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Mixing location-irrelevant and location-relevant trials: Influence of stimulus mode on spatial compatibility effects

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The performance advantage for spatially compatible mappings of physical locations to keypress responses, relative to incompatible mappings, is eliminated when stimulus color, rather than location, is relevant on half of the trials. In Experiment 1, we compared the effects of mixing for different stimulus modes (physical locations, arrow directions, and location words) to determine whether this elimination of the stimulus–response compatibility (SRC) effect would generalize to other stimulus modes. The SRC effect was unaffected when the location information was conveyed by arrows and was amplified when the location information was conveyed by words. In Experiment 2, we used vocal *left–right* responses instead of keypresses, and the SRC effects for all three stimulus modes were enhanced by mixing. In both experiments, for all stimulus modes, mixing reduced or reversed correspondence effects for trials on which the location information was irrelevant when the mapping for those trials on which it was relevant was incompatible. These findings suggest that when trial types are mixed, direct activation of the corresponding response, regardless of mapping, does not occur for physical locations mapped to keypresses. However, such activation does occur when stimuli or responses are verbal, apparently because performance is mediated in part by activation of a verbal name code for the stimulus.

In recent years, considerable interest has been shown in the effects of mixing tasks or stimulus–response (S–R) mappings within sets of trials (e.g., Los, 1996). When two tasks are mixed, subjects must prepare, or be set, for both tasks, maintaining the associations between stimuli and responses defined by the instructions for each task. Then, upon stimulus presentation, a decision must be made as to which task or mapping is appropriate for a specific trial, and if response accuracy is to be high, responding must be controlled by the appropriate set of S–R associations. Consequently, responding takes longer and is more effortful with mixed presentation than with pure blocks of a single trial type (e.g., Proctor & Fisicaro, 1977). Processing may also change in other ways because mixing increases uncertainty, mental load, and intertrial variability (Los, 1996).

A fruitful area of research for studying the effects of mixing trial types is that of S–R compatibility (SRC). SRC effects are differences in reaction time (RT) and accuracy that can be attributed to the relation between stimuli and responses. Considerable evidence indicates that SRC effects have their bases primarily in response-selection processes (Hommel & Prinz, 1997; Proctor & Reeve, 1990). For two-choice tasks in which left and right stimuli are mapped to left and right keypresses, the mapping that maintains spatial correspondence between stimuli and responses produces faster and more accurate responding than the one that does not (e.g., Shaffer, 1965).

When stimulus location is irrelevant and a nonspatial dimension such as color is relevant, a similar but smaller spatial correspondence effect is obtained (Lu & Proctor, 1995): The left response is faster when the stimulus occurs in the left position than when it occurs in the right position, and the right response shows the opposite relation. This spatial correspondence effect is known as the Simon effect, after J. R. Simon, who was the first to demonstrate and investigate it (see Simon, 1990, for a review of his work). It is similar to the more widely known Stroop color-naming effect, first demonstrated by J. R. Stroop (1935/1992), in which an irrelevant, noncorresponding color word interferes with the naming of the color in which the word is printed. With regard to irrelevant spatial information, the term *Simon effect* is most often used for cases in which the relevant stimulus dimension is not conceptually similar to the irrelevant location dimension; the term *spatial Stroop effect* sometimes is used when the two stimulus dimensions are conceptually similar (i.e., both refer to spatial locations). There is debate over whether the Simon effect obtained when the stimulus dimensions are similar has the same processing basis as the spatial Stroop effect obtained when the dimensions are dissimilar (see, e.g., Lu & Proctor, 2001). However, in the most well-known model of correspondence effects, the *dimensional overlap model* of Korn-

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blum (1994), the Simon effect is attributed to response-selection processes and the spatial Stroop effect to interference in stimulus-identification processes.

Most contemporary accounts of spatial compatibility effects, including the Simon effect, postulate two response-selection routes (Hommel & Prinz, 1997), one that is direct (or automatic) and one that is indirect (or intentional). By way of the direct route, a stimulus activates response codes through long-term S–R associations that are overlearned or innate. By way of the indirect route, a stimulus activates responses through short-term associations or translation rules defined by the task instructions (Barber & O'Leary, 1997; Tagliabue, Zorzi, Umiltà, & Bassignani, 2000). For SRC proper, the task-defined associations are in agreement with the long-term associations (compatible mapping) or in opposition to them (incompatible mapping). The advantage for the compatible mapping over the incompatible mapping is attributed to both indirect translation's being more efficient and the direct response activation's being facilitatory when it is correct and inhibitory when it is incorrect. For the Simon effect, the task-defined associations of a nonspatial stimulus dimension to keypresses are unrelated to the long-term S–R associations for the irrelevant spatial dimension. This effect is presumed to arise solely from the direct activation of the corresponding response produced by the long-term location associations.

Mixed Compatible and Incompatible Mappings

Trials for which the S–R mapping is spatially compatible can be mixed with ones for which it is not. When mixed and blocked presentations of compatible and incompatible mappings are compared, the typical finding is that mixing slows responses more on compatible trials than on incompatible trials (e.g., De Jong, 1995; Duncan, 1978; Stoffels, 1996b; Van Duren & Sanders, 1988). In the first study of this type, Shaffer (1965) used a mapping signal (a horizontal or vertical line) to designate whether the mapping of left and right location stimuli to left and right keypresses for the trial was compatible or incompatible. When the mapping signal was presented prior to the imperative stimulus, an SRC effect of 45 msec was obtained; however, when the mapping signal was presented simultaneously with or after the imperative stimulus, the SRC effect was eliminated (−8 and 7 msec, respectively). Subsequent studies in which tasks with four stimuli were mapped to the index and middle fingers of each hand, two compatibly and two incompatibly, have also shown a strong reduction of the SRC effect (Duncan, 1978; Ehrenstein & Proctor, 1998; Stoffels, 1996b).

Reduction of the SRC effect under mixed mapping conditions is not limited to physical location stimuli. De Jong (1995) used a mapping-signal procedure similar to that of Shaffer (1965), but with the mapping signal being a high- or low-pitch tone, the stimuli upward-pointing arrows tilted to the left or right, and the responses left and right keypresses. At the shortest stimulus onset asynchrony (SOA) of 100 msec between the mapping and imperative stimuli, the SRC effect was only 18 msec. In contrast, the effect was 45 msec for pure blocks of compatible and incompatible mappings. Stoffels (1996a) used a four-choice task, in which left- and right-pointing arrows of different colors were mapped to four responses made with the index and middle fingers of each hand. For mixed presentation, the mapping of arrow direction to response location was compatible for the two inner locations and incompatible for the two outer locations, or vice versa. The inner or outer locations (and mapping in the mixed blocks) were designated by arrow color (white vs. black or light vs. dark gray). The SRC effect was 83 msec for blocked presentation but only 22 msec for mixed presentation.

