominally irrelevant to the task. When responses are to be based on a non-spatial feature, such as stimulus color or shape rather than its location, performance is better when the stimulus and response locations correspond compared to when they do not. For example, if a participant is instructed to press a left button whenever a circular stimulus appears in green and a right button whenever the stimulus appears in red, then responses will be faster if the green stimulus appears on the left and the red stimulus on the right than vice versa. This spatial correspondence effect is called the Simon effect after its discoverer, J. R. Simon [3]. As with the SRC effects, the Simon effect also occurs for physical-location, arrow-direction, and location-word stimuli. The size of the Simon effect varies as a function of the stimulus and response modalities. For example, the Simon effect is usually twice as larger for auditory than visual stimuli [1].

Kornblum et al. [2] developed a dimensional overlap model to explain compatibility effects. For stimulus and response sets that have a dimensional overlap (perceptual, conceptual, or structural similarity), response selection occurs via two routes: direct and indirect. The direct route is based on automatic response tendencies. Kornblum et al. define automatic, “as the process that leads to the activation of a congruent response” (p. 262). The level of activation varies with the amount of dimensional overlap between the stimulus and response sets, such that the more overlap, the greater the benefit for congruent responses and the greater the cost for incongruent responses. Degree of overlap can explain why compatibility effects are larger with specific combinations of stimulus and response modes. Before response selection is complete, information goes through a verification stage to determine whether the automatically activated response is the correct response to be selected based on the task instructions. If the automatically activated response is correct, then the response is executed. If not, then the automatically activated response is inhibited, and the correct response is retrieved and executed. There is a delay for inhibiting the automatically activated response along with retrieving the correct response. According to the dimensional overlap model [2], compatible stimulus-response mappings yield shorter reaction time than incompatible mappings because the compatible mapping benefits from automatic activation via the direct route and more efficient response translation via the indirect route. For incompatible spatial mappings, there is no benefit in response selection via the direct route, but response selection via the indirect route is more efficient if a response-selection rule can be applied (e.g., respond at the mirror-opposite location) than if the individual stimulus-response pairings are arbitrary. Although both routes contribute to the effects of SRC proper, only the direct route contributes to the Simon effect.

1.2 Practice and Transfer

S-R compatibility and Simon effects have been of basic and applied interest because they have been shown to be robust, persisting even after extensive practice. Studies that have had participants complete between 900-3,000 trials over multiple blocks, days, or weeks have shown that participants become faster and more accurate all mappings, but the benefit for compatible mapping over the incompatible one is not eliminated [4, 5]. Dutta and Proctor [6] had participants complete 300 trials a day for 8 days (total of 2,400 practice trials) with a compatible or incompatible spatial mapping for two-choice and four-choice reaction tasks. For all mappings and tasks, participants showed a practice effect in which RT decreased by roughly 30 ms by the 4th day. For the two-choice reaction tasks, performance leveled off at that point, but for the four-choice task, there was an additional benefit of practice: RT continued to decrease by another 11 ms by the 8th day. The additional benefit of practice for the four-choice task is usually attributed to the additional number of response choices [2]. However, the benefit for the compatible mapping is not eliminated. Similar practice effects have been found with the Simon task as well [3]. Thus, studies of practice with SRC proper and the Simon effect show that activation of the spatially corresponding response cannot be overridden easily.

However, studies that have employed a practice-transfer paradigm to examine the influence of prior spatial mappings on the Simon effect show that compatibility effects are more malleable than that suggested by the aforementioned practice studies [4, 5, 7]. In these studies, participants practiced with as few as 72 trials with a spatially incompatible mapping of stimulus locations to responses and then were subsequently transferred to a Simon task where responding was to be based on stimulus color or shape. After practice with the incompatible mapping, the inherent advantage for corresponding stimulus-response relations giving rise to the Simon effect was eliminated or even reversed. The elimination of the Simon effect supports the notion that natural response tendencies can be overridden and that the underlying mechanisms of the transfer effect are powerful enough to prevail over the long-term associations. Moreover, the transfer effect has been shown to persist over a 1-week delay [7].

In the initial studies, the stimuli varied in left-right physical locations and responses were made with left-right keypresses in both the practice and transfer sessions. Comparing the similarities and differences between stimulus modes within a practice-transfer paradigm could provide insight on the nature of the stimulus-response associations that are being acquired and transferred to the Simon task. Proctor et al. [8] examined all possible combinations of practice and transfer for physical location, arrow-direction, and location words stimuli mapped to keypress responses.

