No overall right-left prevalence for horizontal and vertical Simon effects

KIM-PHUONG L. VU

California State University, Northridge, California

ANTONIO PELLICANO

University of Padua, Padua, Italy

and

ROBERT W. PROCTOR

Purdue University, West Lafayette, Indiana

The present study confirmed that there is no overall right-left prevalence effect for Simon tasks, in which stimulus location is irrelevant, when (1) the stimulus and response sets vary along both horizontal and vertical dimensions simultaneously, (2) the stimulus set varies along both dimensions, but the response set varies along only one dimension, and (3) the stimuli and responses vary in one of four possible locations and responses are made by a unimanual joystick movement. In all experiments, Simon effects of similar magnitude were evident for both the horizontal and the vertical dimensions. The findings suggest that the right-left prevalence effect observed with two-dimensional location-relevant tasks is not due to stronger overall automatic activation of horizontal codes but to different translation efficiencies in intentional response selection processes.

Stimulus-response compatibility (SRC) is a major factor contributing to the speed with which response selection occurs. SRC is usually studied in choice reaction tasks for which subjects make assigned responses to attributes of the stimuli, such as their locations or colors. In a typical two-choice spatial SRC task, a left or right key-press is made in response to a stimulus in a left or right location (e.g., Shaffer, 1965). Performance is better with a spatially compatible mapping of stimuli to responses (i.e., left stimulus to left response and right stimulus to right response) than with an incompatible mapping (i.e., left stimulus to right response and right stimulus to left response). For tasks in which responding is based on a non-spatial stimulus attribute (e.g., color), performance is still better when the stimulus and the response locations correspond than when they do not (Simon & Small, 1969), a phenomenon known as the *Simon effect* (see Lu & Proctor, 1995, and Simon, 1990, for reviews).

SRC effects are obtained regardless of whether both the stimulus and the response sets are arrayed along the horizontal or the vertical dimension. For SRC proper, the horizontal and the vertical compatibility effects are of similar magnitude (Nicoletti & Umiltà, 1984; Vu, Proctor, &

Pick, 2000). Thus, when measured in isolation, there does not seem to be an inherent advantage for the horizontal or the vertical dimension. In contrast, when the stimulus and the response sets vary along both the horizontal and the vertical dimensions simultaneously (e.g., when the locations are endpoints of the major diagonals of imaginary squares), a right-left prevalence effect is often obtained for SRC proper: The SRC effect is larger for the horizontal dimension than for the vertical dimension (e.g., Nicoletti & Umiltà, 1984, 1985; Nicoletti, Umiltà, Tresoldi, & Marzi, 1988).

Vu and Proctor (2001, 2002) showed that right-left prevalence is not due to an inherent advantage of the horizontal dimension over the vertical dimension but, rather, to the fact that in many situations, the stimulus or the response environment (e.g., responding with the left and the right hands) provides a salient frame of reference for horizontal coding. In fact, Vu and Proctor demonstrated that top-bottom prevalence could be obtained when the stimulus or the response environment was made to favor the vertical dimension. Moreover, they showed that the largest difference in SRC effects for the two dimensions occurred when the same dimension was salient for both the stimulus set and the response set.

Rubichi, Nicoletti, Pelosi, and Umiltà (2004) confirmed Vu and Proctor's (2001, 2002) findings that the salience of the response dimension is important in determining the relative magnitude of the compatibility effects for the horizontal and the vertical dimensions. In Rubichi et al.'s (2004) study, the stimuli varied along both dimensions simultaneously, as in previous studies, but the responses

We thank Lindsay Bell, Drew Davidson, Randi Guernsey, Colleen Johnson, and Naomi Rippy for their assistance with data collection. Correspondence regarding this article should be sent to K.-P. L. Vu, who is now at the Department of Psychology, California State University, Long Beach, CA 90840, or to R. W. Proctor, Department of Psychological Sciences, Purdue University, 703 Third Street, West Lafayette, IN 47907-2004 (e-mail: kvu8@csulb.edu or proctor@psych.purdue.edu).

were arrayed along only one dimension at a time, with response keys operated by horizontal effectors (i.e., both hands or both feet) or vertical effectors (i.e., the ipsilateral hand and foot). They obtained only a horizontal SRC effect when horizontal effectors were used for responding and a vertical SRC effect when vertical effectors were used. However, when the task was changed so that the stimuli were mapped orthogonally to effectors, requiring subjects to process both the horizontal and the vertical dimensions (e.g., when the effectors were hands, the subjects responded to the top-left and top-right stimuli with the right hand and to the bottom-left and bottom-right stimuli with the left hand), Rubichi et al. (2004) found a right-left prevalence effect: The horizontal SRC effect was present regardless of whether responses were made with horizontal or vertical effectors, but a vertical SRC effect was evident only when vertical effectors were used. Rubichi et al. (2004) suggested that the right-left prevalence effect when both dimensions must be processed may be due to the salience of intrinsic factors, in addition to environmental factors.

There has been disagreement about whether right-left prevalence occurs for the Simon task. Proctor, Vu, and Nicoletti (2003) found Simon effects of similar magnitude for the vertical and the horizontal dimensions with a neutral display in which the stimuli were presented at equal distances along the four corners of an imaginary square. They also showed that by making one dimension more salient than the other, the Simon effect for that dimension can be increased, relative to that for the alternative dimension. However, when collapsed across horizontally and vertically salient conditions, no overall right-left prevalence effect was evident.