The most widely accepted explanation for the reduction of the SRC effect with mixed compatible and incompatible mappings is called the *alternative-routes model* (De Jong, 1995; Stoffels, 1996a, 1996b; Van Duren & Sanders, 1988). It is a version of the dual-route response-selection accounts, described earlier, in which the direct response-selection route is presumed to be used only for pure blocks of compatible mappings. This route is suppressed, and the indirect route is used when the mappings are incompatible or when compatible and incompatible mappings are mixed. The reason the direct route cannot be used for compatible trials when mappings are mixed is that it would lead to incorrect responses on incompatible trials. De Jong tested this account against two others. One, the *transient priming hypothesis*, assumes that the corresponding response receives activation by way of the direct route under both blocked and mixed conditions, but because responding is slowed in the mixed condition, this activation is no longer present during response selection. The other, the *bias hypothesis*, assumes that subjects are biased to prepare for the incompatible mapping, resulting in a cost when the current trial is compatible. De Jong concluded that only the alternative-routes model could account for the results of his experiments in which response priming and probabilities of the mappings were varied.

Mixed Location-Relevant and -Irrelevant Trials

In another variation of the mixing procedure, location-relevant stimuli, which are mapped either compatibly or incompatibly to responses, are mixed with location-irrelevant stimuli (for which color is the relevant dimension). Consistent with the terminology used in earlier studies, we use the terms *location-relevant* and *location-irrelevant* to refer not only to physical locations but also to the location information conveyed by left- or right-pointing arrows and the words *left* and *right.* When location-relevant and -irrelevant trials are mixed, one pair of task-defined S–R associations relates the location information to responses (in a manner consistent with or in opposition to the long-term associations between stimuli and their corresponding responses), and the other pair relates stimulus color to responses. If the direct response-selection route is suppressed under mixed conditions for which stimulus location is irrelevant on half of the trials, the SRC effect for location-relevant trials should be eliminated, as it is when compatible and incompatible mappings are mixed. Also, whether the task-defined associations for the location-relevant mapping produce activation on location-irrelevant trials can be determined by comparing the direction and magnitude of the Simon effect when the location-relevant mapping is compatible or incompatible. If those associations contribute to response activation, the Simon effect should reverse to favor the noncorresponding responses when the location-relevant mapping is incompatible, or if it does not reverse, the effect should be smaller in magnitude than when the mapping is compatible. Because direct response activation by way of long-term associations should favor the corresponding response regardless of the location-relevant mapping, a reverse Simon effect of the same magnitude as the positive Simon effect would suggest that the effects are solely a function of the task-defined associations.

De Jong (1995, Experiment 3) used this procedure, with the mapping signal being a high- or low-pitch tone occurring either 10 or 800 msec prior to the imperative stimulus. The mapping signal indicated whether color or arrow direction was relevant on a given trial. The compatibility effect for location-relevant trials did not differ reliably across the two preparation intervals, being 33 msec at the 10-msec interval and 38 msec at the 800-msec interval. For location-irrelevant trials, when the mapping stimulus was presented 10 msec before the imperative stimulus, a positive Simon effect (benefit for correspondence of arrow direction and response) of approximately 100 msec was obtained when the location-relevant mapping was compatible, and the effect was reduced to about 30 msec when the mapping was incompatible. De Jong's study demonstrates that the Simon effect for arrow direction is not due solely to direct activation of the corresponding response via the long-term association, because the effect was larger when the task-defined location associations also designated corresponding responses than when they designated noncorresponding responses.

We have conducted several experiments similar to De Jong's (1995) Experiment 3, but we used physical location stimuli rather than arrow-tilt stimuli to convey the location information (Marble & Proctor, 2000; Proctor, Vu, & Marble, in press). The stimuli were circles presented in left and right locations, and stimulus color designated whether physical location was relevant (white) or irrelevant (red or green) on a given trial. The location-relevant trials showed no SRC effect, an outcome similar to that found when compatible and incompatible spatial mappings are mixed (Shaffer, 1965). For the location-irrelevant trials, the typical Simon effect increased in magnitude for the blocks in which the location-relevant mapping was compatible and reversed for the blocks in which the mapping was incompatible (44 and −64 msec, respectively, in Marble & Proctor's Experiment 1; 48 and −47 msec, respectively, in Proctor et al.'s, in press, Experiment 1). That is, with an incompatible location-relevant mapping, responses on location-irrelevant trials were faster and more accurate when the stimulus and response locations did not correspond than when they did. The fact that this reversed effect obtained with an incompatible location-relevant mapping was at least as large as the positive Simon effect obtained with a compatible mapping suggests that the long-term corresponding S–R associations of the direct route were not contributing to performance.

Proctor, Marble, and Vu (2000) conducted similar experiments to those of Marble and Proctor (2000), using only an incompatible location-relevant mapping, with the location information being conveyed by the words *left* or *right* and left- or right-pointing arrows, as well as physical locations. As before, a white color designated location information as relevant, and a red or green color designated color as relevant. The reverse Simon effect was also obtained for words and arrows for an incompatible mapping of the location information to responses. However, the magnitude of the reversal was smaller for words ($M = -34$ msec) than for arrows ($M = -56$ msec)[1] and physical locations ($M = -64$ msec). The reversal of the Simon effect when the mappings were incompatible implies that, for all stimulus modes, the task-defined associations were influencing performance.

Because the focus of the Proctor et al. (2000) study was on the effects that incompatibly mapped location-relevant information has on location-irrelevant trials as a function of stimulus mode, conditions in which the location-relevant mapping was compatible were not included. Thus, it was not possible to determine whether, as predicted by the alternative-routes model, mixing would eliminate the SRC effect for arrow directions and location words. Likewise, it could not be determined whether the reverse Simon effect for these stimuli with an incompatible mapping was as large as the positive Simon effect obtained with a compatible mapping, as is the case for physical location stimuli. Such a comparison of absolute values of the Simon effects under the alternative location-relevant mappings is necessary in order to evaluate whether the effects are due entirely, or only partially, to the task-defined associations. In Experiment 1, we evaluated performance with three stimulus modes (physical locations, arrow directions, and location words) mapped compatibly or incompatibly to keypress responses in pure blocks of location-relevant trials or in mixed blocks in which half of the trials were location-irrelevant. In Experiment 2, vocal *left–right* responses were used to determine whether different results obtained for the three stimulus modes in Experiment 1 could be attributed to the stimulus properties alone, to the combination of the stimulus modes with manual responses, or to properties of verbal coding.

EXPERIMENT 1

In Experiment 1, the subjects performed tasks with left–right physical locations, left–right pointing arrows, or *left–right* words mapped compatibly or incompatibly to left–right keypress responses. In the pure conditions, the location information was relevant for all trials, and only a single mapping was in effect. In the mixed conditions, trials for which the location information was irrelevant (and stimulus color relevant) were intermixed with the location-relevant trials. On the basis of the results of Proctor et al. (in press), we expected that the SRC effect for physical location stimuli evident in the pure blocks would be eliminated in the mixed blocks. Also, for location-irrelevant trials, physical locations were expected to show equivalent positive and reverse Simon effects when the location mappings were compatible and incompatible, respectively. The question of interest was whether arrow and word stimuli would show similar results, as the alternative-routes model suggests.

Method

Subjects

One hundred ninety-two students from Purdue University participated for credit toward course requirements. All were naive to the experiment and reported having normal or corrected-to-normal vision.