In the practice session, participants performed with an incompatible mapping of locations, arrows, or words. Within each of these conditions, different groups of participants were transferred to a Simon task in which they responded to the color of the location, arrow, or word stimuli. With as little as 84 practice trials with an incompatible spatial mapping, the Simon effect was eliminated for location and arrow stimuli, regardless of whether the same stimulus mode was use in the practice and transfer sessions or not. The complete transfer of associations between locations and arrows suggests that these stimulus modes share visual-spatial codes. With practice of location word stimuli, there was no transfer to physical location stimuli after 84 practice trials, suggesting that verbal-spatial associations are distinct from visual-spatial ones.

One reason for the separation of verbal-spatial and visual-spatial codes in this task is that there is a salient distinction between how the physical locations and location words are displayed in the practice and transfer task, as illustrated in Fig. 1. Physical locations stimuli are presented in left and right locations and overlaps with the physical locations of the response keys. Location words are centrally presented and the meaning of the words overlaps with the left-right physical location of the response keys. This difference in the presentation of the stimuli may lead participants to treat the location word practice task as separate from the physical location Simon transfer task. Vu [9] showed that with only 84 practice trials, the associations for horizontal and vertical locations are kept distinct, but after extended practice, general response-selection procedures are learned and transferred across dimensions to the Simon task. Proctor et al. [8] showed that even after extended practice with incompatibly mapped location words, though, there was no transfer to the Simon task for physical locations. One question that arises then is, what do participants learn in the practice session? Is it the spatial associations of left stimulus-right response and right stimulus-left response, or is it more specific associations of left circle-right key and right circle-left key / the word "left"-right key and the word "right"-left key. Current evidence suggests the latter. However, if there is a way to make the practice and transfer task more similar, then the spatial associations may transfer between location words and physical locations. In the present study, the practice task using location word stimuli was made to be more similar to the transfer task using physical location stimuli by manipulating the task instructions for the practice session.

Instructions on the practice task can either explicitly describe an incompatible spatial mapping, or they can refer to a dimension such as color with the incompatible spatial mapping implemented implicitly. In previous studies, participants were explicitly instructed to respond to the stimulus location with an incompatible spatial mapping in the practice session. In the present study, the participants were given instructions to respond based on the color of the stimulus in both the practice and transfer sessions. Although both tasks are nominally Simon tasks, the proportion of noncorresponding-to-corresponding stimuli in the practice session was 1.0 to 0 in Condition 1, making it equivalent to an incompatible spatial compatibility task. Condition 2 use a standard Simon task (proportion of noncorresponding-to-corresponding trials is .5 to .5) in both the practice and transfer sessions to serve as a control group.

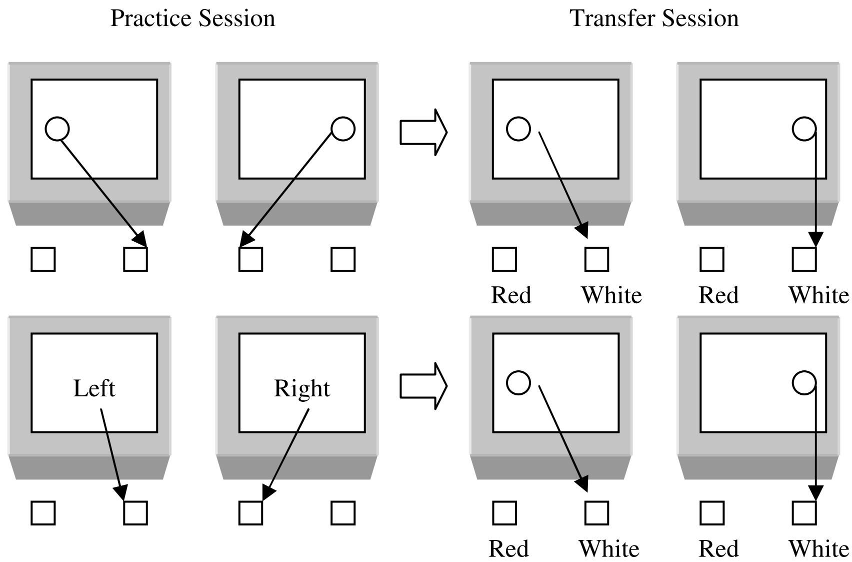

Fig. 1. Illustration of the practice and transfer task when physical locations are used for both the practice and transfer sessions (top) and when location word stimuli are used for the practice session and physical location stimuli for the transfer session (bottom). For the transfer session, only one color-to-response mapping is illustrated.

