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Does right–left prevalence occur for the Simon effect?

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In four experiments, we investigated whether a right–left prevalence effect occurs for the Simon task, in which stimulus location is irrelevant, when the stimulus and the response sets vary along horizontal and vertical dimensions simultaneously. Simon effects were evident for both dimensions, and they were of similar magnitude, indicating no prevalence effect. Manipulations of the relative salience of the dimensions for the stimulus and the response sets resulted in a larger Simon effect for the more salient dimension than for the less salient one, but there was no overall prevalence effect. The results indicate that manipulations of salience affect the relative magnitudes of automatic response activation for the vertical and the horizontal dimensions but that the right–left prevalence effect is due to a coding bias in intentional response selection processes when stimulus location is relevant.

When stimulus and response sets in a choice reaction task vary along both horizontal and vertical dimensions, the mapping of stimuli to responses can be compatible on one dimension, both dimensions, or neither. In such tasks, a right–left prevalence effect is often obtained for which the stimulus–response (S–R) compatibility (SRC) effect is greater for the horizontal dimension than for the vertical dimension, although each dimension yields SRC effects of similar magnitude when the S–R sets vary along only one dimension (Nicoletti & Umiltà, 1984; Vu, Proctor, & Pick, 2000). All studies of the prevalence effect to date have used tasks for which stimulus location is relevant. In the present study, we examine whether right–left prevalence also occurs for the Simon task, in which stimulus location is irrelevant and a nonspatial attribute of the stimulus is relevant.

The right–left prevalence effect was discovered and explored by Nicoletti and Umiltà (1984, 1985; Nicoletti, Umiltà, Tressoldi, & Marzi, 1988). They found the effect to be strong and reliable but were unable to arrive at a satisfactory explanation, because they could not eliminate the right–left prevalence effect with any of several manipulations of the stimulus and response sets. Hommel (1996) was successful in eliminating the effect, showing that it was not present when the responses were unimanual movements of a joystick along a diagonal. This finding led him to conclude that the right–left prevalence effect is dependent on the use of right–left effectors. However, Vu et al. (2000) found that, even with right–left effectors, the right–left prevalence effect was reduced when the hands were placed in close proximity on a keyboard, as compared with when they were held apart on a handgrip apparatus. Consequently, they suggested an alternative account of the prevalence effect, which is that responses are coded on the basis of the dimension that is salient for a specific S–R arrangement.

Vu and Proctor (2001) tested the effector-based and relative salience accounts and found evidence that favored the latter. They showed that the right–left prevalence effect can be eliminated when responses are made with two fingers on a single hand (which are right–left effectors that typically produce SRC effects; see, e.g., Heister, Schroeder-Heister, & Ehrenstein, 1990) and that a top–bottom prevalence effect can be obtained when the response arrangement makes the top–bottom distinction more salient than the right–left distinction. Specifically, top–bottom prevalence occurred when one hand was placed over the other on a keyboard so that the hand on top made the upper response and the hand on bottom made the lower response. Moreover, top–bottom prevalence was also evident when responses were made with the ipsilateral hand and foot. Vu and Proctor (2002) showed that similar results are obtained when the relative salience of the stimulus dimensions is manipulated by varying spatial proximity and that the largest difference in SRC effects for the two dimensions occurs when the same dimension is salient for both the stimulus set and the response set.

SRC effects are typically attributed to two processes that affect the speed of response selection for stimulus and response sets that have dimensional overlap, or similarity (Kornblum, Hasbroucq, & Osman, 1990; Umiltà & Nicoletti, 1990). The first is direct (or automatic) activation of the corresponding response through long-term S–R associations: Responding is faster and more

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accurate when the response automatically activated by the stimulus is the correct response than when it is not. The second process is indirect intentional translation through the short-term S–R associations and rules defined for the task: Intentional translation is faster when the S–R mapping for the task maintains spatial correspondence than when it does not. Thus, when responding is based on stimulus location, the compatible mapping benefits from both automatic and intentional processes, relative to the incompatible mapping.

Because all studies of the prevalence effect to date have used SRC tasks for which stimulus location is relevant, the extent to which the effect is a consequence of automatic activation or intentional translation is not clear. This point is evident in two interpretations of the factors underlying the prevalence effect. Andre and Wickens (1990) emphasized dimensional overlap and seemed to imply that automatic activation is crucial, stating that "Apparently, then, when stimuli and response sets overlap in both dimensions, location compatibility effects are dominated by the left–right dimension" (p. 20). In contrast, Umiltà and Nicoletti (1990) attributed the effect to intentionally attending to stimulus location, stating that

> A subject, if engaged in processing one spatial dimension in a controlled way, is unable to process simultaneously another spatial dimension, not even automatically. In the case of the left–right dominance, it can be argued that, for unknown reasons, the left–right dimension preferentially attracts attention and, because of this, undergoes controlled processing at the expense of the above–below dimension. (p. 105)

Although Umiltà and Nicoletti were unable to find the reason why the right–left dimension preferentially attracts attention, the findings of Vu and Proctor (2001, 2002) suggest that coding is facilitated for the dimension made salient by the S–R environment. An interpretation of Vu and Proctor's findings, based on Umiltà and Nicoletti's attentional account, is that the horizontal dimension preferentially attracts attention because most response environments (e.g., responding with the right and the left hands) favor horizontal coding. In a recent study, Rubichi, Pelosi, Nicoletti, and Umiltà (in press) suggested that the advantage for the horizontal dimension may be due to the fact that horizontal codes are available earlier than vertical codes.

One way to evaluate the contributions of automatic activation and intentional translation is to use a Simon task in which stimulus location is irrelevant. When stimuli occur in left and right locations but a nonspatial dimension, such as color, is relevant, responding is faster and more accurate when the stimulus location corresponds with that of the correct response than when it does not. This correspondence effect, known as the Simon effect (see Lu & Proctor, 1995), is typically attributed solely to the automatic route (e.g., Zorzi & Umiltà, 1995). Consequently, examination of whether prevalence effects occur in the Simon task should reveal the extent to which such effects are due to intentional or automatic processes.

Four experiments were conducted using methods similar to those of Vu and Proctor (2002), but with stimulus location irrelevant and color relevant. In Experiment 1, the Simon effect was measured for the vertical and horizontal dimensions when responses were made on the handgrip apparatus, which yields a strong right–left prevalence effect when location is relevant. In Experiment 2, subjects responded on the numeric pad of a keyboard, with their hands adjacent to each other, and display salience was varied to favor the horizontal dimension, the vertical dimension, or neither. If right–left prevalence effects have their basis, at least in part, in the direct or automatic response activation route, prevalence effects should be obtained in Experiments 1 and 2. If intentional translation processes are primarily responsible for the prevalence effect, no prevalence effect should be obtained.