Apparatus and Stimuli

The stimuli were presented on IBM-compatible microcomputers, with 14-in. VGA color monitors. Micro Experimental Laboratory (MEL 2.01) was used to control the experiment. The subjects sat directly in front of the monitor, at a viewing distance of approximately 55 cm. The stimuli were red, green, or white (MEL color codes 4, 2, and 15, respectively) physical locations [circles: 5-mm (0.52°) diameter, presented in left or right locations (60 mm from center at 6.23° viewing angle)], words [*left* or *right* (approximately 12 × 5 mm and 15 × 5 mm, visual angles of 1.56° × 0.52° and 1.24° × 0.52°, respectively), presented at the center of the screen], and filled arrows [2.54-cm (2.64°) long, with the width of the arrowhead being 2.86 cm (2.98°) and the width of the tail being 1.27 cm (1.32°), presented in the center of the computer screen]. Responses were made by pressing the "z" and "/" keys on the computer keyboard, the leftmost and rightmost keys on the bottom row, with the index finger of each hand.

Procedure

Stimulus mode (physical locations, arrows, or words), location-relevant mapping (compatible or incompatible), and condition (pure or mixed) were manipulated between subjects, with 16 subjects tested in each group, in order to minimize carry-over effects. All other variables were manipulated within subjects. The subjects were presented with red, green, and white circles (in left or right physical locations), arrows, or location words. For the pure conditions, the subjects were instructed to respond on the basis of location information alone, while ignoring the stimulus color. In the pure compatible condition, the corresponding key was to be pressed (e.g., the left key if the circle was in the left location and the right key if the circle was in the right location), whereas in the pure incompatible condition, the noncorresponding key was to be pressed (e.g., the left key if the circle was in the right location and the right key if the circle was in the left location). For the mixed conditions, the subjects were to respond with a right or left keypress according to the color of the stimuli (red or green) and to the location information of the white stimuli. In the mixed compatible condition, they were to press the corresponding key to the white stimuli, whereas in the mixed incompatible condition, they were to press the noncorresponding key to the white stimuli. For the red and green stimuli, the subjects were instructed to ignore the location information provided by the stimulus when they selected the correct response (the red stimulus was assigned to the left response and the green stimulus to right response for half the subjects, and vice versa for the other half).

Each subject was tested in a single session consisting of 400 trials (pure condition, 400 location-relevant trials; mixed condition, 200 location-irrelevant and 200 location-relevant trials). For all conditions, the order in which the trial types appeared was randomized. The subjects were instructed to respond as quickly and accurately as possible. RT was measured from stimulus onset to the depression of a response key. The stimulus remained present until a response was made, and the intertrial interval was 1 sec. A 400-Hz error tone was presented for 500 msec for incorrect responses, followed by the 1-sec intertrial interval.

Results

Trials in which RT was less than 200 msec or greater than 2,000 msec (less than 1% for all experiments) were discarded. The first 20 trials were considered practice and were not included in the analyses. Mean correct RT and percentage error (PE) were submitted to analyses of variance (ANOVAs). For the pure blocks of location-relevant trials, only trials for the white stimuli were included in the analyses to equate the number of trials with that for the mixed condition.

Location-Relevant Trials

A 2 (condition: pure or mixed) × 2 (compatibility: compatible or incompatible) × 3 (stimulus mode: physical locations, arrows, or words) ANOVA was conducted for RT and PE (see Table 1 for means). Condition, compatibility, and stimulus mode were all between-subjects factors.

Reaction time. There was a main effect of stimulus mode [$F(2,180) = 67.49$, $MS_e = 7,287$, $p < .001$]. Responses were slower for location words ($M = 658$ msec) than for physical locations ($M = 504$ msec) and arrows ($M = 508$ msec). Condition also showed a main effect [$F(1,180) = 580.90, p < .001$], with RT being shorter in the pure condition ($M = 408$ msec) than in the mixed condition ($M = 705$ msec). In addition, there was a significant main effect of compatibility [$F(1,180) = 19.85, p < .001$], reflecting an overall 55-msec SRC effect.

The condition × stimulus mode interaction was significant [$F(2,180) = 6.02$, $p = .003$]. The mixing effect (the advantage for the pure condition over the mixed condition) was smallest for arrows [mean difference (MD) = 241 msec], intermediate for physical locations (MD = 306 msec), and largest for words (MD = 345 msec). The three-way interaction of condition × compatibility × stimulus mode was also significant [$F(2,180) = 8.21, p < .001$]. Separate analyses were performed for each of the three stimulus modes in order to clarify this interaction.

For the physical location stimuli, condition interacted with compatibility [$F(1,60) = 4.51, MS_e = 7,655, p = .038$]. In the pure condition, there was an SRC effect of 77 msec [$F(1,30) = 12.21, p = .002$], but mixing slowed RT 93 msec more for the compatible than for the incompatible mapping, resulting in a nonsignificant 16-msec reverse SRC effect for the mixed condition ($F < 1.0$). For the arrow stimuli, there was a marginal main effect of compatibility [$F(1,60) = 3.87$, $MS_e = 5,754$, $p = .054$], and compatibility did not interact with condition ($F < 1.0$). The SRC effect was 32 msec for the pure condition [$F(1,30) = 3.56$, $p = .069$] and 42 msec for the mixed condition [$F(1,30) =$

1.58, $p = .219$]. For the word stimuli, there was a main effect of compatibility [$F(1,60) = 17.67$, $MS_e = 8{,}453$, $p < .001$], and compatibility interacted with condition [$F(1,60) = 10.76$, $p = .002$]. In the pure condition, there was a nonsignificant 21-msec SRC effect ($F < 1$), but mixing slowed RT 151 msec less for the compatible than for the incompatible mapping, yielding an SRC effect of 172 msec for the mixed condition [$F(1,30) = 23.22$, $p < .001$].

Percentage error. There was a main effect of stimulus mode [$F(2,180) = 11.66$, $MS_e = 6.17$, $p < .001$]. Responses were most accurate with physical locations ($M = 2.4\%$), followed by arrows ($M = 3.4\%$) and words ($M = 4.5\%$). There was also a main effect of compatibility [$F(1,180) = 20.51$, $p < .001$], with the SRC effect being 1.6%. The condition × stimulus mode interaction was significant [$F(2,180) = 8.47$, $p < .001$]. The subjects were more accurate in mixed blocks than in pure blocks for arrows ($MD = 2.0\%$), but they were more accurate in pure than in mixed blocks for physical locations ($MD = 0.97\%$) and words ($MD = 1.3\%$). There was also a significant stimulus mode × compatibility interaction [$F(2,180) = 5.56$, $p = .005$]. For physical locations, there was no difference in PE between compatible and incompatible mappings. However, the subjects were more accurate with compatible than with incompatible mappings for arrow ($MD = 1.5\%$) and word ($MD = 3.1\%$) stimuli.

The three-way interaction of condition × compatibility × stimulus mode [$F(2,180) = 13.23$, $p < .001$] was significant. In the pure condition, the SRC effect was larger for physical locations ($MD = 2.1\%$) and arrows ($MD = 2.0\%$) than for words ($MD = 0.62\%$). In the mixed condition, the SRC effect was smaller for physical locations ($MD = 1.7\%$) and arrows ($MD = 0.98\%$) than for words ($MD = 5.7\%$).