In contrast, Rubichi, Nicoletti, and Umiltà (2005, Experiment 1) reported a right-left prevalence effect for Simon stimuli when the stimulus set varied along both dimensions but responses were arrayed along only a single dimension at a time and were executed by effectors that were coded along the same response dimension. That is, in different blocks of trials, both hands or both feet were used to execute horizontal responses, and the ipsilateral hand and foot were used to execute vertical responses. When the responses and effectors were horizontal, 48-msec horizontal and -8-msec vertical Simon effects were evident, whereas when the responses and effectors were vertical, 16-msec vertical and 7-msec horizontal Simon effects were obtained. Although the Simon effect was larger for the dimension made salient by the response set, Rubichi et al. (2005) concluded that right-left prevalence was evident, because the horizontal Simon effect with horizontal responses was larger than the vertical Simon effect with vertical responses.

In Rubichi et al.'s (2005) Experiment 2, contralateral hand and foot responses were used as a more "equisalient" response set, because the response locations could be coded in terms of both dimensions (e.g., top-right/bottom-left or top-left/bottom-right). However, they noted that the hand and foot are more likely to be coded in terms of the

vertical than the horizontal dimension, stating, "Consider a hand and a foot: If you have to denote them in spatial terms, you would consider the hand as the 'upper' effector and the foot as the 'lower' effector, rather than considering them as right and left effectors" (p. 172). For this reason, Rubichi et al. (2005) claimed that the use of contralateral effectors should, if anything, benefit the vertical dimension. However, they found a horizontal Simon effect of 26 msec and a nonsignificant vertical Simon effect of -3 msec. In contrast to Rubichi et al.'s (2005) reasoning that the contralateral hand and foot are equisalient or vertically salient, Vu and Proctor (2001, 2002) showed that although ipsilateral hand-foot responses are coded as top-bottom effectors, contralateral hand-foot responses tend to be coded as right-left effectors (see also Hommel, 1996). Thus, if the use of contralateral effectors affords horizontal coding, the right-left prevalence effect obtained in Rubichi et al.'s (2005) Experiment 2 may have been due to the saliency characteristics of the response set, rather than to an inherent dominance of horizontal codes.

A stronger case for right-left prevalence could be made, though, if the magnitude of the horizontal Simon effect obtained with contralateral hand-foot responses was significantly larger than that of the vertical Simon effect obtained with ipsilateral hand-foot responses. However, such a comparison was not made by Rubichi et al. (2005). Instead, they conducted a different type of experiment to provide further evidence for a right-left prevalence effect with the Simon task. In their Experiment 3, they used a four-choice version of the task in which the stimuli could appear in one of four locations at a corner of an imaginary square and responses were arrayed similarly and were executed with four effectors (i.e., the left and right hands and feet). Rubichi et al. (2005) obtained a significant horizontal Simon effect, but the vertical Simon effect was not significant.

The purpose of the present study was to reconcile the difference between Proctor, Vu, and Nicoletti's (2003) and Rubichi et al.'s (2005) findings and to determine whether right-left prevalence occurs for Simon tasks with neutral stimulus-response (S-R) sets or across horizontal and vertical response sets. This is important because it will provide evidence regarding whether the prevalence effect is a consequence of automatic activation or intentional translation. Because the Simon effect is typically attributed solely to automatic activation of the response code corresponding to the stimulus location, any prevalence effect obtained with the Simon task can be attributed to differences in automatic activation of the horizontal and vertical codes (e.g., Zorzi & Umiltà, 1995). The approach taken in the present study was to remove, or average across, possible contributions of differential salience produced by the response effectors.

EXPERIMENT 1

Before evaluating whether there is a right-left prevalence effect for two-dimensional Simon tasks, it is im-

portant to determine whether horizontal S-R sets yield larger Simon effects than do vertical S-R sets when measured in isolation. If there is stronger activation of horizontal codes than of vertical codes with unidimensional S-R sets, it may not be surprising to find a right-left prevalence effect with two-dimensional S-R sets. However, if the magnitudes of the horizontal and the vertical dimensions are similar under unidimensional conditions, as is the case for SRC proper, and a right-left prevalence effect arises with two-dimensional S-R sets, we can determine the factors that allow horizontal codes to dominate vertical codes when both are available. Thus, the purpose of Experiment 1 was to determine the magnitudes of the horizontal and vertical Simon effects when the S-R sets were arrayed along a single dimension.

Method

Subjects. Twenty experimentally naive undergraduates from Purdue University participated for partial course credit. All reported having normal or corrected-to-normal vision.

Apparatus and Stimuli. An IBM-compatible microcomputer was used to present stimuli and record the subject's response and RT. Micro Experimental Laboratory (MEL, Version 2.01) was used to program the experiment. The stimuli were solid red or green (MEL Color Codes 4 and 2) circles with a diameter of 1.5 cm (visual angle approximately 1.43°) and were displayed on a 14-in. VGA monitor. The distance of the monitor from the subject was about 60 cm. Responses were made by pressing a key on the numeric pad of a QWERTY keyboard. The numeric pad was aligned with the center of the screen. For the horizontal Simon task, the stimuli were presented 7.5 cm to the left or right of the center of the screen, and responses were made by pressing the 4 or the 6 key with the left or right index finger, respectively. For the vertical Simon task, the stimuli were presented 7.5 cm above or below the center of the screen, and responses were made by pressing the 8 or the 2 key. The left index finger was used to execute the top response, and the right index finger the bottom response, to avoid any additional benefit of pairing up with right and down with left (see Cho & Proctor, 2003, for a review of the up-right/down-left advantage).

Procedure. The experiment was conducted in a quiet, dimly lit room. All the subjects were tested in one session consisting of two blocks (one with the horizontal Simon task and one with the vertical Simon task) of 440 trials each. Half of the subjects performed the horizontal Simon task first, and half the vertical Simon task first. The first 40 trials of each block 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. The color-to-response assignment was counterbalanced between subjects, but the color-to-finger assignment remained the same for the two blocks for each subject (i.e., if red was assigned to the left finger and green to the right finger, the subjects would press the left [4] key to red stimuli and the right [6] key to green stimuli for the horizontal Simon task and the top [8] key to red stimuli and the bottom [2] key to green stimuli for

the vertical Simon task). Reaction time (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.