In Experiments 3 and 4, the horizontal and vertical salient displays of Experiment 2 were paired with horizontal and vertical salient response arrangements, the adjacent placement used in Experiment 2 versus one in which a hand was placed on top of the other (Experiment 3), and contralateral versus ipsilateral hand and foot responses (Experiment 4). Experiments 3 and 4 allowed determination of whether stimulus and response salience affects strength of activation and, thus, performance when stimulus location is irrelevant to the task, just as it does when stimulus location is relevant.

EXPERIMENT 1

In Experiment 1, a procedure similar to those used previously to study the prevalence effect was used, except that color was the relevant stimulus dimension, rather than the spatial location of the stimulus. Vu et al. (2000) distinguished strong and weak forms of right–left prevalence. For the strong form, right–left prevalence occurs regardless of whether the instructions emphasize the horizontal or the vertical dimension. For the weak form, the advantage is not evident with vertical instructions, but because the advantage for the horizontal dimension with horizontal instructions is larger than the advantage for the vertical dimension with vertical instructions, a prevalence effect is evident when the data are collapsed across instructions. Vu et al. obtained the strong form of right–left prevalence when subjects responded with their hands held widely apart on a handgrip apparatus. Consequently, this apparatus was used in Experiment 1. If right–left prevalence is a function of the codes used for intentional S–R translation, there should be no prevalence effect for the Simon task, since the Simon effect is attributed to automatic activation. However, if the right–left prevalence effect is due, at least in part, to stronger automatic activation of horizontal than of vertical response codes, a right–left prevalence effect should be evident.

Nicoletti and Umiltà's (1984, 1985) data were consistent with a variant of the automatic activation explanation, suggesting that right–left prevalence may be due to the fact that the horizontal response codes are available prior to the vertical response codes (Hommel, 1996; Rubichi et al., in press). To evaluate this possibility, reaction time (RT) distribution analyses were performed in order to examine the temporal properties of horizontal and vertical codes. If right–left prevalence is due to the fact that the horizontal response codes are available prior to the vertical response codes, the right-prevalence effect should be most evident when responses are fast, because the Simon effect for the horizontal dimension tends to decrease with time, as the activation diminishes (Hommel, 1993). The opposite pattern should be evident for the vertical dimension.

Method

Subjects. Twenty-four undergraduate volunteers were recruited from Purdue University for partial credit toward their introductory psychology course requirement. All reported having normal or corrected-to-normal vision and color vision.

Apparatus and Stimuli. A personal computer was used to present stimuli and record the subjects' responses and RTs. Micro Experimental Laboratory (MEL, Version 2.1) was used to program the experiment. The stimuli were displayed on a 14-in. VGA monitor, which was viewed by the subject from approximately 60 cm. The stimuli were solid circles with a diameter of 15 mm (a visual angle of approximately 1.43º) of either red or green color (MEL Color Codes 4 and 2, respectively). The circles were presented in one of four corners (top left, bottom right, top right, or bottom left), approximately 107 mm (10.1º) from center. The circles were presented one at a time in locations at angles of 45º (top right), 135º (top left), 225º (bottom left), or 315º (bottom right).

Responses were made on the apparatus used in Vu et al.'s (2000) Experiment 3 (see their Figure 2). Two removable handgrips were mounted between two vertical metal rods surrounding the computer screen. The metal rods were approximately 60 cm apart, and the inner metal rod was approximately 26 cm away from the computer screen. The handgrips had microswitches attached to them and were approximately 15 cm long, extending horizontally toward the center of the computer screen. The horizontal and vertical distances between the microswitch of each handgrip and the central fixation point on the screen were approximately 15 cm.

Design and Procedure. The experiment was conducted in a quiet, dimly lit room. The subject held onto the handgrips with his/her thumbs oriented horizontally and used the thumbs to press the microswitches. The responses were registered through the MEL response box, which was placed on top of the computer monitor. Half of the subjects responded with the handgrips mounted in the top-right and bottom-left corners, and half with the handgrips mounted in the top-left and bottom-right corners. One grip was labeled "red bar" and the other "green bar," with the order counterbalanced between subjects. The labels were not visible during the experiment because subjects placed their hands over them. The red stimuli were assigned to the "red bar" and the green circle to the "green bar."

All the subjects were tested in one session of 440 trials. The first 40 trials were considered practice and were not included in the analysis. On each trial, a red or a green circle was displayed in one of the four possible locations and remained on the screen until a response was made. RT was measured from stimulus onset to registration of a response, and the next trial followed after a 1-sec delay. A 400-Hz tone was presented for 500 msec for incorrect responses, followed by the 1-sec intertrial interval. The experimenter stayed in the room during the entire experiment.

Results

RTs less than 200 msec or greater than 2,000 msec were excluded from analyses for this and all subsequent experiments (fewer than 1% of all the trials). Mean RT and percentage of error (PE) for each condition are shown in Table 1. The RT and PE data were submitted to 2 (horizontal correspondence) $\times$ 2 (vertical correspondence) analyses of variance (ANOVAs).

The main effect of horizontal correspondence was significant for RT [$F(1,23) = 20.09, p = .001$] and was almost significant for PE [$F(1,23) = 4.19, p = .052$], and the main effect of vertical correspondence was significant for both measures [Fs(1,23) = 21.36 and 6.92, ps = .001 and .015, respectively]. The Simon effect was of similar magnitude for the horizontal [mean differences (*MD*s) = 16 msec and 0.70%] and the vertical (*MD*s = 15 msec and 0.80%) dimensions. The interaction between horizontal and vertical correspondence was not significant (Fs < 1).

An RT distribution bin analysis (see, e.g., De Jong, Liang, & Lauber, 1994; Zhang & Kornblum, 1997) was performed on the Simon effect for the horizontal and the vertical dimensions. RTs for each subject were ranked from shortest to longest in each condition as a function of correspondence and were divided into 10 bins, for which means were obtained. Simon effects for each bin were then determined by subtracting corresponding RT from noncorresponding RT. We report the original degrees of freedom but used the Huynh–Feldt adjustment for the p value. The dimension (horizontal or vertical) $\times$ bin interaction was significant [$F(9,207) = 4.90, p < .001$; see Figure 1]. Pairwise t tests performed on the horizontal and vertical Simon effects for each bin showed that the horizontal Simon effect was larger than the vertical one for the first six bins [ts(23) $\geq$ 2.12, ps $\leq$ .045, except for Bin 5, for which $t(23) = 2.02, p = .055$], with a nonsignificant tendency for a reversal at the two longest bins [ts(23) > 1.80, ps > .09].