Location-Irrelevant Trials

A 2 (correspondence: corresponding or noncorresponding) × 2 (compatibility on location-relevant trials: compatible or incompatible) × 3 (stimulus mode: physical locations, arrows, or location words) ANOVA was conducted for the RT and PE data (see Table 2 for means).

Reaction time. There was a main effect of stimulus mode [$F(2,90) = 17.60$, $MS_e = 22{,}640$, $p < .001$]. RT was shortest when the location mode was arrows ($M = 643$ msec), followed by physical locations ($M = 719$ msec) and words ($M = 801$ msec). There was also a main effect of correspondence [$F(1,90) = 18.85$, $MS_e = 1{,}072$, $p < .001$], with RT being 21 msec shorter when stimulus and response locations corresponded than when they did not.

The two-way interaction between correspondence and stimulus mode was significant [$F(2,90) = 6.84$, $MS_e = 1{,}072$, $p = .002$]. For physical location stimuli, RT was no faster when S–R locations corresponded than when they did not, but for location words and arrow directions, RTs were 42 and 21 msec faster, respectively, when S–R locations corresponded. The two-way interaction between correspondence and compatibility was also significant [$F(1,90) = 60.26$, $p < .001$]. When the location-relevant mapping was compatible, a positive Simon effect of 57 msec was obtained, but when the location-relevant mapping was incompatible, the Simon effect was a reverse −16 msec. Most important, the three-way interaction between correspondence, compatibility, and stimulus mode was also significant [$F(2,90) = 8.91$, $p < .001$].

To clarify the three-way interaction, separate analyses were performed for each stimulus mode. For physical locations, there was no correspondence effect ($F < 1.0$), but this variable entered into a two-way interaction with compati-

Table 1
Mean Reaction Times and Percent Errors for the Location-Relevant Task in Experiments 1 and 2 as a Function of Stimulus Mode, Condition, and Compatibility

	Compatibility					
	Compatible		Incompatible		SRC Effect	
Stimulus Mode Conditon	*M*	*PE*	*M*	*PE*	*M*	*PE*
			Experiment 1			
Physical locations						
Pure	313	0.83	390	2.94	77	2.11
Mixed	665	3.68	649	2.01	−16	−1.67
Arrow directions						
Pure	371	3.36	403	5.40	32	2.04
Mixed	607	1.93	649	2.91	42	0.98
Location words						
Pure	475	3.51	496	4.13	21	0.62
Mixed	744	2.32	916	7.99	172	5.67
			Experiment 2			
Physical locations						
Pure	414	0.78	435	0.65	21	−0.13
Mixed	671	2.22	736	3.32	65	1.10
Arrow directions						
Pure	483	0.45	517	1.33	34	0.88
Mixed	593	1.04	660	1.93	67	0.89
Location words						
Pure	467	0.50	582	1.92	115	1.42
Mixed	599	0.48	781	2.64	182	2.16

Table 2
Mean Reaction Time and Percent Error for the Mixed Location-Irrelevant Task in Experiments 1 and 2 as a Function of Stimulus Mode and Compatibility

	Compatibility					
	Corresponding		Noncorresponding		Simon Effect	
Stimulus Mode	*M*	*PE*	*M*	*PE*	*M*	*PE*
			Experiment 1			
Physical locations						
Compatible	710	1.42	752	6.67	42	5.25
Incompatible	728	6.09	684	0.66	−44	−5.42
Arrow directions						
Compatible	591	0.52	669	8.30	78	7.78
Incompatible	675	6.50	638	1.52	−37	−4.98
Location words						
Compatible	767	1.39	819	6.37	52	4.98
Incompatible	793	5.56	825	5.96	32	0.40
			Experiment 2			
Physical locations						
Compatible	663	0.94	719	4.72	56	3.78
Incompatible	742	5.09	721	2.03	−21	−3.06
Arrow directions						
Compatible	616	0.89	676	3.80	60	2.91
Incompatible	679	3.75	662	1.87	−17	−1.88
Location words						
Compatible	683	1.95	743	6.25	60	4.30
Incompatible	783	6.03	791	3.06	8	−2.97

bility [$F(1,30) = 22.64$, $MS_e = 1{,}311$, $p < .001$]. The Simon effect was 42 msec with compatible mappings [$F(1,15) = 8.14$, $p = .012$] and −44 msec with incompatible mappings [$F(1,15) = 17.54$, $p < .001$]. For arrows, there was a significant main effect of correspondence [$F(1,30) = 8.24$, $MS_e = 845$, $p = .007$] that was qualified by a two-way interaction of this variable with compatibility [$F(1,30) = 62.16$, $p < .001$]. With compatible mappings, the Simon effect was 78 msec [$F(1,15) = 63.10$, $p < .001$], and with incompatible mappings, the Simon effect was −37 msec [$F(1,15) = 11.60$, $p = .004$]. For location words, there was also a significant main effect of correspondence [$F(1,30) = 26.32$, $MS_e = 1{,}060$, $p < .001$], but this variable did not enter into a two-way interaction with compatibility [$F(1,30) = 1.42$, $p = .24$]. Positive Simon effects of 52 and 32 msec were obtained for compatible [$F(1,15) = 17.55$, $p < .001$] and incompatible [$F(1,15) = 9.00$, $p = .009$] mappings, respectively.

Percentage error. There was a significant main effect of correspondence [$F(1,90) = 8.51$, $MS_e = 10.04$, $p = .004$], with responses being more accurate when stimulus and response positions corresponded than when they did not ($MD = 1.3\%$). The two-way interaction between correspondence and stimulus mode was marginally significant [$F(2,90) = 3.08$, $p = .051$]. For physical locations, there was no difference in PE between corresponding and noncorresponding trials. For words and arrows, responses were more accurate for corresponding than for noncorresponding trials (*MD*s = 2.7% and 1.4%, respectively). The two-way interaction between correspondence and compatibility was also significant [$F(1,90) = 104.24$, $p < .001$]. With compatible location mappings, a positive Simon effect of 6.0% was obtained, but with incompatible mappings, a reverse Simon effect of −3.3% was obtained. The three-way interaction between correspondence, compatibility, and stimulus mode was also significant [$F(2,90) = 7.22$, $p = .001$].

To clarify the three-way interaction, separate analyses were performed for each stimulus mode. For physical locations, there was no effect of correspondence ($F < 1.0$), but this variable entered into a two-way interaction with compatibility [$F(1,30) = 42.49$, $MS_e = 10.73$, $p < .001$]. For compatible mappings, the Simon effect was 5.3% [$F(1,15) = 24.81$, $p < .001$], but for incompatible mappings, it was a reverse −5.4% [$F(1,15) = 18.74$, $p = .001$]. For arrows, there was a nonsignificant Simon effect [$F(1,30) = 2.73$, $MS_e = 11.49$, $p = .109$], but it entered into a two-way interaction with compatibility [$F(1,30) = 56.73$, $p < .001$]. For compatible mappings, the Simon effect was 7.8% [$F(1,15) = 28.02$, $p < .001$], whereas for incompatible mappings, it was a reverse −5.0% [$F(1,15) = 34.91$, $p < .001$]. For the location words, there was a significant Simon effect [$F(1,30) = 14.67$, $MS_e = 7.89$, $p = .001$], and it entered into a two-way interaction with compatibility [$F(1,30) = 10.60$, $p = .003$]. For compatible mappings, the Simon effect was 5.0% [$F(1,15) = 32.84$, $p < .001$], and for incompatible mappings, the Simon effect was not significant ($MD = 0.40\%$; $F < 1.0$). Thus, the pattern of results for the PE data is similar to that for RT.