Results

RTs less than 200 msec or greater than 2,000 msec were excluded from the analyses in the present and subsequent experiments (fewer than 1% of all the trials). Mean correct RTs and percentages of errors (PEs) were submitted to separate 2 (dimension: vertical or horizontal) $\times$ 2 (correspondence: corresponding or noncorresponding) analyses of variance (ANOVAs; see Table 1 for means).

For both RT and PE, the only significant effect was the main effect of correspondence [$F_s(1,19) = 52.30$ and 20.19 , $MS_{\text{GS}} = 196$ and 3.75 , $ps < .001$]. Overall, Simon effects of 22 msec and 2.0% were obtained. For both measures, the interaction between dimension and correspondence was not significant ($F_s < 1$), with the horizontal Simon effects ($M_s = 23$ msec and 1.5%) being of similar magnitude to the vertical Simon effects ($M_s = 22$ msec and 2.4%).

Discussion

When measured in isolation, the horizontal and the vertical Simon effects were of similar size. The lack of a difference in Simon effects for the two dimensions indicates that there is no difference in the overall degree of activation for horizontal and vertical codes when responding is based on one dimension. Vu et al. (2000) showed, for SRC proper, that a prevalence effect occurred when the S-R sets varied along both dimensions simultaneously, even though equivalent SRC effects were obtained for each dimension in isolation. Thus, a right-left prevalence effect could arise for the Simon effect with two-dimensional S-R sets, which we evaluated in Experiment 2.

EXPERIMENT 2

Proctor, Vu, and Nicoletti (2003) presented a colored stimulus to one of four locations of an imaginary square and arrayed the two response alternatives along one of the major diagonals of another imaginary square. The subjects responded to the stimuli by pressing microswitches on two widely separated handgrips. With this display-response configuration, no right-left prevalence for the Simon effect was evident. Proctor, Vu, and Nicoletti's Experiment 2 replicated the finding of no right-left prevalence when responses were on a numeric pad of a key-

Table 1
Mean Reaction Times (RTs) and Percentages of Error (PEs) for
Corresponding and Noncorresponding Trials and Simon Effects
in Experiment 1 as a Function of Dimension (Horizontal or Vertical)

Dimension	Corresponding		Noncorresponding		Simon Effect	
	RT	PE	RT	PE	RT	PE
Vertical	445	2.10	467	4.46	22	2.36
Horizontal	436	2.57	459	4.10	23	1.53

board, instead of the handgrip apparatus. Because both of Proctor, Vu, and Nicoletti's experiments showed no right-left prevalence with a neutral display when right-left effectors were used for responding, they suggested that automatic activation of response codes is not sufficient to produce the prevalence effect.

This conclusion was called into question by Rubichi et al.'s (2005) Experiment 1, in which the Simon effect was larger for the horizontal than for the vertical dimension, using the same display layout as that in Proctor, Vu, and Nicoletti (2003). However, in Rubichi et al.'s (2005) experiment, the responses varied along only one dimension at a time, and two-dimensional response sets were formed by combining trials across different blocks (e.g., for horizontal effectors, the block for which responding was made with the left and right hands was considered top-left and top-right effectors and the block for which responding was made with the feet as bottom-left and bottom-right effectors). Rubichi et al. (2005) found that the response dimension greatly influenced the magnitudes of the horizontal and vertical Simon effects. When the responses were executed with horizontal effectors, only a horizontal Simon effect was obtained. Similarly, when the responses were executed with vertical effectors, only a vertical Simon effect was obtained. However, the horizontal Simon effect with horizontal effectors was three times larger than the vertical Simon effect with vertical effectors, which Rubichi et al. (2005) interpreted as a right-left prevalence effect.

Proctor, Vu, and Nicoletti's (2003) study differed from Rubichi et al.'s (2005) Experiment 1 in two respects. First, the responses in Proctor, Vu, and Nicoletti's study were two-dimensional (i.e., varied along both dimensions at the same time), whereas those in Rubichi et al.'s (2005) study were unidimensional (i.e., varied along only one dimension within a block, with the other dimension held constant). Second, Proctor, Vu, and Nicoletti had subjects respond with their left and right hands, whereas Rubichi et al. (2005) had subjects respond with their two hands in one block and with two feet in another block for their horizontal effectors condition and with the ipsilateral hand and foot for their vertical effectors condition. Although the number of hand/foot responses was equal when collapsed across all of Rubichi et al.'s (2005) conditions, it can be argued that responding with both hands or with both feet in different trial blocks is not the same as responding with a hand and a foot in the same trial block. First of all, responses made with the hands are usually faster than those made with the feet (e.g., Vu & Proctor, 2001). Second, it is well known that the Simon effect arises primarily from relative location coding (see, e.g., Umiltà & Nicoletti, 1985). Thus, when the effectors are horizontal, it is likely that they are coded as left and right, rather than as top-left and top-right (hands) or bottom-left and bottom-right (feet). Similarly, when the effectors are held constant to the left or right side, they are coded as top and bottom, rather than as top-left and bottom-left

or top-right and bottom-right. That Simon effects were obtained only for the dimension along which the effectors varied in Rubichi et al.'s (2005) study is consistent with this possibility.

Another problem with averaging across blocks for which responses were made by both hands, both feet, or one hand and a foot is that it is unknown whether larger unidimensional Simon effects are obtained with different sets or combinations of effectors. Furthermore, the horizontal effectors used in Rubichi et al.'s (2005) Experiment 1 involved only a right-left location distinction, but the vertical effectors involved both a top-bottom location distinction and an effector (hand, foot) distinction. In fact, when Rubichi et al. (2005) used contralateral hand-foot responses in their Experiment 2, they obtained only a horizontal Simon effect, and it was just 10 msec larger than the vertical Simon effect obtained with ipsilateral effectors. The reason why Rubichi et al. (2005) did not directly compare performance with contralateral and ipsilateral effectors is that with contralateral effectors, a top-bottom effector distinction can be made, in addition to the left-right effector distinction. However, evidence seems to suggest that subjects do code contralateral hand and foot responses as left and right, rather than as top and bottom, when the S-R sets vary along both dimensions (see Vu & Proctor, 2001, 2002; see also Hommel, 1996).

