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Influences of response position and hand posture on the orthogonal Simon effect

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When lateralized responses are made to the locations of vertically arrayed stimuli, two types of mapping effect have been reported: an overall up–right/down–left advantage and mapping preferences that vary with response position. According to Cho and Proctor's (2003) multiple asymmetric codes account, these orthogonal stimulus–response compatibility effects are due to the correspondence of stimulus polarity and response polarity, as determined by the positions relative to multiple frames of reference. The present study examined these two types of orthogonal compatibility for situations in which participants made left–right responses to the colours of a vertically arrayed stimulus set, and stimulus location was irrelevant. Although a significant orthogonal Simon effect was not evident when responding at a centred, neutral response position, the effect was modulated by response eccentricity (Experiment 2) and hand posture (Experiment 3). These effects are qualitatively similar to those obtained when stimulus location is task relevant. The results imply that, as Proctor and Cho's (2006) polarity correspondence principle suggests, the stimulus polarity code activates the response code of corresponding polarity even when stimulus location is irrelevant to the task.

When people make lateralized responses to stimuli appearing left or right of a fixation point, performance is better when stimuli are assigned to their spatially corresponding responses than when they are not. This spatial stimulus–response compatibility (SRC) effect has been studied and has been found to occur in various conditions, including situations in which stimulus location is irrelevant to the task (see Proctor & Vu, 2006, for review). For example, when participants are instructed to make a left or right response to the colour of an imperative stimulus presented in a left or right location, the spatial correspondence between stimulus and response still influences choice reaction time (RT). This effect is called the Simon effect (see Hommel & Prinz, 1997).

The spatial SRC effect can be obtained when the stimulus and response sets are in orthogonal orientations (e.g., Bauer & Miller, 1982), a phenomenon that is called the *orthogonal SRC effect*. When participants are instructed to make lateralized responses to a vertically arrayed stimulus set,

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performance is usually better when the right response is assigned to the up stimulus and the left response to the down stimulus than when the mapping is opposite. Recent studies have attributed this *up–right/down–left advantage* to coding asymmetry (Adam, Boon, Paas, & Umiltà, 1998; Cho & Proctor, 2001; Lippa & Adam, 2001; Proctor & Cho, 2001; Weeks & Proctor, 1990; Umiltà, 1991). According to the multiple asymmetric codes account (Cho & Proctor, 2003; Proctor & Cho, 2006), the two stimulus alternatives and two response alternatives are coded asymmetrically, with "up" and "right" coded as the polar referents (unmarked, or + polarity) for their respective dimensions and "down" and "left" relative to them (marked, or − polarity; Olson & Laxar, 1973; Seymour, 1974). The mapping of up to right and down to left yields better performance than the opposite mapping because it maintains correspondence of the + polarity codes and the − polarity codes. Among the evidence in support of this account of the up–right/down–left advantage is that it occurs for a variety of stimulus sets (physical locations, arrow directions, location words) and response sets (bimanual keypresses, unimanual aimed movements, unimanual toggle-switch movements, and vocal "left"–"right" utterances; Adam et al., 1998; Michaels, 1989; Weeks & Proctor, 1990; Weeks, Proctor, & Beyak, 1995; see Cho & Proctor, 2003, for a review).

Orthogonal SRC is modulated by response position (e.g., Michaels, 1989; Weeks et al., 1995; see Figure 1c). In Weeks et al.'s Experiment 1, participants made unimanual left–right switch movement responses to a vertically arrayed stimulus set at two ipsilateral positions, two contralateral positions, and body midline. The up–right/down–left advantage at the midline increased at the two right response positions and reversed to an up–left/down–right advantage at the two left response positions, regardless of whether the left or right hand was used for responding. This influence of response position on orthogonal SRC is called the *response eccentricity effect*.