Discussion

For location-relevant trials, the results for the physical location stimuli replicated those of previous experiments. An SRC effect was obtained in the pure condition ($M =$

77 msec), but not in the mixed condition ($M = -16$ msec). However, arrows and words showed different patterns of results. For arrows, the pure condition also showed an SRC effect ($M = 32$ msec), but the mixed condition did as well ($M = 42$ msec). For words, the SRC effect was a nonsignificant 21 msec in the pure condition but 172 msec in the mixed condition. The value for the pure condition was smaller than the 60–70 msec value that we obtained for words under similar conditions in other studies (Proctor & Wang, 1997; Wang & Proctor, 1996), but the value for the mixed condition was much larger than what we have found for pure conditions in any previous experiment. Thus, this experiment illustrates that mixing trials on which the location information is irrelevant with trials on which it is relevant does not eliminate the SRC effect for all stimulus modes.

The elimination of the SRC effect under mixed presentation conditions with physical location stimuli is consistent with the view that the direct response-selection route is suppressed when location-relevant and -irrelevant trials are mixed. However, if this view were generally correct, the arrow stimuli, and possibly the words, would be expected to yield similar results. That is, when left–right arrows and words are mapped to left–right manual or vocal responses, the combinations of arrow–manual and word–vocal are relatively more compatible than the combinations of arrow–vocal and word–manual (Wang & Proctor, 1996), a pattern similar to that shown when physical locations and words are compared. Also, arrows tend to automatically activate their corresponding responses (Eimer, 1995). So, the fact that the SRC effect was not eliminated with mixed presentation implies that, at least for the arrow stimuli, the direct route could still have been a factor. Even more problematic for the alternative-routes account is the increased SRC effect for location words in the mixed mapping condition.

For location-irrelevant trials, physical location stimuli showed a positive Simon effect of 42 msec when the location-relevant mapping was compatible and a reverse Simon effect of −44 msec when the mapping was incompatible. For the arrows, the Simon effect was also positive when location-relevant mapping was compatible and reversed when it was incompatible, but the positive Simon effect of 78 msec was larger than the reverse Simon effect of −37 msec. The location words showed a positive Simon effect of 52 msec when the location-relevant mapping was compatible, and, although the effect was reduced to 32 msec when the location-relevant mapping was incompatible, it did not reverse.[2]

The picture that emerges from the results for the intermixed location-relevant and -irrelevant trials is that as one moves from spatial locations to nonverbal symbols to location words, the tendency to activate the corresponding response becomes progressively stronger. With physical locations, there is no advantage for the compatible mapping over the incompatible mapping on location-relevant trials, and the reverse Simon effect obtained with the incompatible location-relevant mapping is as large as the positive Simon effect obtained with the compatible mapping. With arrow directions, there is an advantage for the compatible mapping over the incompatible mapping, and the reverse Simon effect is smaller than the positive Simon effect. With words, there is a very large advantage for the compatible mapping over the incompatible mapping, and, at least in the present experiment, the Simon effect does not reverse when the location-relevant mapping is incompatible. These data imply that, under mixed presentation conditions, the corresponding response is activated more when the location-relevant mapping is incompatible for arrows, and particularly for words, than for physical locations.

This tendency to activate the corresponding response, which is particularly strong for location words, likely reflects a propensity to name the word regardless of mapping under mixed presentation conditions. A possible account for performance with location words under pure and mixed conditions is as follows: Because the set-level compatibility of the location words to keypresses is relatively low (Wang & Proctor, 1996), in the pure conditions, the word *left* can be associated to the right keypress and the word *right* to the left keypress almost as easily as the word *left* can be associated to the left keypress and the word *right* to the right keypress. Consequently, the SRC effect is small, being nonsignificant in this experiment. The mixed conditions cannot benefit from the simple associations used in the pure conditions because each location word cannot be associated with a unique response. However, since words tend to activate their corresponding names, an identity or opposite rule can be applied to the activated name in order to generate the name of the appropriate keypress response. For the compatible mapping, the facilitation provided by the activation of the corresponding name and the efficiency of the identity rule leads to fast responding. For the incompatible mapping, the activation of the corresponding name competes with that of the name of the correct response and the opposite rule takes longer to apply, leading to slow responding.

Comparisons of the results obtained for location words and physical locations support the hypothesis that under mixed conditions, subjects tend to name the words regardless of the mapping. Specifically, the mixing cost was smaller for words (269 msec) than for physical locations (352 msec) with the compatible mapping, but was larger for words (420 msec) than for physical locations (259 msec) with the incompatible mapping. This pattern of facilitation and interference would be expected because the stimulus name corresponds with the correct response for the compatible mapping and the incorrect response for the incompatible mapping.

EXPERIMENT 2

Experiment 1 showed different response patterns for physical locations, arrow directions, and location words. Of particular interest is the fact that the SRC effect for word stimuli was much larger with mixed presentation than with blocked presentation. This finding is inconsistent with the alternative-routes model, which predicts the customary outcome that performance with compatible S–R mappings suffers more than that with incompatible mappings when the two are mixed (Los, 1996), as well as when either is mixed with location-irrelevant trials (Marble & Proctor, 2000).

There are three possible reasons for why mixed presentation for words strongly enhanced the SRC effect, and these can be evaluated by using vocal "left"–"right" responses instead of keypresses, which was done in Experiment 2. First, the effect may reflect a greater tendency to name words under mixed conditions, regardless of the response mode. In that case, the pattern of SRC effects obtained under mixed conditions with vocal responses should be similar to that obtained with keypress responses in Experiment 1.

Second, the pattern of SRC effects obtained could be a function of the degree of set-level compatibility (i.e., the relative compatibility between stimulus and response sets) and not of the properties of the stimulus modes themselves. With keypresses, physical location stimuli are relatively more compatible than arrows, which are more compatible than location words (Wang & Proctor, 1996). In terms of dual-route models, this difference reflects that direct activation of the corresponding response is strongest for physical location stimuli and weakest for location words. That is, the relative strengths of the long-term associations are a function of the combination of stimulus mode and response modality. It may be the case that the ordering of mixing effects across the three stimulus modes in Experiment 1 reflects the differences in set-level compatibility. Because the degree of set-level compatibility for the respective stimulus sets reverses when the responses are vocal (Greenwald, 1970; Proctor & Wang, 1997), if the effects of mixing are due to set-level compatibility, the pattern of results for the different stimulus modes should be opposite those obtained with keypresses in Experiment 1.