In Experiment 2A, we replicated Proctor, Vu, and Nicoletti's (2003) Experiment 2, to confirm that there is no right-left prevalence for the Simon effect with a neutral display when responses are arrayed along both dimensions simultaneously. In Experiment 2B, we performed a conceptual replication of Rubichi et al.'s (2005) Experiment 1, using unidimensional responses, but with only the hands used for responding. This response arrangement is like that used in the present Experiment 1, which yielded unidimensional Simon effects of similar magnitude for both dimensions. Thus, although the two hands are used to execute the responses arrayed along the horizontal or vertical dimension, there should not be an inherent advantage for either dimension.

Experiment 2A

Method

Twenty new undergraduate volunteers were recruited from the same subject pool as that in Experiment 1. The apparatus, stimuli, and procedure were the same as those used in Experiment 1, except for the differences noted here. The stimuli were presented in one of four corners of an imaginary 15×15 cm ($14^\circ \times 14^\circ$) square and appeared randomly one at a time in locations at angles of 45° (top-right), 135° (top-left), 225° (bottom-left), or 315° (bottom-right) with respect to the center of the screen.

The subjects responded to each stimulus by pressing the 1, 3, 7, or 9 key. 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. The subjects performed the identical task in both blocks of the experiment, with their responses being on one diagonal for one block and the alternative diagonal for the second block.

Table 2
Mean Reaction Times (RTs) and Percentages of Error (PEs) for
Corresponding and Noncorresponding Trials and Simon Effects in
Experiments 2A and 2B as a Function of Dimension (Horizontal or Vertical)

Dimension	Corresponding		Noncorresponding		Simon Effect	
	RT	PE	RT	PE	RT	PE
Experiment 2A						
Vertical	437	2.22	452	3.79	15	1.57
Horizontal	436	2.26	453	3.75	17	1.49
Experiment 2B						
Vertical	469	1.98	495	3.87	26	1.89
Horizontal	455	1.86	485	3.36	30	1.50

Results

Mean correct RT and PE for each condition are shown in Table 2. Two (horizontal correspondence: corresponding or noncorresponding) $\times$ 2 (vertical correspondence: corresponding or noncorresponding) ANOVAs were performed on the RT and PE data.

The main effects of horizontal correspondence [$F_s(1,19) = 60.25$ and 25.75 , $ps < .001$] and vertical correspondence [$F_s(1,19) = 27.33$ and 25.66 , MS_e s = 146 and 1.93, $ps < .001$] were significant for RT and PE. Simon effects of similar magnitude were obtained for vertical (15 msec and 1.57%) and horizontal (17 msec and 1.49%) dimensions. The interaction between vertical and horizontal correspondence was not significant for RT ($F < 1$), or PE ($F = 1.25$, $p = .28$).

Experiment 2B

Method

Twenty new undergraduate volunteers were recruited. The apparatus and procedure were similar to those used in Experiments 1 and 2A. The stimuli were identical to the ones used in Experiment 2A, and responses were identical to the ones used in Experiment 1. The same stimuli were used in both blocks, with half of the subjects responding with the vertical response arrangement first and half with the horizontal arrangement first.

Results

Mean correct RT and PE data were submitted to 2 (response dimension: vertical or horizontal) $\times$ 2 (correspondence on response dimension: corresponding or noncorresponding) ANOVAs. The only significant effects for RT and PE were the main effects of correspondence on the response dimension [$F_s(1,19) = 168.10$ and 22.41 , MS_e = 94.04 and 2.57, $ps < .001$]. Overall, Simon effects of 28 msec and 1.7% were obtained. For both measures, the interaction between dimension and correspondence was not significant ($F_s < 1$), with the horizontal ($Ms = 26$ msec and 1.89%) and vertical ($Ms = 30$ msec and 1.50%) Simon effects being of similar size.

Discussion

Consistent with the findings of Experiment 1, there was no difference in magnitude of the horizontal and vertical Simon effects when responses were arrayed along either two dimensions simultaneously or only one dimension at a time. The finding of no right-left prevalence effect

for the Simon task with a neutral display implies that the effect observed for SRC proper, when stimulus location is relevant, is not a consequence of automatically activated horizontal codes overriding vertical codes. This conclusion is in agreement with that reached by Proctor, Vu, and Nicoletti (2003), but in contrast to that reached by Rubichi et al. (2005, Experiment 1).

In Rubichi et al.'s (2005) Experiment 1, a right-left prevalence effect was obtained when the effectors varied along one dimension at a time. When response locations vary along one dimension, but not the other, there is evidence that a Simon effect occurs for the dimension along which responses vary, but not for the dimension that is held constant (e.g., Ansorge & Wühr, 2004). Thus, when horizontal effectors are used, only a Simon effect for the horizontal dimension should be obtained, and when vertical effectors are used, only a vertical Simon effect should be obtained—which is what Rubichi et al. (2005) found. In the present Experiment 2B, responses were arrayed only along one dimension at a time, which meant that response codes should be activated only for the dimension along which responses were currently arrayed. Right-left prevalence was not observed in this case, indicating that there was no inherent difference in the overall level of activation for horizontal and vertical codes when the same set of effectors was used for responding to each dimension.