1.3 Present Study

This study was conducted to evaluate whether practice with non-corresponding mappings of location-words can reverse the Simon effect with as few as 84 practice trials when the practice session emphasizes color-to-response mappings rather than spatial mappings. If the Simon effect is reduced in the transfer session then this would indicate that specific, color-response associations transfer between stimulus modes, but the spatial relations do not. Two conditions were employed: condition 1 consisted of 0% to 100% corresponding to noncorresponding trials, and condition 2 50% to 50% corresponding to noncorresponding trials (which is the composition of a standard Simon task). Condition 1 is equivalent to a spatial incompatible mapping, where the stimulus and the response can be summarized by a rule to respond opposite to the spatial locations. At the end of the session, participants were asked if they were aware of the any patterns or differences between the two sessions to determine whether learning of spatial associations were implicit or explicit [10].

2 Method

2.1 Participants

A total of 80 students from California State University Long Beach participated for experimental credits towards an Introductory Psychology course requirement. There were 14 males and 66 females, age ranging between 18 to 39 years (M = 19.35, SD = 3.02). All subjects reported having normal or corrected-to-normal vision. Forty participants were assigned to one of the two practice conditions that varied in the proportion of noncorresponding-to-corresponding trials.

2.2 Design

A practice-transfer paradigm was used in which subjects practiced with a location-word Simon task in which the percent of corresponding to noncorresponding responses was 0%-100% (condition 1) or 50%-50% (condition 2/control) and then subsequently transferred to a standard Simon task using physical location stimuli. In the transfer Simon task, the percent of noncorresponding-to-corresponding trials was the standard 50%-50%. Although Simon stimuli were used in practice sessions, the fact that all trials were noncorresponding in condition 1 makes it equivalent to a spatially incompatible mapping if responses were to be based on stimulus location and not color.

To analyze the effects of the practice session on the Simon effect, the study employed a 2 (Condition: 1 and 2) x 2 (Correspondence: noncorresponding and corresponding) mixed design. Condition was the between-subjects factor. The dependent measures were reaction time and percent error.

2.3 Apparatus and Stimuli

Micro Experimental Laboratory (MEL v 2.01) was used to program all components of the experiment, including stimulus presentation, timing of events, recording the responses, and presenting the instructions. The program was run on a personal computer with a 14" VGA color monitor. The participants were tested individually in a dimly lit room directly in front of the monitor at a viewing distance of 60 cm. Participants responded with the number pad of the keyboard that was aligned to the center of the monitor. Responses were made on the computer keyboard's number pad by pressing the "4" and "6" keys with the index finger of each hand. Stimuli in the practice sessions for both conditions were the words "left" and "right" presented in lowercase letters at the center of the screen (approximate size of 12 mm x 5mm and 15 mm x 5 mm with visual angles of 1.56° x 0.52° and 1.24° x 0.52°, respectively) occurring in either red or green (MEL color codes 4 and 2, respectively). In the transfer sessions, filled red and green circles of 5 mm (visual angle 1.43°) diameter were presented to the right or left location approximately 3 inches from the center of the screen.

2.4 Procedure

For the practice session, participants were instructed to respond to the color of the location word stimuli, while ignoring the meaning of the word. Half of the participants were told to press the "4" key when the location word was presented in the color "red" and the "6" key when the location word was presented in the color "green". For the other half of the participants, the color-to-response assignment was reversed. Participants were instructed to respond as quickly and accurately as possible. The practice sessions included 72 trials plus 12 warm-up trials. Every trial started with a fixation point that remained on screen for 1,000 ms, and then the target stimulus was presented for 1,500 ms or until the participant responded. If the allotted time lapsed without a response or if an incorrect response was made, a 400-Hz error tone was presented for 500 ms, followed by a blank inter-trial interval of 1,000 ms.

Upon completing the practice session, the participant notified the experimenter, who then set up the program for the transfer session, allowing the participant to take a break. The participant then completed the transfer session in which they were instructed to respond to the color of the circles while ignoring the spatial location. The transfer sessions included 144 trials and 12 warm-up trials. The color-to-response assignment, trial timing, and all other constraints remained the same as in the practice session. At the end of the experiment, all participants filled out a quick survey that collected demographic information along with a question that asked if they noticed a pattern and if so, to identify the pattern. The pattern recognition data are presented in the Discussion section.

3 Results

Reaction time (RT) was measured as the time between stimulus onset and the depression of a response key. For the RT analysis, only correct responses were used, and percent error (PE) was analyzed separately. Trials in which RT was less than 200 ms or greater than 2,000 ms were excluded as outliers (< 1% of all trials); the first 12 trials were also excluded and considered warm-up trials.