Orthogonal SRC is also modulated by hand posture. Michaels and Schilder (1991) had

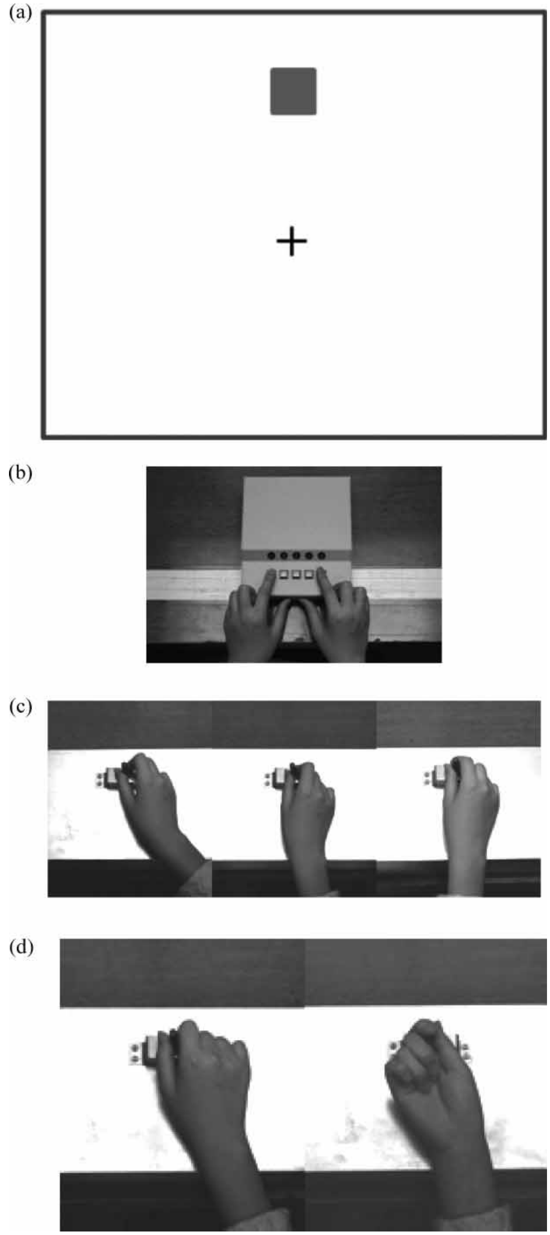

Figure 1. *(a) The stimulus display used in Experiment 1. (b) The bimanual keypress response mode used in Experiment 1. (c) The hand postures of unimanual toggle-switch movement response used in Experiment 2, illustrated for the right hand in the left, body midline, and right response positions, respectively. (d) The hand postures used in Experiment 3, illustrated for the right hand in prone and supine posture, respectively.*

participants make unimanual toggle-switch movements to a vertically arrayed stimulus set at the body midline in one of two hand postures: prone (palm down) or supine (palm up; see Figure 1d). The right hand showed an up–left/down–right advantage in the prone posture and an up–right/down–left advantage in the supine posture. However, the left hand showed the opposite relation of an up–right/down–left advantage in the prone posture and an up–left/down–right advantage in the supine posture. According to Michaels and Schilder, this *hand posture effect* and the response eccentricity effect are due to the motoric states of the response hand.

Cho and Proctor (2002, Exp. 1) demonstrated that response position and hand posture influence orthogonal SRC additively. They obtained a hand posture effect of similar magnitude at three response positions (body midline, and left or right of midline). According to their multiple asymmetric codes account, the response position is spatially coded with respect to multiple frames of reference. In their experiment, the response position was coded relative to the main part of the responding hand, as well as relative to the stimulus display, influencing the polarities of the response alternatives. For example, at the right response position, the spatial code "right" is formed. This "right" code provides an additional positive code for the right response, resulting in a larger up–right/down–left advantage. However, at the left response position, the spatial code "left" is formed, which contributes a positive code to the representation of the left response alternative. Consequently, the up–right/down–left advantage tends to reverse to an up–left/down–right advantage at left response positions. The multiple spatial codes for the response position influence the polarities of the response alternative additively. This multiple coding asymmetry account can explain not only the overall up–right/down–left advantage, but also the response eccentricity and hand posture effects.