One possible reason why Rubichi et al. (2005, Experiment 1) found a large difference in magnitudes of the horizontal and vertical Simon effects, whereas our experiment showed none, is that in their experiment, subjects performed with different pairs of effectors across trial blocks (two hands, two feet, right hand and foot, and left hand and foot). If these various effector combinations yield different baseline Simon effects, comparisons based on averaging across combinations may be skewed by the larger effect obtained for one of these combinations. For example, if the Simon effect for right-left feet were substantially larger than that for the other combinations, this would inflate the magnitude of the horizontal Simon effect.

EXPERIMENT 3

In Rubichi et al.'s (2005) discussion of the contralateral hand-foot condition used in their Experiment 2, they ac-

knowledgeed the possibility that the right–left prevalence effect obtained in that condition could be due to the horizontal dimension being more salient than the vertical dimension (see also, Hommel, 1996; Vu & Proctor, 2001, 2002). To provide evidence against this possibility, they conducted a third experiment in which subjects responded to the stimuli with all four effectors, the two hands and two feet. According to Rubichi et al. (2005), this four-effector response set was, in principle, more equisalient than the contralateral hand–foot response arrangement. Still, they found a right–left prevalence effect, and this effect cannot be attributed to averaging responses made with different effectors in different blocks of trials.

However, the horizontal and the vertical dimensions are not necessarily equally salient for this four-effector response set, because the left and the right effectors are distinguished by a salient frame of reference, the body midline, as well as by cerebral asymmetry (see Nicoletti & Umiltà, 1985). To remove the anatomical distinction between effectors completely, in the present Experiment 3, we used unimanual joystick movements. The use of unimanual joystick movements has been shown to be effective for removing any effector-based coding bias for two-dimensional S–R sets when stimulus location is relevant (see, e.g., Hommel, 1996; Vu & Proctor, 2001). As in Rubichi et al.'s (2005) Experiment 3, the stimuli could appear in one of the four corners of an imaginary square. The responses were joystick movements along a diagonal to one of four possible response locations at the corners of a separate imaginary square.

Method

Twenty new undergraduates participated. The stimuli, apparatus, and procedure were identical to those in the previous experiments, except for the differences noted. Responses were made by moving the handle of a custom-made joystick to one of four locations. The joystick was placed on the same table as the computer, approximately 45 cm in front of the seated subject. The subject operated the joystick by holding the top of the handle with the thumb, index, and middle fingers of the dominant hand. There were four possible stimulus colors (red, green, purple, and blue; MEL Color Codes 4, 2, 21, and 9, respectively) mapped to four response locations. The color-to-response mappings were the following: red = top-left, green = top-right, purple = bottom-left, and blue = bottom-right response. To help the subjects remember the color-to-response assignment, prior to the test block, each colored stimulus was presented in the center of the screen four times in a row, and the subject was to move the joystick to the assigned response location. To ensure that the subject had sufficient practice making the joystick movements to the four different colored stimuli, he or she was given a practice block of 96 trials. As in Rubichi et al.'s (2005) Experiment 3, the subject then performed two blocks of 120 test trials.

Results

Mean correct RT and PE for each condition are shown in Table 3. Two (horizontal correspondence: corresponding or noncorresponding) $\times$ 2 (vertical correspondence: corresponding or noncorresponding) ANOVAs were performed on the RT and PE data. For both measures, the main effects of vertical correspondence [$F_s(1,19) = 37.70$ and 18.82 , $MS_{\epsilon}s = 25,253$ and 18.83 , $ps < .001$] and horizontal correspondence [$F_s(1,19) = 12.06$ and 12.21 , $MS_{\epsilon}s = 1,021$ and 4.63 , $ps < .001$] were significant. Post hoc t tests showed that the Simon effects were of similar magnitude for the vertical (35 msec and 0.7%) and the horizontal (25 msec and 0.4%) dimensions. Although the interaction between vertical and horizontal correspondence was significant for RT and PE [$F_s(1,19) = 27.10$ and 17.73 , $MS_{\epsilon}s = 23,139$ and 6.53 , $ps < .001$], the interactions reflect the fact that performance was better when the stimulus and response corresponded on both dimensions than when they corresponded along only one or neither dimension ($ps < .001$), rather than there being a prevalence effect.

Discussion

Rubichi et al. (2005) found a right–left prevalence effect, using four two-dimensional stimuli mapped to all four hands and feet, and concluded that “interestingly, the prevalence of horizontal coding has been obtained with an S–R environment that did not enhance the horizontal dimension” (p. 173). However, the present Experiment 3 showed no right–left prevalence using unimanual joystick movements, which can be considered more “neutral” than responding with the four effectors, because it completely removes any difference regarding the dimension along which subjects code the different effectors (see Hommel, 1996; Vu & Proctor, 2001, 2002). The findings of Experiment 3 are also consistent with the findings of Experiment 2, which showed no right–left prevalence with two-dimensional Simon tasks.

When the stimulus and the response sets vary along the horizontal and vertical dimensions simultaneously, as in Experiments 2A and 3 and Rubichi et al.'s (2005) Experiment 3, performance can be evaluated with respect to whether the stimuli and the responses are mapped compatibly along both, one, or neither of the dimensions (see Table 4). Performance is usually best when both dimensions are mapped compatibly and worst when both are mapped incompatibly, as in Experiment 2A. More interesting is whether performance is better when compatibility is maintained along only one dimension. In Ex-

Table 3
Mean Reaction Times (RTs) and Percentages of Error (PEs) for Corresponding and Noncorresponding Trials and Simon Effects in Experiment 3 as a Function of Dimension (Horizontal or Vertical)

Dimension	Corresponding		Noncorresponding		Simon Effect	
	RT	PE	RT	PE	RT	PE
Vertical	662	0.84	697	1.54	35	0.70
Horizontal	667	1.00	692	1.39	25	0.39