Discussion

Simon effects of similar magnitude were evident for the horizontal and the vertical dimensions, indicating that there was no right–left prevalence effect. This result is in contrast to the strong right–left prevalence effect obtained with the handgrip apparatus when stimulus location was relevant (Vu et al., 2000). It suggests that the

Table 1
Mean Reaction Time (RT, in Milliseconds) and Mean Percentage of Error (PE) in Experiment 1 as a Function of Vertical Correspondence and Horizontal Correspondence

	Vertical Correspondence			
	Corresponding		Noncorresponding	
Horizontal Correspondence	RT	PE	RT	PE
Corresponding	416	1.67	432	2.29
Noncorresponding	433	2.17	447	3.17

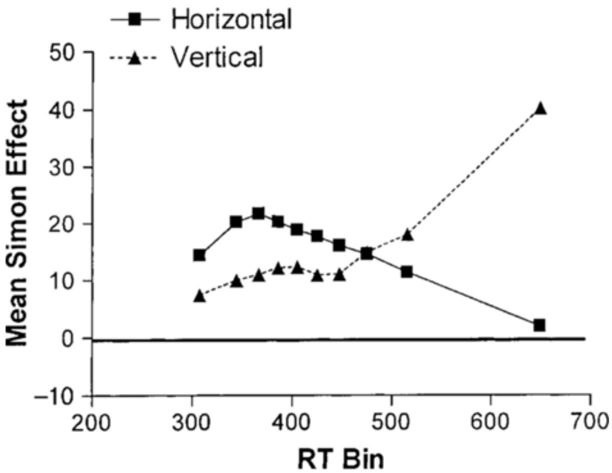

Figure 1. Mean Simon effect (in milliseconds) for the horizontal and vertical dimensions as a function of reaction time (RT) bin in Experiment 1.

prevalence effect obtained when location is relevant is not due to an inherent advantage of the horizontal dimension over the vertical one. Automatic activation of response codes due to dimensional overlap does not seem sufficient to produce right–left prevalence. Rather, the prevalence effect appears to be restricted to situations in which stimulus location is relevant and must be attended to.

Although there was no overall difference in Simon effects for the vertical and the horizontal dimensions, RT bin interacted with dimension. For the two thirds of the distribution with the shortest RTs, the horizontal dimension showed a larger Simon effect than did the vertical dimension. The difference was sufficiently reversed at the two bins with the longest RTs to offset the advantage for the horizontal dimension at the shorter RT bins. This pattern, which is similar to that reported by Rubichi et al. (in press) when stimulus location is relevant to the task, is consistent with the possibility that the horizontal spatial code is available prior to the vertical spatial code.

EXPERIMENT 2

One purpose of Experiment 2 was to determine whether the relative magnitudes of the Simon effects for the horizontal and vertical dimensions can be systematically altered by manipulating display salience, as when stimulus location is relevant (Vu & Proctor, 2002). In addition to the neutral stimulus display from Experiment 1, displays were used in which the horizontal or the vertical dimension was salient. Display salience was defined operationally in terms of spatial proximity. The dimension along which the stimuli were widely separated was defined as salient relative to the dimension along which they were close together (see Vu & Proctor, 2002, for evidence that this manipulation alters the relative salience of the two dimensions). The second purpose of Experiment 2 was to evaluate the generalizability of the finding of an absence of a prevalence effect for the Simon task, by having subjects respond on a keyboard, rather than with the handgrip apparatus used in Experiment 1.

Method

Subjects. Seventy-two new undergraduate volunteers were recruited from the same subject pool as that in Experiment 1.

Apparatus, Stimuli, and Procedure. The display and stimuli for the neutral condition were the same as those in Experiment 1. For the vertical salient display, the stimuli were presented in locations at angles of 75º (top right), 105º (top left), 255º (bottom left), or 285º (bottom right) from center. For the horizontal salient display condition, the stimuli were presented one at a time in locations at angles of 15º (top right), 165º (top left), 195º (bottom left), or 345º (bottom right) from center.

The subjects responded to each stimulus by pressing the 1, 3, 7, or 9 key on the numeric pad of the computer's keyboard. The keyboard was placed so that the numeric pad was aligned with the center of the screen and the midline of the subject's body. The index fingers of each hand were placed on two of the four response keys (either the 7 and 3 keys or the 1 and 9 keys), with the left index finger on the leftmost and the right index finger on the rightmost of the two keys.

Twenty-four subjects were assigned to the neutral display, 24 to the vertical salient display, and 24 to the horizontal salient display. Half of the subjects responded with the 3 and 7 keys, and half with the 1 and 9 keys. The red circle was assigned to the 3 (or 9) key and the green circle to the 7 (or 1) key for half the subjects, and vice versa for the other half. In all other respects, the procedure was the same as that in Experiment 1.

Results

Mean RT and PE for each condition are shown in Table 2. The RT and PE data were submitted to 2 (horizontal correspondence) × 2 (vertical correspondence) × 3 (display salience: horizontal, equivalent, or vertical) ANOVAs.

Reaction time. The main effects of horizontal correspondence [$F(1,69) = 66.08$, $p < .001$] and vertical correspondence [$F(1,69) = 67.86$, $p < .001$] were significant. The Simon effect was of similar magnitude for the horizontal (MD = 15 msec) and the vertical (MD =

Table 2
Mean Reaction Time (RT, in Milliseconds) and Mean Percentage of Error (PE) in Experiment 2 as a Function of Vertical Correspondence, Horizontal Correspondence, and Display Salience

	Vertical Correspondence			
	Corresponding		Noncorresponding	
Horizontal Correspondence	RT	PE	RT	PE
Horizontal Salient Display				
Corresponding	442	2.13	442	2.71
Noncorresponding	455	3.72	467	4.71
Neutral Display				
Corresponding	480	1.13	494	2.17
Noncorresponding	492	2.00	505	3.25
Vertical Salient Display				
Corresponding	426	1.92	453	3.88
Noncorresponding	445	2.71	465	5.09

14 msec) dimensions. There was also a main effect of display salience [$F(2,69) = 6.59$, $p = .002$], with RT being longer for the neutral condition ($M = 493$ msec) than for the horizontal ($M = 452$ msec) and the vertical ($M = 447$ msec) conditions.

Vertical correspondence interacted with display salience [$F(2,69) = 8.01$, $p = .001$]. With the neutral display, a 14-msec vertical Simon effect was obtained. This effect increased to 24 msec with the vertical salient display and decreased to 7 msec with the horizontal salient display, although the effect was still significant in this condition [$F(1,23) = 4.29$, $p = .05$]. The effect of display salience on horizontal correspondence was not significant [$F(2,69) = 1.11$, $p = .334$; MDs = 19 msec for the horizontal salient display, 12 msec for the neutral display, and 16 msec for the vertical salient display].