3.1 Practice Sessions

A one-way analysis of variance (ANOVA) was run comparing overall RT and PE as a function of condition. The effect of practice condition was not significant for either RT or PE, *Fs* < 1.0 (see Table 1 for means). This finding indicates that participants were performing at similar levels prior to the transfer session. An additional analysis was performed to determine the Simon effect for location words in condition 2. A repeated measures ANOVA was conducted on mean RT and PE for corresponding and noncorresponding trials in condition 2. The effect of correspondence was significant for RT, $F(1, 39) = 5.32$, $p < .03$, with the Simon effect being 17 ms. The effect of correspondence for PE was not significant, $F(1, 39) = 1.68$, $p > .20$.

Table 1. Means for both practice sessions

Condition (C-NC trials)	Mean	
	RT	PE
1. 0-100%	532	2.70
2. 50-50%	548	3.09

3.2 Transfer Sessions/Simon Effect

A 2 (Correspondence: corresponding or noncorresponding) x 2 (Practice Condition: 1: 0-100% or 2: 50-50%) mixed ANOVA was performed on mean RT and PE. The main effect of correspondence was marginally significant for RT $F(1, 78) = 3.37$, *p*s = .07, but not PE $F < 1.0$ (see Table 2 for means). The main effect of practice condition was not significant for either measure, Fs < 1.0. The interaction between correspondence and practice condition; however, was significant for both measures, Fs(1, 78) = 47.00 and 8.42, ps = .00 and .005. Follow-up analyses were performed to determine the effects of practice condition on the correspondence effect. The Simon effect reversed in condition 1, where the corresponding to noncorresponding trials was 0-100%, for both RT and PE, Fs(1, 39) = 32.78 and 4.31, ps = .00 and .04, respectively. For condition 2, in which the corresponding to noncorresponding trials was 50-50%, the Simon effect was significant for RT but not significant for PE, Fs(1, 39) = 10.98 and 1.05, ps = .002 and .31, respectively. Simon effect sizes can be seen in Table 2.

Because condition 2 was intended to serve as a control condition, an ANOVA was performed to determine if the Simon effect varied as a function of practice and transfer session. There was no significant difference in Simon effects across the two sessions in condition 2 for RT or PE, Fs < 1.0.

Table 2. Means and Simon Effect for both transfer sessions

Condition (C-NC trials)		Mean		Simon Effect	
Correspondence		RT	PE	RT	PE
1. 0-100%	C	553	3.31		
	NC	524	2.06	-28**	-1.2%
2. 50-50%	C	532	1.84		
	NC	548	2.77	+16**	+1.0%

Note: C = corresponding, NC = non-corresponding
* $p < .05$, ** $p < .002$

4 Discussion

When all the trials were non-corresponding in the practice block (condition 1), the Simon effect was significantly reversed in the transfer block. Thus, prior practice with noncorresponding mappings of location words to keypresses can influence the Simon effect for physical location stimuli in a subsequent session. The Simon effect was present in condition 2, which was the control condition. This implies that practice with the color-response associations alone does not eliminate the Simon effect.

To determine whether the impact of the spatial correspondence relation was implicit or explicit, participants were asked if they had noticed any patterns during the experiment and, if so, to specify the pattern. This question was not asked until after the conclusion of the experimental sessions when participants filled out the demographic form, so there was no possibility that the question could have primed the participants to look for patterns during the experimental sessions. For condition 1, the majority of participants, 77.5%, responded with a correct pattern recognition response, indicating that they had indeed noticed the complete noncorresponding relation (Yes = 31/40). Only 22.5% of the participants responded that they either had not noticed a pattern or proceeded to elaborate on an erroneous pattern (No = 9/40). Because the majority of participants in condition 1 did in fact notice the pattern that stimulus assignment color was always presented on the side opposite to the response, we cannot attribute the transfer effect to learning implicitly [9]. To determine whether the impact of the transfer effect was affected by the explicit recognition of the spatial incompatible relation, reaction times were compared for those who noticed the pattern and those who did not notice a pattern. No significant differences were found between the two groups. This finding requires further investigation to evaluate the differences that are encountered when the participant is explicitly informed of the pattern, compared to when they notice it themselves.

In daily life we switch between verbal and spatial tasks such as when we follow directions in a navigation task. For example, when driving, we may be looking at our Global Positioning System (GPS) to determine where to go. We might see that there is a left turn coming up and so we automatically switch on our left blinker and start moving to the left lane preparing for the turn. GPS directions provided while driving could be commands presented verbally, visually, or both. Currently, the GPS is designed to give directions that are compatible with the response (e.g., turn left or turn right), but more advance systems can give information about locations to avoid (e.g., traffic jams). In this case, a spatially incompatible response is made to the location to be avoided. This study showed that people can be influenced by a spatially incompatible mapping that is no longer relevant to the current task. Thus, designers should take care in making sure that the impact of spatial incompatibility of subsequent tasks is minimized.

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