Table 4
Mean Reaction Times (RTs) and Percentages of Error (PEs)
in the Present Experiments 2A and 3 and Rubichi, Nicoletti,
and Umiltà's (2005) Experiment 3 as a Function of
Compatibility Along the Two Dimensions: Compatible on Both
Dimensions (Both), Compatible Only on the Vertical Dimension
(Vertical), Compatible Only on the Horizontal Dimension
(Horizontal), and Compatible on Neither Dimension (Neither)

Condition	Experiment 2A		Experiment 3		Rubichi et al.	
	RT	PE	RT	PE	RT	PE
Both	429	1.62	629	0.38	670	1.9
Vertical	446	2.89	694	1.31	702	2.3
Horizontal	443	2.81	705	1.63	690	3.2
Neither	460	4.69	689	1.46	690	3.4

periment 3, there was a nonsignificant 11-msec advantage for the vertical dimension ($p = .27$), whereas in Rubichi et al.'s (2005) Experiment 3, there was a 12-msec advantage for the horizontal dimension, but this was accompanied by a 0.90% PE disadvantage for the horizontal dimension. Thus, looking across both studies, there seems to be no overall right-left prevalence effect for the four-choice version of the Simon task. What is more important to note, though, is that for this version of the task, performance was best for the *both* condition, in which correspondence was maintained on both the horizontal and the vertical dimensions, and was about the same for the remaining three conditions. These findings imply that incompatibility is especially harmful to the four-choice versions of the task, because both dimensions must be coded.

GENERAL DISCUSSION

Vu and Proctor (2001, 2002) showed that the right-left prevalence effect for SRC proper does not reflect a limitation in the capacity to process both dimensions. Rather, because the horizontal and the vertical codes are redundant, responding can be based on a single code when it is made salient. They suggested that the reason why right-left prevalence occurs is that, in many situations, the stimulus and response environments provide a more salient frame of reference for horizontal coding than for vertical coding. More recently, Rubichi et al. (2004) suggested that intrinsic factors, such as the temporal dynamics of the two types of codes, could also make the horizontal dimension more salient than the vertical dimension.

Differences in direct activation of horizontal and vertical codes alone can be evaluated using two-dimensional Simon tasks. Proctor, Vu, and Nicoletti (2003) showed that the magnitudes of the horizontal and vertical Simon effects could be altered by manipulating the relative salience of the two dimensions. In Proctor, Vu, and Nicoletti's Experiments 1 and 2, the horizontal and the vertical Simon effects were of similar magnitude when a neutral display was used, even though responses were made with the left and right hands. When display salience was manipulated, the vertical Simon effect increased with the

vertically salient display, relative to the neutral display, and decreased with the horizontally salient display. The horizontal Simon effect was less affected by the display manipulation, being of similar magnitude for all three displays. The fact that the horizontal Simon effect was relatively unaffected by the display salience manipulation alone suggests that when responding with the left and right hands, a simple left-right distinction of stimulus location (regardless of how far apart they are arrayed) is sufficient to produce horizontal coding of those locations. Coding along the vertical dimension, using the hands as effectors, is enhanced, though, only by making the frame of reference for vertical coding more salient in the display. It is important to note, though, that collapsed across horizontally and vertically salient displays, the magnitudes of the effects are similar. Thus, the robustness of the horizontal Simon effect across all three display manipulations is likely a result of using the left and right hands for responding, rather than of a prevalence of horizontal codes in general.

In contrast to Proctor, Vu, and Nicoletti's (2003) findings, Rubichi et al. (2005, Experiment 1) apparently found a right-left prevalence effect for the Simon task when the stimuli were two-dimensional but responses varied along only one dimension at a time. Furthermore, Rubichi et al. (2005) found a benefit for the horizontal dimension over the vertical dimension in conditions that they thought to be equispatial on both the horizontal and the vertical dimensions: when responses were made by contralateral hand-foot effectors and when both the hands and the feet were used in a four-choice version of the task. However, there are several factors in Rubichi et al.'s (2005) study that may have promoted horizontal coding, rather than vertical coding. First, in their Experiment 1, Rubichi et al. (2005) used different effectors for the different blocks of trials but did not measure baseline Simon effects for each combination of effector pairs.

Second, although Rubichi et al. (2005) considered contralateral hand and foot responses to be equally salient on the horizontal and the vertical dimensions, Vu and Proctor (2001, 2002) showed that contralateral hand and foot responses tend to be coded along the horizontal dimension, rather than along the vertical dimension. Thus, it is not surprising to find a horizontal advantage with contralateral hand and foot responses, but this advantage would not be taken to be a strong indicator for a prevalence of horizontal coding unless the horizontal advantage obtained with contralateral hand-foot responses was larger than the vertical advantage obtained with ipsilateral hand-foot responses. Because Rubichi et al. (2005) did not directly compare ipsilateral and contralateral hand-foot conditions, it is premature to conclude, on the basis of the contralateral effector condition alone, that there is an overall right-left prevalence effect. Third, with all four hands and feet as response effectors, there is still a problem with how the effectors are coded. Although it can be assumed that each effector represents the two dimensions equally, it may be the case that the horizontal di-

mension is still salient because the body midline provides a salient referent and movements of the ipsilateral hand and foot are controlled by the same, contralateral cerebral hemisphere of the brain.

The present study showed no overall right–left prevalence effect for Simon tasks, using two-dimensional S–R sets (Experiments 2A and 3) that were equally salient on both dimensions or two-dimensional stimuli mapped to unidimensional responses (Experiment 2B) when collapsed across both horizontally and vertically salient conditions. These results are in agreement with Proctor, Vu, and Nicoletti's (2003) conclusion that there is no inherent overall advantage in automatic activation of horizontal codes over vertical codes. These findings also suggest that the right–left prevalence effect observed in Rubichi et al.'s (2005) study was a result of their using different effectors for the different blocks of trials or effectors that tend to be coded in terms of the horizontal dimension (i.e., contralateral effectors).