The three-way interaction of horizontal correspondence, vertical correspondence, and display salience was also significant [$F(2,69) = 3.26$, $p = .044$]. With the neutral display, the Simon effects for the horizontal and the vertical dimensions were of similar magnitude (MD = 2 msec). However, with the horizontal salient display, the horizontal Simon effect was 12 msec larger than the vertical Simon effect [$F(1,23) = 6.76$, $p = .016$], but with the vertical salient display, the horizontal Simon effect was 8 msec smaller than the vertical Simon effect [$F(1,23) = 4.46$, $p = .046$].

Percentage of error. The overall pattern of PE followed the same trends as the effects for the RT data. There were main effects of horizontal correspondence [$F(1,69) = 28.28$, $p < .001$] and vertical correspondence [$F(1,69) = 36.12$, $p < .001$], with the Simon effect being 1.3% for the former and 1.4% for the latter. Vertical correspondence and display salience interacted [$F(1,69) = 3.26$, $p = .044$], with the vertical Simon effect being 2.2% for the vertical salient display, 1.1% for the neutral display, and 0.8% for the horizontal salient display. No other effects were significant.

Bin analysis. RT bin interacted with dimension [$F(9,621) = 8.33$, $p < .001$]. As in Experiment 1, the horizontal Simon effect tended to decrease as RT bin increased, whereas the vertical Simon effect increased. RT bin did not interact with display salience [$F(18,621) = 1.78$, $p = .154$], and the three-way interaction was also nonsignificant ($F < 1$). The absence of significant interactions involving display salience indicates that the major effect of this variable was to elevate the Simon effect overall for the dimension that was salient and to reduce it for the dimension that was not salient (see Figure 2), rather than altering the shapes of the functions. The distribution function for the neutral display was similar to that in Experiment 1, with the Simon effect being larger for the horizontal dimension than for the vertical dimension in the two thirds of the distribution with the shortest RTs and smaller in the remainder. The distribution functions cross between Bins 6 and 7 for the neutral display, Bins 9 and 10 for the horizontal salient display, and Bins 3 and 4 for the vertical salient display.

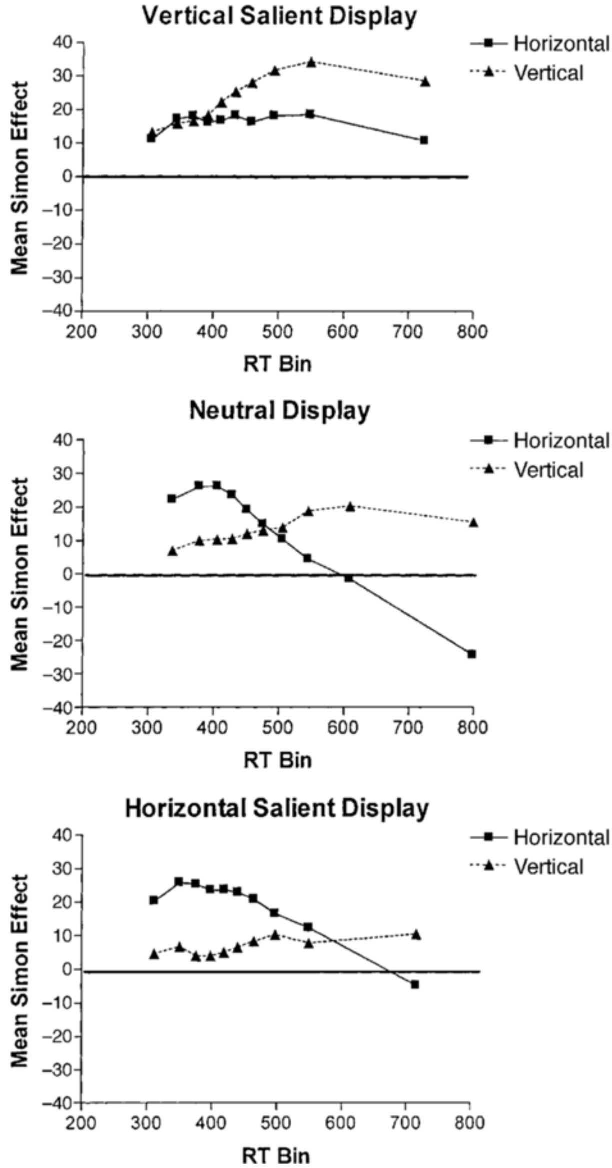

Figure 2. Mean horizontal and vertical Simon effects (in milliseconds) for each display condition as a function of reaction time (RT) bin in Experiment 2.

Discussion

Consistent with the findings of Experiment 1, right–left prevalence was not evident with the neutral display. Furthermore, there was no overall prevalence effect across the horizontal salient and the vertical salient displays. On the basis of the two experiments, it can be concluded that there is no overall right–left prevalence effect when stimulus location is irrelevant. As was mentioned in the discussion of Experiment 1, this finding implies that the right–left prevalence effect observed when stimulus location is relevant is not a consequence of automatically activated horizontal codes overriding vertical codes.

Although the vertical and the horizontal Simon effects were of similar magnitude with the neutral display, the Simon effect was larger for the vertical dimension than for the horizontal dimension with the vertical salient display, and vice versa with the horizontal salient display. The distribution analyses suggest that the manipulations of display salience influence mainly the overall magnitudes of the Simon effects, and not the shapes of the distribution. This implies that the relative magnitude of activation for the horizontal and the vertical codes is affected, but not their pattern of activation across RT bins. The Simon effect for the horizontal dimension attained a maximum around the second and third RT bins, regardless of the display salience, and the Simon effect for the vertical dimension attained a maximum around the eighth or ninth bin.

EXPERIMENT 3

When stimulus location is the relevant stimulus attribute, right–left prevalence can be altered to top–bottom prevalence by using response sets for which the vertical dimension is more salient than the horizontal dimension (Vu & Proctor, 2001, 2002). Furthermore, the benefit for a particular dimension is largest when that dimension is salient for both the stimulus and the response sets. Experiment 3 was designed to evaluate whether altering the salience of the response set influences the magnitudes of the Simon effects for the horizontal and vertical dimensions and whether the largest benefit for the salient dimension occurs when the stimulus and the response sets emphasize that dimension. For the stimulus manipulation, the horizontally and vertically salient displays were identical to those in Experiment 2. For the response manipulation, the hands were positioned adjacent to each other for the horizontal salient response condition and one on top of the other for the vertical salient response condition. These response arrangements were chosen because they yield right–left prevalence and top–bottom prevalence, respectively, when stimulus location is relevant (Vu & Proctor, 2001).

Method

Sixty-four new subjects from the same subject pool as that in Experiments 1 and 2 participated. Sixteen subjects were assigned to each of the four display–response salience combinations. The apparatus, stimuli, and procedure were identical to those in Experiment 2, except for the differences noted. Only the horizontal and the vertical salient displays were used, paired with horizontal and vertical salient response arrangements. For the horizontal salient response condition, responses were made with the hands placed adjacent to each other, as in Experiment 2. For the vertical salient response condition, the subject placed one hand on top of the other. The top hand was used to make the top response, and the bottom hand the bottom response. Regardless of which hand was on top, the right index finger was used to make the left response, and the left index finger to make the right response.