The orthogonal SRC effect is not as clearly evident when stimulus location is task irrelevant as when it is relevant. Wallace (1971, 1972) showed a nonsignificant orthogonal Simon effect in his experiments when participants were asked to make left–right keypresses to the colours of stimuli that could occur in up, down, left, and right locations. This nonsignificant tendency of the orthogonal Simon effect was replicated by Proctor, Vu, and Marble (2003) in an experiment in which location was the relevant dimension for the left and right stimulus locations and colour for the up and down locations.

Cho and Proctor (2004) reported stronger evidence of an orthogonal Simon effect for an experiment in which participants made left–right responses to the up or down location of the imperative stimulus relative to a fixation row that was presented randomly on the upper or lower part of the screen at three different positions (left, centre, and right). Thus, the entire display of fixation and imperative stimulus was located in either the upper half of the display screen or the lower half. The responses were unimanual toggle-switch movements made with the left or right hand in a prone or supine posture. Whether the display was in the upper half of screen or the lower half, which was an irrelevant stimulus dimension, produced no overall Simon effect. However, there were significant interactions of this variable with response eccentricity and hand posture that showed patterns of changes in the Simon effect that were qualitatively similar to those obtained for effects of orthogonal SRC proper. That is, a 9-ms upper-right/lower-left advantage at the right response position reversed to an 8-ms upper-left/lower-right advantage at the left response position. Also, the left hand showed a larger upper-right/lower-left advantage (and the right hand a larger upper-left/lower-right advantage) in the prone than in the supine posture. These results indicate that coding asymmetry of upper or lower display location influenced the response-selection process, even though display location was irrelevant to the task.

Recently, Nishimura and Yokosawa (2006) reported evidence from a more standard orthogonal Simon task that an irrelevant stimulus location dimension is coded asymmetrically and influences the response selection process. In their Experiment 1, participants made left–right keypresses, centred at midline, to the colour of an imperative stimulus appearing above or below a fixation point. The results showed a significant 12-ms up–right/down–left advantage, unlike the nonsignificant effects reported in prior studies that also used keypress responses (Proctor et al., 2003; Wallace, 1971, 1972). According to Nishimura and Yokosawa, the orthogonal Simon effect was tested directly in their experiment but not in the prior experiments because those experiments included intermixed trials on which the imperative stimulus appeared left or right of the fixation point. Nishimura and Yokosawa argued that intermixing left and right stimulus locations could have caused the up–down stimuli to be coded as left or right relative to the immediately preceding left or right stimulus, making horizontal coding more salient and attenuating the orthogonal Simon effect.

In Nishimura and Yokosawa's (2006) Experiment 2, participants made bimanual keypresses to the colour of the imperative stimulus at left, centre, and right response positions. The results showed a nonsignificant 4-ms up–right/down–left advantage at the centre position that increased to a significant 16-ms advantage at the right response position and reversed to a significant 9-ms up–left/down–right advantage at the left response position. Thus, like the orthogonal SRC effect, and like Cho and Proctor's (2004) findings for irrelevant display location in the upper or lower part of the screen, the orthogonal Simon effect was modulated by response eccentricity. These results, again, imply that when stimulus location is task irrelevant, stimulus and response locations are coded as positive or negative polarity with respect to multiple frames of reference, and choice RT is influenced by the polarity correspondence of the stimulus and response codes, as hypothesized by Cho and Proctor's (2003) multiple asymmetric codes account.

It is important to note, though, that the orthogonal Simon effect at the centre response position was only a nonsignificant 4 ms in Nishimura and Yokosawa's (2006) Experiment 2, even though the imperative stimulus appeared only above or below the fixation point, as in their Experiment 1. This outcome is similar to the results of the studies for which stimuli also occurred in left and right positions (Proctor et al., 2003; Wallace, 1971, 1972). If the nonsignificant results in those studies were due to the task context of presenting the stimuli in several different locations, a significant orthogonal Simon effect should have been obtained in Nishimura and Yokosawa's Experiment 2 since the imperative stimulus also appeared only above or below the fixation point.