In Proctor, Vu, and Nicoletti's (2003) Experiment 1 and the present Experiment 2A, for which both the stimulus and the response sets varied along the horizontal and the vertical dimensions simultaneously, Simon effects of similar magnitude were obtained for both dimensions. This is consistent with the notion that both horizontal and vertical spatial codes are formed for two-dimensional S–R sets. However, in Rubichi et al.'s (2005) Experiments 1A and 1B, for which the stimuli varied along both dimensions, but responses along only a single dimension at a time, Simon effects were obtained only for the dimension along which the responses varied. Although this finding can be interpreted as the horizontal dimension being more salient when horizontal effectors were used and the vertical dimension being more salient when vertical effectors were used, as Rubichi et al. (2005) did, another interpretation of the results is that responses were coded along a single dimension because the response sets varied along only one dimension at a time.

This point is illustrated by Ansorge and Wühr's (2004) Experiment 1, in which the role of response discrimination in producing the Simon effect was examined. In their study, the Simon stimuli could appear in one of four locations (left of, right of, above, or below center), and responses were unimanual movements from a centered home key to response keys that could be coded two-dimensionally (e.g., movement from the home key [5 key] of a numeric keypad to the 7 key was an up-left movement, whereas movement to the 1 key was a down-left movement), but the response arrangement varied along one dimension at a time (i.e., the 7 and 1 keys or the 9 and 3 keys for the vertical dimension, or the 7 and 9 keys and the 1 and 3 keys for the horizontal dimension). With this arrangement, only one dimension could be used to discriminate the response locations (the discriminating axis), because the other was held constant within a block (the nondiscriminating axis). Simon effects were computed as a function of whether the stimuli and the responses corresponded on the discriminating or the

nondiscriminating axis, and Ansorge and Wühr found that Simon effects were obtained only for the discriminating axis. In fact, they concluded that "the absence of a Simon effect in the nondiscriminating conditions presumably resulted from the uselessness of the nondiscriminating codes for the purpose of response discrimination" (p. 370).

Although Ansorge and Wühr's (2004) Experiment 1 was not designed to evaluate the prevalence effect for two-dimensional S–R sets, it illustrates an important point for the present purposes: When the response array is held constant in one dimension but varies in another, responses are coded in terms of the dimension that varies. This finding implies that in Rubichi et al.'s (2005) Experiment 1, responses were coded only along the horizontal dimension when horizontal effectors were used, regardless of whether the effectors were hands or feet. Similarly, responses were coded only along the vertical dimension when ipsilateral hand–foot effectors were used, regardless of whether they were to the right or the left of center. Thus, it does not seem appropriate to recombine and analyze the data as if they were varying along both dimensions simultaneously.

In the present Experiment 2B, because the responses were arrayed along only one dimension, there is no question that the response codes were based on that dimension alone. Yet no right–left prevalence effect was evident. This finding suggests that the effect observed in Rubichi et al.'s (2005) Experiment 1 may have been due to the different sets of effectors used in the different blocks of trials. Rubichi et al. (2005) obtained a 48-msec horizontal Simon effect when responses were made with horizontal effectors, which is larger than the 15- to 25-msec unidimensional horizontal Simon effects typically obtained with bimanual responses (e.g., Proctor, Vu, & Marble, 2003). Hence, the larger overall horizontal Simon effect might have been due to the feet's yielding larger Simon effects than did the hands. Because baseline Simon effects for the different pairs of effectors were not obtained, it is unknown whether the larger horizontal Simon effects were, indeed, due to the use of different effector pairs or not.

Rubichi et al.'s (2005) Experiment 3 was the first in which the prevalence effect was examined with a four-choice version of the Simon task. Rubichi et al. (2005) noted that the use of all the hands and feet should produce an approximately equisalient response set. Because they obtained an overall significant Simon effect for the horizontal dimension, but not for the vertical dimension, they concluded that there was a right–left prevalence effect under equisalient conditions. However, with the unimanual joystick movements used in the present Experiment 3, Simon effects were obtained for both dimensions, with the vertical Simon effect being at least as large as the horizontal Simon effect. Because unimanual responses completely remove any possible bias in the dimension along which the different effectors are coded, the results from the present Experiment 3 clearly show that there is

no right-left prevalence effect for neutral stimulus and response sets. As was mentioned earlier, Ansorge and Wühr (2004) examined horizontal and vertical Simon effects when responses were unimanual two-dimensional movements along discriminating or nondiscriminating axes. Although in their study they did not use two-dimensional stimulus sets, it is worth noting that they also found a tendency for larger vertical than horizontal Simon effects along the discriminating axes. Thus, there does not seem to be an advantage for the horizontal dimension for Simon tasks in which unimanual responses are used.

For the four-choice versions of the Simon task, S-R correspondence along both dimensions is the most critical factor for producing quick and accurate performance. In fact, in both Rubichi et al.'s (2005) Experiment 3 and the present Experiment 3, there was no benefit for maintaining correspondence on one dimension (i.e., the horizontal or the vertical condition), as compared with when correspondence was not maintained on either dimension (i.e., the *neither* condition). Thus, when the stimulus location does not correspond directly to the response location on both dimensions, the conflicting spatial codes slow performance, regardless of whether the conflict occurs in one or both dimensions.