Results

Mean RT and PE for each condition are shown in Table 3. The RT and PE data were submitted to 2 (horizontal correspondence) × 2 (vertical correspondence) × 2 (display salience: horizontal or vertical) × 2 (response salience: horizontal or vertical) ANOVAs.

Table 3
Mean Reaction Time (RT, in Milliseconds) and Mean Percentage of Error (PE) in Experiment 3 as a Function of Vertical Correspondence, Horizontal Correspondence, Display Salience, and Response Salience

	Vertical Correspondence			
	Corresponding		Noncorresponding	
Horizontal Correspondence	RT	PE	RT	PE
Horizontal Salient Display–Horizontal Salient Response				
Corresponding	443	1.56	455	2.25
Noncorresponding	466	2.69	468	2.94
Horizontal Salient Display–Vertical Salient Response				
Corresponding	484	1.13	501	2.44
Noncorresponding	499	2.50	512	4.06
Vertical Salient Display–Horizontal Salient Response				
Corresponding	429	0.81	452	2.06
Noncorresponding	451	2.00	473	4.51
Vertical Salient Display–Vertical Salient Response				
Corresponding	472	0.81	508	2.88
Noncorresponding	479	0.88	511	2.69

Reaction time. There were main effects of horizontal correspondence [$F(1,60) = 68.80, p < .001$] and vertical correspondence [$F(1,60) = 63.44, p < .001$], with the Simon effect being 14 msec for the horizontal dimension and 19 msec for the vertical dimension. There was also a main effect of response salience [$F(1,60) = 8.64, p = .005$], with RTs being shorter with the horizontal salient (adjacent) hand placement ($M = 455$ msec) than with the vertical salient (top–bottom) hand placement ($M = 496$ msec).

Horizontal correspondence interacted with response salience [$F(1,60) = 9.91, p = .003$], with the horizontal Simon effect being 11 msec larger with horizontal salient responses than with vertical salient responses. Horizontal correspondence did not interact with display salience ($F < 1$), but the three-way interaction of those variables with response salience approached significance [$F(1,60) = 3.08, p = .084$]. The horizontal Simon effect was only 5 msec when both the display and the response salience were vertical but averaged 17 msec for the remaining conditions.

The interaction of vertical correspondence with response salience approached significance [$F(1,60) = 3.73, p = .058$], with the vertical Simon effect being 10 msec larger with vertical salient responses than with horizontal salient responses. Vertical correspondence also interacted with display salience [$F(1,60) = 12.66, p = .001$], with the vertical Simon effect being 18 msec larger with the vertical salient display than with the horizontal salient display. However, the three-way interaction of these variables was not significant ($F < 1$).

Percentage of error. There were main effects of horizontal correspondence [$F(1,60) = 23.42, p < .001$] and vertical correspondence [$F(1,60) = 43.65$, $p < .001$], with the Simon effect being of similar magnitude for the horizontal ($M = 1.04\%$) and the vertical ($M = 1.43\%$) dimensions. The three-way interaction of horizontal correspondence with display salience and response salience was also significant [$F(1,60) = 8.27$, $p = .006$]. The horizontal Simon effect was −0.06% when both the stimulus and the response sets favored the vertical dimension, 1.81% with the vertical salient display and horizontal salient response arrangement, 1.5% with the horizontal salient display and vertical salient response arrangement, and 0.9% when both the stimulus and the response salience favored the horizontal dimension. Vertical correspondence interacted with display salience [$F(1,60) = 4.87$, $p = .031$], with the vertical Simon effect being 0.95% larger with vertically salient displays than with horizontally salient displays.

Bin analysis. The relative magnitudes of the horizontal and the vertical Simon effects varied as a function of display salience and response salience, as has been described in the mean RT analysis. The only significant effect involving bin was the dimension × bin interaction [$F(9,540) = 4.91$, $p = .012$; see Figure 3]. As in the previous experiments, the Simon effect for the vertical dimension increased as RT bin increased. For the horizontal dimension, the Simon effect was relatively constant across Bins 2–9, being slightly smaller at Bins 1 and 10.

Discussion

The manipulation of response salience resulted in a larger Simon effect for the salient dimension than for the nonsalient dimension. The manipulation of display salience had a weaker effect, with a significantly larger Simon effect being evident for the salient dimension only on the vertical dimension. The Simon effects for the vertical and the horizontal dimensions were of similar magnitude when the display salience did not match, and the Simon effect was 11 msec larger for the horizontal than for the vertical dimension when the display-and-response salience was horizontal but was 29 msec larger for the vertical than for the horizontal dimension when the display-and-response salience was vertical. This