The third possibility is that the pattern of SRC effects obtained under mixed presentation is due to activation of the stimulus name when the task encourages verbal coding. Such would be the case not only for location words mapped to keypress responses, but for all stimulus modes mapped to verbal, vocal responses. If the enhanced SRC effect under mixed conditions is due to the naming of the stimulus, regardless of the S–R mapping, when the task environment encourages verbal coding, mixing should enhance the SRC effect for all three stimulus modes when verbal, vocal responses are required in Experiment 2.

Method

Subjects

One hundred ninety-two new undergraduates with the same characteristics as in Experiment 1 participated.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and responses were identical to those of Experiment 1, except that the subjects responded by making a vocal "left" or "right" response into a microphone instead of pressing a key on the keyboard. Responses were recorded with a microphone attached to a MEL response box (Model 200A), which contained a voice key. RT was measured from stimulus onset to the triggering of the voice key. The identity of the response was entered by the experimenter, who pressed a left key for the left response, a right key for the right response, a third key for *other* responses (i.e., the response started with "left" and changed to "right" before completion or the response was "red" instead of "right"), and a fourth key for *experimenter mistake* (i.e., the experimenter pressed the wrong key on the previous trial, since experimenter mistakes cannot be corrected for the current trial). When the experimenter made an error, he or she corrected the response identity on the next trial, which was eliminated. Because the flow of trials was disrupted, the next trial was also excluded. Less than 1% of all trials were eliminated due to experimenter errors and *other* responses.

Results

Location-Relevant Trials

A 2 (condition: pure or mixed) × 2 (compatibility: compatible or incompatible) × 3 (stimulus mode: physical locations, arrows, or words) ANOVA was conducted for RT and PE data (see Table 1).

Reaction time. Stimulus mode showed a significant main effect [$F(2,180) = 7.91$, $MS_e = 5,142$, $p = .001$]. There was no difference in RTs to physical locations (M = 564 msec) and arrows (M = 563 msec), with RT being longer to words (M = 607 msec). Condition also showed a main effect [$F(1,180) = 338.50$, $p < .001$], with responses being faster in the pure condition (M = 483 msec) than in the mixed condition (M = 673 msec). In addition, there was a significant main effect of compatibility [$F(1,180) = 60.65$, $p < .001$], with the SRC effect being 81 msec.

The condition × stimulus mode interaction was significant [$F(2,180) = 19.55$, $p < .001$]. The mixing cost was larger for physical locations (MD = 280 msec) than for words (MD = 127 msec) and arrows (MD = 166 msec). Stimulus mode interacted with compatibility [$F(2,180) = 10.74$, $p < .001$], with the SRC effect being larger for words (MD = 149 msec) than for physical locations (MD = 43 msec) and arrows (MD = 51 msec). The condition × compatibility interaction was also significant [$F(1,180) = 5.45$, $MS_e = 5,142$, $p = .021$], with RTs being only 56 msec shorter for the compatible mappings than for the incompatible mappings in the pure condition, but 105 msec shorter in the mixed condition. There was no three-way interaction of condition × compatibility × stimulus mode ($F < 1.0$), indicating that the pattern of a larger SRC effect with mixed presentation than with pure presentation was obtained for all three stimulus modes (MDs = 67, 44, and 33 msec for words, physical locations, and arrows, respectively).

Percentage error. The main effect for condition was significant [$F(1,180) = 22.84$, $MS_e = 2.09$, $p < .001$], with more accurate responses in the pure (M = 0.94%) than in the mixed (M = 1.9%) conditions. There was also a significant main effect of compatibility [$F(1,180) = 25.58$, $p < .001$], with the SRC effect being 1.1%. Condition interacted with stimulus mode [$F(2,180) = 6.50$, $MS_e = 2.09$,

$p = .002$]. The subjects were more accurate in pure than in mixed blocks, with the difference being the largest with physical locations ($MD = 2.1\%$), followed by arrows ($MD = 0.60\%$) and words ($MD = 0.35\%$). There was also a significant stimulus mode × compatibility interaction [$F(2,180) = 3.40$, $p = .036$]. The subjects were more accurate with compatible than with incompatible mappings, with the SRC effect being the largest for words ($MD = 1.8\%$), followed by arrows ($MD = 0.89\%$) and physical locations ($MD = 0.49\%$).

Location-Irrelevant Trials

A 2 (correspondence: corresponding or noncorresponding) × 2 (condition: pure or mixed) × 2 (compatibility on location-relevant trials: compatible or incompatible) × 3 (stimulus mode: physical locations, arrows, or words) ANOVA was conducted for the RT and PE data (see Table 2).

Reaction time. The main effect of stimulus mode was significant [$F(2,90) = 8.64$, $MS_e = 15{,}722$, $p < .001$]. RT was fastest when the location mode was arrows ($M = 658$ msec), followed by physical locations ($M = 711$ msec) and words ($M = 750$ msec). There was also a main effect of compatibility [$F(1,90) = 6.56$, $p = .012$], with responses being faster when the location-relevant mapping was compatible ($M = 683$ msec) than when it was incompatible ($M = 730$ msec).

There was a main effect of correspondence [$F(1,90) = 29.39$, $MS_e = 960$, $p < .001$], showing a Simon effect of 25 msec. The two-way interaction between correspondence and compatibility was also significant [$F(1,90) = 59.78$, $p < .001$]. When the location-relevant mapping was compatible, a positive Simon effect of 59 msec was obtained, but when the location-irrelevant mapping was incompatible, a reverse Simon effect of −10 msec was obtained. The three-way interaction of correspondence, stimulus mode, and compatibility was not significant ($F < 1.0$). This lack of interaction indicates that the pattern of a large positive Simon effect with compatible location-relevant mapping (60 msec for words and arrows and 56 msec for physical locations) and, at most, a small reversal with incompatible location-relevant mapping (8 msec for words, −17 msec for arrows, and −21 msec for physical locations) was evident for all stimulus modes.

Percentage error. There was a significant main effect of stimulus mode [$F(2,90) = 4.20$, $MS_e = 11.88$, $p = .018$], with responses being most accurate when the location mode was arrows ($M = 2.6\%$), followed by physical locations ($M = 3.2\%$) and words ($M = 4.3\%$). The two-way interaction between correspondence and compatibility was also significant [$F(1,90) = 62.70$, $MS_e = 7.60$, $p < .001$]. When the location-relevant mapping was compatible, a positive Simon effect of 3.7% was obtained, but when location-irrelevant mapping was incompatible, a reverse Simon effect of −2.6% was obtained. Again, the three-way interaction of correspondence, stimulus mode, and compatibility was not significant ($F < 1.0$). This lack of interaction indicates that the pattern of a positive Simon effect with compatible location-relevant mappings, and a smaller reversal with incompatible location-relevant mappings, was evident for all stimulus modes.

Discussion

In the pure location-relevant blocks, the SRC effect was much larger for the location words (115 msec) than for the arrow (34 msec) and physical location (21 msec) stimuli. This is the opposite of the relation found with keypresses in Experiment 1, as indicated by a between-experiments ANOVA that showed a significant stimulus mode × compatibility × experiment interaction [$F(2,180) = 5.45$, $MS_e = 8{,}355$, $p = .005$] for the pure conditions. This pattern of results shows that the compatibility of the verbal–vocal and spatial–manual sets is higher than that of the verbal–manual and spatial–vocal sets (Greenwald, 1970; Proctor & Wang, 1997).