Rubichi et al. (2005) explained this pattern of under-additive effects in terms of *logical recoding*, a concept introduced by Hedge and Marsh (1975). The latter authors found that when subjects were instructed to respond to a stimulus of one color by pressing a button of the alternative color, the Simon effect reversed, so that RT was shorter when the stimulus location did not correspond to the response location than when it did. Hedge and Marsh's logical recoding account of this reversal of the Simon effect was that the *opposite* rule for mapping of stimulus color to response color was also applied to the irrelevant dimension of stimulus location (see also Hommel, 1996). This logical recoding explanation would not seem to be applicable to the tasks used to study the two-dimensional Simon effect, because the mapping of stimulus color to response key is arbitrary. Nevertheless, Rubichi et al. (2005) argued that their results seem "to indicate that the logical recoding explanation does apply even when the S-R mappings are arbitrary" (p. 174). Their interpretation was that when there is correspondence or noncorrespondence on both dimensions, a *same* rule or an *opposite* rule can be applied to both the horizontal and the vertical stimulus codes. However, when there is correspondence on one dimension and noncorrespondence on the other, a mixture of *same* and *opposite* rules is activated, but the *opposite* rule dominates, tending to favor noncorresponding responses.

The logical recoding account would predict that performance should be better for the *neither* condition than for the horizontal and vertical conditions, because there is conflict in activation of response rules for the latter conditions, but not for the former condition (see Rubichi et al., 2005). However, as is illustrated in Table 4, per-

formance was no better for the *neither* condition than for the horizontal and vertical conditions in our Experiment 3 or Rubichi et al.'s Experiment 3. Thus, the logical recoding account proposed by Rubichi et al. (2005) does not seem to explain the pattern of results obtained in our study or theirs. Instead, the data seem to indicate that non-correspondence on any dimension slows performance.

In summary, the results of Experiment 1 indicate that there is no advantage for the horizontal dimension with unidimensional Simon tasks. Furthermore, Experiments 2 and 3 showed that there is no overall right-left prevalence effect for two-dimensional S-R sets when they are neutral or when collapsed across horizontal and vertical response sets. These results imply that there is no inherent difference in the overall level of automatic activation for horizontal and vertical codes, although the relative degree of activation for the respective codes can be altered by varying the salience of the dimensions (see Proctor, Vu, & Nicoletti, 2003). The absence of a right-left prevalence effect in the Simon task under conditions that yield such an effect in tasks for which stimulus location is relevant suggests that the prevalence effect reflects the relative salience of the spatial codes on which intentional response selection processes operate.

REFERENCES

- ANSORGE, U., & WÜHR, P. (2004). A response-discrimination account for the Simon effect. *Journal of Experimental Psychology: Human Perception & Performance*, **30**, 365-377.
- CHO, Y. S., & PROCTOR, R. W. (2003). Stimulus and response representations underlying orthogonal stimulus-response compatibility effects. *Psychonomic Bulletin & Review*, **10**, 45-73.
- HEDGE, A., & MARSH, N. W. A. (1975). The effects of irrelevant spatial correspondences on two-choice response time. *Acta Psychologica*, **39**, 427-439.
- HOMMEL, B. (1996). No prevalence of right-left over top-bottom spatial codes. *Perception & Psychophysics*, **58**, 102-110.
- LU, C.-H., & PROCTOR, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review*, **2**, 174-207.
- NICOLETTI, R., & UMILTÀ, C. (1984). Right-left prevalence in spatial compatibility. *Perception & Psychophysics*, **35**, 333-343.
- NICOLETTI, R., & UMILTÀ, C. (1985). Responding with hand and foot: The right/left prevalence in spatial compatibility is still present. *Perception & Psychophysics*, **38**, 211-216.
- NICOLETTI, R., UMILTÀ, C., TRESSOLDI, E. P., & MARZI, C. A. (1988). Why are right-left spatial codes easier to form than above-below ones? *Perception & Psychophysics*, **43**, 287-292.
- PROCTOR, R. W., VU, K.-P. L., & MARBLE, J. G. (2003). Eliminating spatial compatibility effects for location-relevant trials by intermixing location-irrelevant trials. *Visual Cognition*, **10**, 15-50.
- PROCTOR, R. W., VU, K.-P. L., & NICOLETTI, R. (2003). Does right-left prevalence occur for the Simon effect? *Perception & Psychophysics*, **65**, 1318-1329.
- RUBICHI, S., NICOLETTI, R., PELOSI, A., & UMILTÀ, C. (2004). Right-left prevalence effect with horizontal and vertical effectors. *Perception & Psychophysics*, **66**, 255-263.
- RUBICHI, S., NICOLETTI, R., & UMILTÀ, C. (2005). Right-left prevalence with task-irrelevant spatial codes. *Psychological Research*, **69**, 167-178.
- SHAFFER, L. H. (1965). Choice reaction with variable S-R mapping. *Journal of Experimental Psychology*, **70**, 284-288.
- SIMON, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In R. W. Proctor & T. G. Reeve

- (Eds.), *Stimulus-response compatibility: An integrated perspective* (pp. 31-86). Amsterdam: North-Holland.
- SIMON, J. R., & SMALL, A. M., JR. (1969). Processing auditory information: Interference from an irrelevant cue. *Journal of Applied Psychology*, **53**, 433-435.
- UMILTÀ, C., & NICOLETTI, R. (1985). Attention and coding effects in S-R compatibility due to irrelevant spatial codes. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 457-471). Hillsdale, NJ: Erlbaum.
- VU, K.-P. L., & PROCTOR, R. W. (2001). Determinants of right-left and top-bottom prevalence for two-dimensional spatial compatibility. *Journal of Experimental Psychology: Human Perception & Performance*, **27**, 813-828.
- VU, K.-P. L., & PROCTOR, R. W. (2002). The prevalence effect in two-dimensional stimulus-response compatibility is a function of the relative salience of the dimensions. *Perception & Psychophysics*, **64**, 815-828.
- VU, K.-P. L., PROCTOR, R. W., & PICK, D. F. (2000). Horizontal versus vertical compatibility: Right-left prevalence with bimanual responses. *Psychological Research*, **64**, 25-40.
- ZORZI, M., & UMILTÀ, C. (1995). A computational model of the Simon effect. *Psychological Research*, **58**, 193-205.

(Manuscript received June 28, 2004;
revision accepted for publication November 8, 2004.)