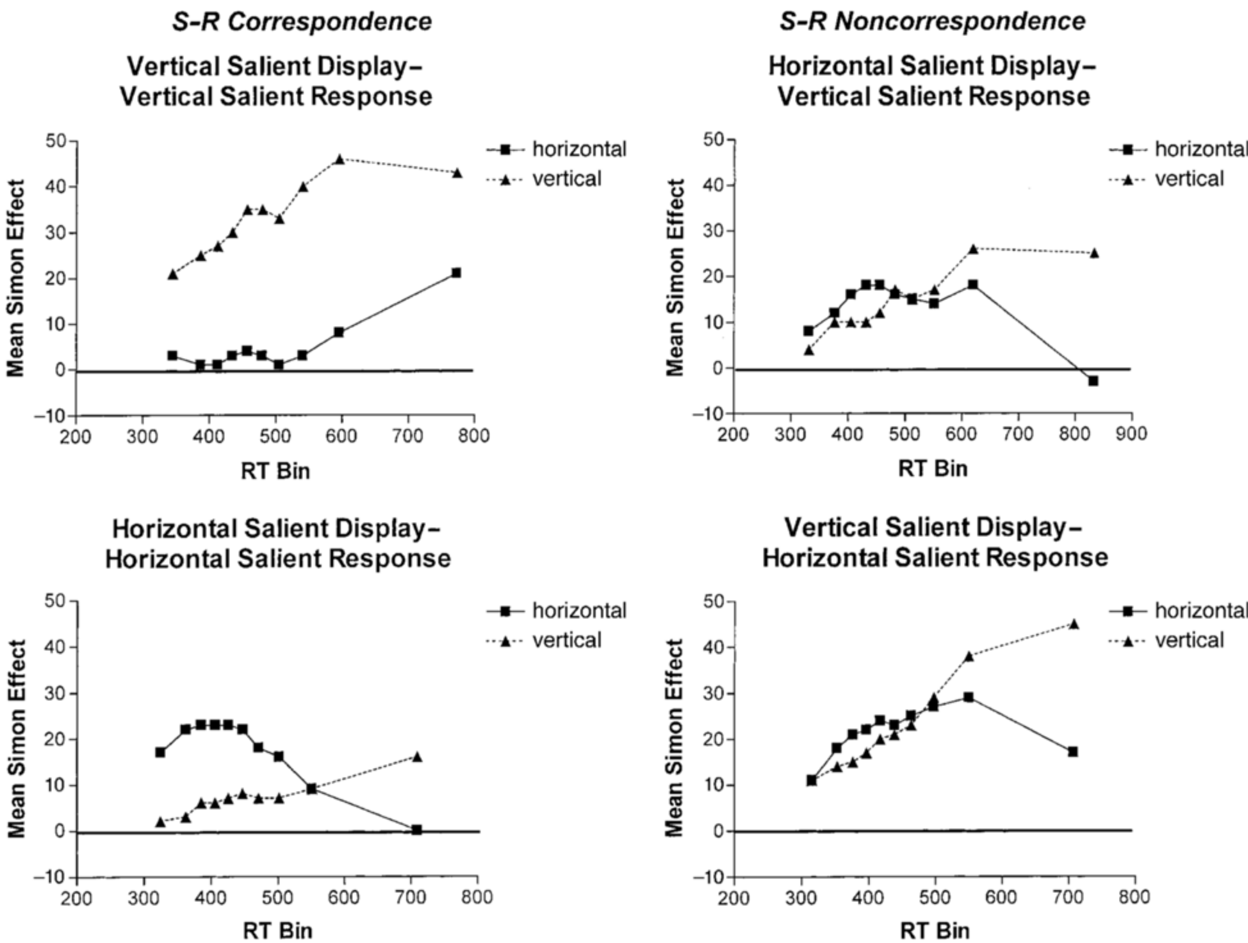

Figure 3. Mean horizontal and vertical Simon effects (in milliseconds) for each display–response salience combination as a function of reaction time (RT) bin in Experiment 3.

asymmetry reflects the fact that display salience influenced the Simon effect primarily for the vertical dimension. As in Experiment 2, the bin analysis suggests that the primary influence of display-and-response salience is to elevate the bin functions for the salient dimension and decrease them for the nonsalient dimension.

EXPERIMENT 4

Vu and Proctor (2001, 2002) showed that the prevalence effect could be obtained when top–bottom effectors are used for responding, with right–left prevalence obtained when contralateral hand–foot responses were used and top–bottom prevalence when ipsilateral hand–foot responses were used. Experiment 4 was designed to evaluate the effects of salience as a function of correspondence between S–R sets with responses made by top–bottom effectors, using a design similar to that in Experiment 3.

Method

Sixty-four new subjects from the same subject pool as that in the previous experiments participated. Sixteen subjects were assigned to each of four conditions. The apparatus, stimuli, and procedure were identical to those in Experiment 3, except as noted. The subjects responded to each stimulus by pressing a button on a handheld bicycle grip or stepping on a Treadlite II foot pedal, connected to a MEL Serial Response Box (Model 200A). Each subject held the handgrip in the palm of his or her hand, with the thumb horizontally oriented, and used his or her thumb to press the microswitch. The subject placed his or her hand on the tabletop, with the handgrip held approximately 30 cm away from the computer screen, 15 cm to the right of central fixation for the right response and 15 cm to the left of fixation for the left response. The foot pedals were placed on the floor, approximately 74 cm directly below the positions of the handgrips. For the horizontal salient response condition, the subject used his or her left or right hand to make the top response and the opposite-side foot to make the bottom response. For the vertical salient response condition, the subject also used his or her right or left hand to make the top response but used the same-side foot to make the bottom response.

Table 4
Mean Reaction Time (RT, in Milliseconds) and Mean Percentage of Error (PE) in Experiment 4 as a Function of Vertical Correspondence, Horizontal Correspondence, Display Salience, and Response Salience

	Vertical Correspondence			
	Corresponding		Noncorresponding	
Horizontal Correspondence	RT	PE	RT	PE
Horizontal Salient Display–Horizontal Salient Response				
Corresponding	496	2.07	487	2.13
Noncorresponding	503	3.19	507	2.44
Horizontal Salient Display–Vertical Salient Response				
Corresponding	468	1.77	483	1.38
Noncorresponding	493	2.19	494	2.81
Vertical Salient Display–Horizontal Salient Response				
Corresponding	441	1.19	455	2.25
Noncorresponding	460	2.33	470	3.13
Vertical Salient Display–Vertical Salient Response				
Corresponding	463	1.88	482	3.13
Noncorresponding	470	1.81	489	4.07

Results

The mean RT and PE for each condition are shown in Table 4. The RT and PE data were analyzed in the same manner as in Experiment 3.

Reaction time. There were main effects of horizontal correspondence [$F(1,60) = 59.63$, $p < .001$] and vertical correspondence [$F(1,60) = 28.43$, $p < .001$], with the Simon effect being 14 msec for the horizontal dimension and 9 msec for the vertical dimension. Vertical correspondence interacted with display salience [$F(1,60) = 13.60$, $p = .001$], with the vertical Simon effect being 12 msec larger with vertical salient displays than with horizontal salient displays. The interaction of vertical correspondence with response salience was also significant [$F(1,60) = 6.18$, $p = .016$], with the vertical Simon effect being 8 msec larger with vertical salient responses than with horizontal salient responses. Neither two-way interaction of horizontal correspondence with display salience or response salience approached significance, but the three-way interaction of these factors did [$F(1,60) = 3.84$, $p = .055$]. Similar to Experiment 3, the horizontal Simon effect was only 8 msec when the salience of both the display and the response was vertical but averaged 16 msec for the remaining conditions.

The four-way interaction of horizontal correspondence, vertical correspondence, display salience, and response salience was also significant [$F(1,60) = 8.87$, $p = .004$]. When the salience of both the stimulus and the response sets favored the vertical dimension, the vertical Simon effect was 12 msec larger than the horizontal Simon effect. Similarly, when the salience of both the stimulus and the response sets favored the horizontal dimension, the horizontal Simon effect was 15 msec larger than the vertical Simon effect. However, due to the fact that the horizontal Simon effect was as large when either the display or the response salience was horizontal as when both were, the horizontal Simon effect was 5 msec larger than the vertical Simon effect with the vertical salient display and horizontal salient response arrangement and was 10 msec larger with the horizontal salient display and vertical salient response arrangement.

Percentage of error. There were main effects of horizontal correspondence [$F(1,60) = 12.85$, $p = .001$] and vertical correspondence [$F(1,60) = 11.07$, $p = .001$], with the Simon effect being of similar magnitude on the horizontal dimension ($M = 0.78\%$) and the vertical dimension ($M = 0.62\%$). Vertical correspondence interacted with display salience [$F(1,60) = 16.24$, $p < .001$], with the vertical Simon effect being 0.64% larger with vertical salient displays than with horizontal salient displays.