For all three stimulus modes, the effect of mixing location-irrelevant trials on performance for the location-relevant trials was similar to that shown in Experiment 1 when word stimuli were paired with keypress responses. That is, the SRC effect was larger in the mixed condition than in the pure condition for physical locations (Ms = 65 and 21 msec), arrows (Ms = 67 and 34 msec), and words (Ms = 182 and 115 msec). Thus, for all stimulus modes, the mixing effects were in the opposite direction to those most often reported in the literature, which is that mixing slows compatible responses more than it does other responses. For all stimulus modes in the present experiment, and when location words were assigned to keypress responses in Experiment 1, mixing location-irrelevant trials with the location-relevant trials was more harmful for the incompatible mapping than for the compatible mapping. These results suggest that, under mixed presentation conditions for which stimuli or responses are verbal, activation of the corresponding response occurs to a large extent for all stimulus modes.

The enhanced compatibility effect obtained with vocal responses in Experiment 2 can be explained by assuming that when location words or vocal responses are used, subjects tend to name the stimulus. Words, in particular, are known to automatically activate their corresponding names when vocal responses are required. In the classic Stroop color-naming task (MacLeod, 1991), described earlier, performance is much worse when the color word is different from the ink color than when it is the same, because of the strong tendency for the word to activate its name. For the mixed location-relevant and -irrelevant tasks in which the stimuli were colored location words and the responses were location names, a strong tendency should exist for the word to activate its corresponding name on all trials, including those on which stimulus color is the relevant dimension. The location name facilitates the compatible mapping and interferes with the incompatible mapping, leading to an enhanced compatibility effect. A lesser tendency to activate the name under these conditions when the stimuli are physical locations or arrows likely accounts for the qualitatively similar pattern of results observed for them.

For the location-irrelevant trials, all three stimulus modes also showed a similar pattern of results. When the location-relevant mapping was compatible, a substantial positive Simon effect was evident for physical locations (*MD* = 56 msec), arrows (*MD* = 60 msec), and words (*MD* = 60 msec). This effect was reversed or eliminated when the mapping was incompatible, being −21 msec for physical positions, −17 msec for arrow directions, and 8 msec for words. The ordering of effects is similar to that obtained with keypresses in Experiment 1, except that the trend for the Simon effect to reverse when the stimuli were physical locations or arrow directions was less strong. This weaker reversal might also reflect a tendency for the stimulus name to be activated.

In summary, the results obtained with vocal responses differ from those obtained with keypresses in two ways. First, for location-relevant trials, the three stimulus modes showed similar patterns of results when the responses were vocal but not when they were manual: Mixing increased the mapping effect for all stimulus modes with vocal responses, but only for words with keypresses. Second, for location-irrelevant trials, both the positive and reverse Simon effects obtained when location-relevant trials were intermixed were more similar across the three stimulus modes when the responses were vocal than when they were manual. Thus, different patterns of results tend to be obtained when the stimulus, response, or both have a verbal property as opposed to when they do not. This implies that under mixed conditions for which the location-relevant mapping is incompatible, subjects tend to activate the corresponding response more often when the stimulus or response has a verbal property than when it does not.

GENERAL DISCUSSION

When spatially compatible and incompatible location-relevant mappings are mixed, the SRC effect is reduced or eliminated (De Jong, 1995; Shaffer, 1965; Stoffels, 1996b). The most widely accepted explanation for this outcome is that compatible mappings benefit from a direct response-selection route that is suppressed under mixed mapping conditions. Mixing location-relevant and -irrelevant trials allows evaluation of this alternative-routes conception through the examination of the SRC effect for location-relevant trials and the Simon effect for location-irrelevant trials.

The SRC Effect

For physical location stimuli, mixing location-relevant and -irrelevant trials also eliminates the typical SRC effect for the location-relevant trials. Responding is no faster when the mapping is compatible than when it is incompatible (Marble & Proctor, 2000; Proctor & Vu, 2002; Proctor et al., in press). Several findings of Proctor et al. (in press) suggest that this elimination of the SRC effect is a consequence of the location-irrelevant and -relevant stimuli's sharing of left and right codes. Their experiments showed that the SRC effect was present when the location-irrelevant stimuli occurred in a centered position and when they varied in position along an orthogonal dimension. The effect was absent, however, when the location-relevant and -irrelevant stimuli occurred in left–right locations, in distinct rows.

In Experiment 1 of the present study, we evaluated whether mixing would also eliminate the SRC effect when the location information is conveyed by arrows or words on both trial types. With physical location stimuli, the results replicated previous findings, showing no SRC effect with mixed presentation (*MD* = −16 msec). For arrows, mixing had no significant influence on the SRC effect, with the effect being 32 msec in the pure conditions and 42 msec in the mixed conditions. This outcome is consistent with that of De Jong (1995), who obtained a 33-msec SRC effect with blocks of mixed compatible and incompatible trials when a mapping stimulus preceded the imperative stimulus by 10 msec. For location words, mixing enhanced the SRC effect substantially, being 172 msec in the mixed conditions compared with 21 msec in the pure conditions. Thus, elimination of the SRC effect with mixed presentation of location-relevant and -irrelevant trials does not generalize beyond the physical location mode. The enhancement of the SRC effect by mixing for location words is as striking as the elimination of the effect for physical locations, because mixing usually reduces the benefit for the easier trial type (Los, 1996).

Physical locations and arrows have higher set-level compatibility with keypress responses than do location words (Proctor & Wang, 1997). This relation is reversed for vocal responses. Therefore, Experiment 2 used vocal "left"–"right" responses to evaluate whether the pattern of results obtained with keypresses was a result of the degree of set-level compatibility of the stimuli with the responses. The results showed that mixing enhanced the SRC effect by 44 msec for physical locations, 33 msec for arrows, and 67 msec for words. This result implies that relative set-level compatibility was not the crucial factor. Rather, across Experiments 1 and 2, the crucial factor seems to have been that the stimulus or response was verbal in nature.

According to the alternative-routes explanation of the elimination of the SRC effect that occurs when compatible and incompatible mappings are mixed (Shaffer, 1965), a direct response-selection route is used when the mapping is compatible for all trials and an indirect route when it is not. The elimination of the SRC effect obtained when location-relevant trials are mixed with location-irrelevant trials can be explained in the same manner. According to this explanation, even when the location-relevant mapping is compatible, the direct route must be suppressed, and the indirect route used, because the direct route would yield an incorrect response on 25% of the trials. However, the results obtained when the location information was conveyed by arrows or words, or with vocal "left"–"right" responses, were not consistent with the alternative-routes explanation. With these S–R modes, the SRC effect was larger when location-irrelevant trials were intermixed than when they were not. The alternative-routes model predicts, in contrast, that mixing should reduce the SRC effect.

The Simon Effect

When stimuli are left and right physical locations and responses are left and right keypresses, the Simon effect for location-irrelevant trials is altered when those trials are mixed with location-relevant trials. The Simon effect is enhanced when the location-relevant mapping is compatible and reversed when the mapping is incompatible (Marble & Proctor, 2000; Proctor et al., 2000). This implies that the short-term, task-defined, associations of stimulus locations to response locations are activated even on trials for which location is not relevant.

Proctor et al. (2000) showed that the reverse Simon effect obtained with an incompatible location-relevant mapping was also evident, though to a lesser extent, when the location information was conveyed by arrows or words. However, their study did not include conditions in which the location-relevant mapping was compatible, thus precluding comparison of the relative magnitudes of the positive and reverse Simon effects. Such conditions were included in our Experiment 1 for all stimulus types. With physical locations, the reverse Simon effect obtained when the location mapping was incompatible was as large as the positive effect obtained when the mapping was compatible. However, with arrows and words, the reverse Simon effect was smaller than the positive effect. The asymmetry in Simon effect magnitudes for arrows and words implies that they produce some activation of the corresponding response, which would add to the positive Simon effect when the mapping is compatible and subtract from the reverse Simon effect when the mapping is incompatible.

When vocal responses were used in Experiment 2, the positive Simon effect was larger than the reverse effect for all stimulus modes. Differences in set-level compatibility can be ruled out as the critical factor for causing the reversal to be smaller than the positive effect because, with vocal responses, the least compatible physical-location stimuli showed the largest reverse Simon effect. Instead, the results point to the presence of a verbal component to the stimuli or responses as being the critical factor.

The asymmetry for the Simon effect was large for all conditions in Experiments 1 and 2, in which either the stimulus set, response set, or both involved location words. This implies that the stimulus tended to activate its corresponding name in those situations. The results obtained with arrows mapped to keypresses imply activation of the corresponding response for all mappings, though to a lesser extent than when there was a verbal component. This could reflect direct activation of the corresponding keypress, but it seems unlikely that arrows would have a stronger tendency than physical locations to directly activate their corresponding responses (De Jong, 1995; Proctor & Wang, 1997). A more likely explanation is that because arrows are symbolic, there is some tendency to name the direction in which the arrow points.

Theoretical Implications

For physical location stimuli mapped to keypress responses, mixing location-relevant and -irrelevant trials eliminated the SRC effect for location-relevant trials, consistent with the view that the direct route is suppressed when a compatible mapping is mixed with a mapping of lesser compatibility. In addition, the reverse Simon effect for location-irrelevant trials obtained when an incompatible location mapping was in effect was as large as the positive Simon effect obtained when a compatible mapping was in effect, which also suggests that the direct route was suppressed.

However, these results do not generalize to other stimulus modes (arrow directions and location words) mapped to keypress responses or to any of the stimulus modes mapped to vocal location-word responses. For these S–R sets, mixing location-irrelevant stimuli with location-relevant ones slowed incompatible responses more than compatible responses. These results imply that the direct route was not suppressed when the stimuli or responses had a symbolic or verbal component. That is, in those cases, the subjects apparently named the stimulus as part of the response-selection process. The results obtained for location-irrelevant trials are consistent with the notion that the direct route is not suppressed. For arrows and words mapped to keypresses, and all stimulus modes mapped to vocal responses, the pattern of Simon effects was asymmetric: The reverse Simon effect obtained with an incompatible location-relevant mapping was smaller than the positive Simon effect obtained with a compatible mapping.

When the stimuli are location words, response selection in mixed conditions seems to be based to the same extent on verbal name codes for both keypress and vocal responses. This is indicated by the fact that the SRC effect was of similar magnitude in Experiments 1 and 2, and the Simon effect obtained with an incompatible location-relevant mapping did not reverse in either experiment. Thus, direct activation of the name corresponding to the stimulus seems to be unavoidable when the stimuli are location words. This activation likely also occurs with a pure incompatible mapping of the words to keypresses, with a possible reason why the SRC effect is small being that subjects can relabel the left response key as "right" and the right response key as "left," since the preexisting associations of words to response keys are not very strong.

For physical locations, direct activation of verbal name codes occurs only when responses are vocal location words. This is indicated by the fact that mixing enhances the SRC effect for location-relevant trials and results in asymmetric positive and reverse Simon effects for location-irrelevant trials when responses are vocal, but eliminates the SRC effect and results in symmetric Simon effects when responses are keypresses. Apparently, response selection to physical-location stimuli can occur without verbal mediation under all conditions when the responses are keypresses, with the corresponding response being directly activated only when the mapping is pure compatible and not when it is pure incompatible or mixed. However, when a vocal, verbal response is required, response selection seemingly is mediated by naming the stimulus location, with this process being direct in the sense that it occurs regardless of whether the mapping is compatible or incompatible. The same holds for arrow directions when responses are vocal, although the results suggest that there might be some reliance on verbal mediation through naming the arrow direction even with keypress responses.

In general, our experiments on mixed location-relevant and -irrelevant mappings show that most effects occur only in certain contexts. SRC effects for physical location stimuli mapped to keypress responses, which are considered to be the most fundamental and hard-wired examples of SRC effects, are eliminated by intermixed location-irrelevant trials. The present study demonstrates that this elimination does not generalize to other stimulus and response modes. Instead, with location word stimuli or vocal "left"–"right" responses, mixing has a more deleterious influence on the more difficult incompatible trials than on the compatible trials. These and other findings (Proctor et al., 2000; Proctor et al., in press) imply that to accurately predict the consequences of mixed presentation for any particular pair of tasks requires consideration of the ways in which the joint task requirements affect the processing of each component task.

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NOTES

1. We have consistently found a reverse Simon effect for arrow direction stimuli when the location-relevant mapping was incompatible, whereas De Jong (1995) found only the effect to be reduced significantly to 30 msec. De Jong's method differed from ours in several respects, including the use of a tone as the mapping signal, arrows tilted slightly to the left or right rather than pointing left or right, and stimulus discriminability as an independent variable. Probably the most significant factor was that the mapping tone preceded the imperative stimulus by 10 msec in De Jong's study, which would have tended to reduce the effect of the location-relevant mapping.

2. The finding of a positive Simon effect for word stimuli when the location-relevant mapping was incompatible does not replicate the find-

ings of Proctor et al. (2000). They found that across three experiments, a reverse Simon effect was obtained for incompatibly mapped location words. However, the reversal for the words was weak in their study, being significant in the RT data for only one of the three experiments. Moreover, an analysis of the Simon effect for individual subjects in the three experiments showed a bimodal distribution, with most subjects showing either a large reverse or positive Simon effect. The reversal was evident in Proctor et al.'s (2000) study because more subjects showed the reverse effect than the positive effect. However, with only 16 subjects, as in the present experiment, it is possible that, by chance, more subjects from the positive mode of the distribution were included in the sample. In fact, only 2 subjects were in the range of ± 10 msec for the Simon effect, with 3 subjects showing a reverse effect and 11 subjects showing a positive effect. Regardless, it is apparent that the word stimuli yielded at most a small, unstable reversal that was not as strong or reliable as the reversals shown by the locations and arrows.

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