Bin analysis. As has been described in the mean RT analysis, the relative magnitudes of the horizontal and the vertical Simon effects varied as function of display salience and response salience. The only significant effects involving bin were the main effect [$F(9,540) = 4.92$, $p = .01$] and the interaction with response salience [$F(9,540) = 4.11$, $p = .021$; see Figure 4]. Overall, the Simon effect showed an inverted-U shaped function. The

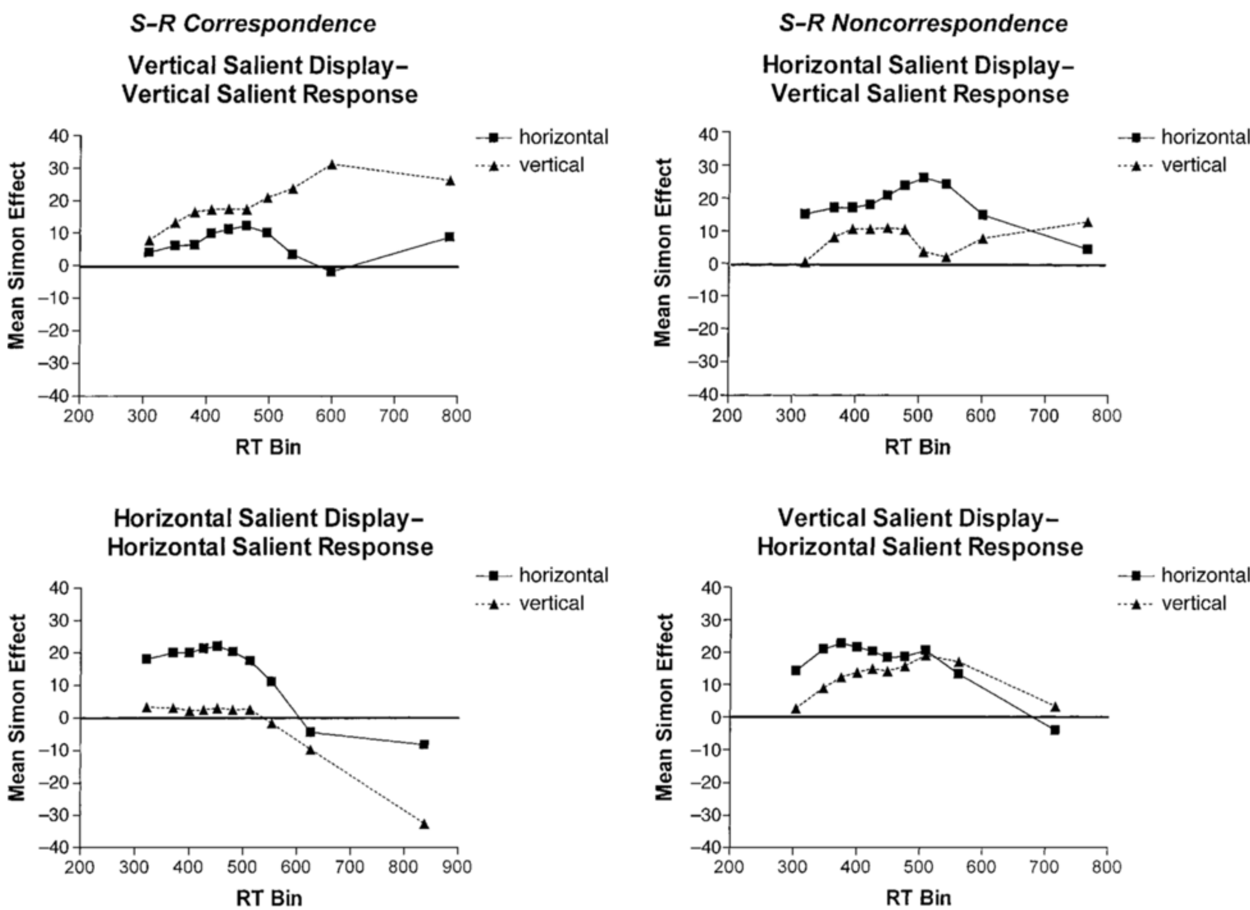

Figure 4. Mean horizontal and vertical Simon effects (in milliseconds) for each display–response salience combination as a function of reaction time (RT) bin in Experiment 4.

interaction reflects primarily a difference in the functions for the response salience conditions at the last two bins, where the Simon effect decreases for the horizontal salient response set, but not for the vertical salient response set. In general, the functions obtained in this experiment tended to be flatter than those in the previous experiments. In particular, for all conditions except that in which both the display and the response were vertically salient, the vertical Simon effect tended to decrease in the second half of the distribution, rather than increase.

Discussion

The manipulation of display-and-response salience affected the pattern of the Simon effect for the vertical dimension, but not for the horizontal dimension. The Simon effect was 15 msec larger for the horizontal dimension than for the vertical dimension when both the display and the response salience were horizontal, whereas it was 12 msec larger for the vertical than for the horizontal dimension when both the display and the response salience were vertical. When the display and the response salience did not match, the overall Simon effect favored the horizontal dimension. This asymmetry reflects the fact that display and response salience influenced the Simon effect significantly only for the vertical dimension.

The bin analysis showed no interaction of display or response salience with RT bin. This outcome suggests that the primary influence of display and response salience is to elevate the bin functions for the salient dimension relative to those for the nonsalient dimension.

GENERAL DISCUSSION

As was described in the introduction, Umiltà and Nicoletti (1990) proposed that when responding to spatial information, attention is attracted to the horizontal dimension and, as a consequence, this dimension receives controlled processing, or intentional translation, at the expense of the vertical dimension. In contrast, Andre and Wickens (1990) emphasized that right–left prevalence occurs when dimensional overlap exists for both horizontal and vertical dimensions, which implies that the right–left prevalence effect is due to automatic activation. The main goal of the present experiments was to determine whether the right–left prevalence effect obtained when stimulus location is relevant is due to automatic activation or intentional translation. Because the relevant stimulus dimension in the present experiments was color and not location, stimulus location should undergo automatic, but not controlled, processing. Therefore, if the prevalence effect is due to automatic activation, it should be evident in the present experiments, but if it is due to intentional translation, it should not be.

In Experiments 1 and 2, which used response arrangements for which the left hand made the left response and the right hand the right response, the vertical and the horizontal dimensions showed Simon effects of similar magnitude with a neutral display that did not favor either dimension. This result was obtained when the hands were placed wide apart on a handgrip apparatus (Experiment 1) and in close proximity on the numeric pad of a keyboard (Experiment 2). Moreover, when the display salience was manipulated in Experiment 2, the Simon effect was no larger overall for the horizontal dimension than for the vertical dimension. For Experiments 3 and 4, in which response effectors and positions were manipulated, the Simon effect tended to be larger for one dimension than for the other when averaged across display and response salience (*p*s = .055 and .050, respectively). However, this difference was only 5 msec in each experiment and was in opposite directions for the two experiments, favoring the vertical dimension in Experiment 3 and the horizontal dimension in Experiment 4. Thus, there was no overall prevalence effect for two-dimensional S–R sets when stimulus location was irrelevant to the task and color was relevant.

This outcome is in agreement with Umiltà and Nicoletti's (1990) suggestion that the right–left prevalence effect observed in previous studies when stimulus location was relevant was due to controlled processing associated with intentional S–R translation. One likely possibility is that when stimulus location is relevant and there is no correspondence on both the vertical and the horizontal dimensions, the distinction between left and right hands tends to bias subjects to code the stimuli as left and right locations mapped to left and right responses. This biasing of intentional coding by the right–left hand distinction is consistent with the fact that the right–left prevalence for SRC proper is larger with the hands separated on the handgrip apparatus than with close proximity on a keypad, whereas this factor has no influence on the relative magnitudes of the vertical and the horizontal Simon effects (Experiments 1 and 2). It is also consistent with the fact that the right–left prevalence effect for SRC proper vanishes when the responses are unimanual joystick movements along a diagonal (Hommel, 1996; Vu & Proctor, 2001).

Although there was no overall prevalence effect for the Simon task, Experiments 2–4 showed that varying display salience or response salience to favor one dimension over the other produced a larger Simon effect for the more salient dimension. For Experiments 3 and 4, in which response salience, as well as display salience, was manipulated, the largest difference in Simon effects for the two dimensions was obtained when the same dimension was salient for both the stimulus and the response sets. Thus, it was possible to create an advantage for one dimension over the other by making it more salient. This effect of salience was not just restricted to the spatial proximity manipulation for the stimulus set, but also occurred at least as strongly for the response set, for which the manipulation involved different hand positions (adjacent for horizontal salient or top–bottom for vertical salient) or hand–foot relations (contralateral for horizontal salient or ipsilateral for vertical salient). The implication of these findings is that salience manipulations have their effects, at least in part, on the automatic response activation route.

Experiments 2–4 of the present study are analogous to Experiments 1–3 of Vu and Proctor (2002), differing mainly in whether stimulus location was irrelevant or relevant to the task. A comparison of the results of those experiments reveals that the effects of the salience manipulation when stimulus location was irrelevant were roughly half the size of those when stimulus location was relevant (see Table 5). The effect of display salience on the advantage for one dimension relative to the other was 39 msec when location was relevant (Vu & Proctor's Experiment 1), as compared with 20 msec when it was not (the present Experiment 2). For the correspondence manipulations, the difference between the advantage for the horizontal dimension when both display and response salience were horizontal and that for the vertical dimension when both display and response salience were vertical was 89 msec with the hand placement manipulation and 70 msec with the hand–foot manipulation when stimulus location was relevant (Vu & Proctor's Experiments 2 and 3), as compared with 40 and 27 msec, respectively, when stimulus location was irrelevant (the present Experiments 3 and 4). If the contribution of the automatic route is assumed to be the same across all tasks, an assumption that is commonly made (e.g., De Jong et al., 1994), this pattern of results suggests that the salience manipulations do not just affect the codes responsible for automatic response activation. That is, if the effects were entirely on the automatic route, they would be expected to be of similar magnitude when location was relevant as when it was not.

A consistent finding across Experiments 2–4 was that there was a greater influence of display salience on the vertical Simon effect than on the horizontal Simon effect. Rubichi et al. (in press) have presented evidence that vertical coding is more dependent on the effectors used for responding than is horizontal coding when stimulus location is relevant to the task. The fact that display salience had a greater influence on the vertical Simon effect than on the horizontal Simon effect suggests that, in general, coding on the vertical dimension may be more sensitive to the specific task environment than coding on the horizontal dimension. This difference between the

Table 5
Mean Differences in Simon Effects (in Milliseconds) for the Horizontal and Vertical Dimensions for Experiments 2–4 of the Present Study and Experiments 1–3 of Vu and Proctor (2002) as a Function of Display and Response Salience

Condition	Study: Present Study	Study: Vu and Proctor (2002)
Display Salience Manipulation		
Vertical salient display	−8	−2
Neutral display	−2	19
Horizontal salient display	12	37
Display–Response Correspondence Manipulation With Top–Bottom and Adjacent Hand Placements		
Vertical display–vertical response	−29	−54
Vertical display–horizontal response	−1	−8
Horizontal display–vertical response	−2	11
Horizontal display–horizontal response	11	35
Display–Response Correspondence Manipulation With Ipsilateral and Contralateral Hand–Foot Placements		
Vertical display–vertical response	−12	−34
Vertical display–horizontal response	5	6
Horizontal display–vertical response	10	3
Horizontal display–horizontal response	15	36

Note—Positive values indicate an advantage for the horizontal dimension, and negative values indicate an advantage for the vertical dimension.

dimensions could account for why right–left prevalence is found in a wider variety of situations than is top–bottom prevalence.

Rubichi et al. (in press) concluded that, when stimulus location is relevant to the task, the temporal dynamics of spatial code formation are different for the horizontal and the vertical dimensions. The RT distribution bin analyses for the present study are generally consistent with this conclusion, in that the Simon effect for the vertical dimension tended to increase across RT bins, whereas the Simon effect for the horizontal dimension did not. However, this apparent difference in temporal dynamics is not directly responsible for the right–left prevalence effect, because it was evident with the neutral displays in the present study that yielded no right–left prevalence effect. Also, if the temporal dynamics of activation were crucial, the manipulations of display and response salience, which did influence the relative magnitudes of the Simon effects for the horizontal and the vertical dimensions, should systematically alter the shapes of the distributions. Instead, the primary effect of those manipulations on the distribution functions was to increase or reduce the Simon effect overall across the entire RT distribution.

In summary, location can be coded on both horizontal and vertical dimensions concurrently, as is indicated by the fact that vertical and horizontal Simon effects of similar magnitude can be obtained within the same condition. That right–left prevalence is absent for the Simon effect suggests that the effect often obtained when stimulus location is relevant apparently reflects a bias in intentional translation for the horizontal dimension, because for most response environments, responses are made by the two hands in adjacent positions. Although right–left prevalence does not occur when stimulus location is irrelevant, the relative effects of horizontal and vertical correspondence vary as a function of the salience of the locations of the respective dimensions, indicating that salience manipulations affect the codes on which automatic activation is based. The effects of salience manipulations are smaller for the Simon effect than for SRC proper, which suggests that salience manipulations affect both the automatic response activation route that produces the Simon effect and the intentional translation route that is also involved in SRC tasks for which location is relevant.

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