Because of the inconsistency of Simon-effect findings at centred response positions and the importance of that effect for determining whether polarity correspondence contributes automatically to orthogonal SRC effects, we examined the orthogonal Simon effect thoroughly in three experiments. In these experiments, participants responded to the colour of an imperative stimulus presented above or below a fixation point with bimanual left–right keypresses (Experiment 1) or unimanual left–right toggle-switch movements (Experiments 2 and 3). Experiment 1 was a procedural replication of Nishimura and Yokosawa's (2006) Experiment 1 to determine whether a statistically significant orthogonal Simon effect can be regularly obtained when the imperative stimulus is presented at only up and down locations. If the nonsignificant orthogonal Simon effect in other studies was due to the intermixing of left and right stimulus locations, as Nishimura and Yokosawa argued, an orthogonal Simon effect should be evident in our Experiment 1, as it was in their Experiment 1.

Nishimura and Yokosawa's (2006) Experiment 2 provided evidence that the orthogonal Simon effect obtained with left–right keypresses is influenced by response eccentricity similarly to the way that orthogonal SRC proper is. In their experiment, participants responded with bimanual left–right keypresses. Although a response eccentricity effect for orthogonal SRC proper has been reported for left–right keypresses (Proctor & Cho, 2003), most studies examining the response eccentricity effect have used unimanual left–right switch movements. Unimanual movements allow comparison of performance with right and left hands, and with the hands held in different postures. Cho and Proctor (2004) found that response eccentricity and hand posture both influenced the effects produced by the entire display being presented in the upper or lower half of the screen. However, their task differed from a standard Simon task in that the relevant stimulus dimension was also up–down location relative to the fixation row, and the irrelevant location dimension was not stimulus location per se but location of the entire display. Consequently, in Experiment 2 we had participants perform a more standard Simon task in which they made unimanual toggle-switch responses to the colours of stimuli presented in up or down locations, with the right or left hand in a typical prone posture at three different positions (left, centre, or right) in different trial blocks. According to the multiple asymmetric codes account, response eccentricity should exert similar effects for unimanual switch movements as for bimanual keypresses, and this response eccentricity effect should be similar for the left and right hands.

When the posture of the hand for unimanual responses is supine, rather than prone, the position of the switch relative to the body of the hand reverses. According to the multiple asymmetric codes account, this reversal changes the coding of response position relative to the hand, resulting in predictable changes in orthogonal SRC. In Experiment 3 we tested whether the orthogonal Simon effect is modulated by hand posture in the predicted manner. Participants held the toggle switch in either a palm down (prone) or palm up (supine) posture. As in Experiment 2, an effect of polarity correspondence between the stimulus and response locations should be most evident when the frame of reference provided by the hand reinforces the coding asymmetry for the left and right responses.

EXPERIMENT 1

The main purpose of Experiment 1 was to attempt to replicate the results of Nishimura and Yokosawa's (2006) Experiment 1. When participants made bimanual left–right keypress responses to the colour of the stimulus appearing above or below a fixation point at the body midline, they found a significant 12-ms up–right/down–left advantage, even though previous studies that used similar procedures have not shown a significant orthogonal Simon effect (Proctor et al., 2003; Wallace, 1971, 1972). As noted, Nishimura and Yokosawa surmised that the difference in results between their experiment and the previous experiments was that in their experiment the imperative stimulus appeared only above or below the fixation point. Thus, Nishimura and Yokosawa suggested that the orthogonal Simon effect occurs when stimuli vary only along the vertical dimension.

To test whether an orthogonal Simon effect is reliably obtained when the stimuli vary only along the vertical dimension, Experiment 1 was conducted using a procedure similar to that of Nishimura and Yokosawa's (2006) Experiment 1, but with more participants than they tested.

Method

Participants
A total of 40 undergraduate students enrolled in Introductory Psychology at Purdue University participated for course credits in partial fulfilment of a course requirement. All of the participants were right-handed and had normal colour vision and normal or corrected-to-normal visual acuity, as determined by self-report.

Stimuli and apparatus

Micro Experimental Laboratory 2 (MEL 2.01) software was used to programme the experiment. Stimuli were presented on the display screen of a personal computer at a viewing distance of approximately 60 cm. Responses were made by pressing the leftmost or rightmost of five keys on a MEL 2.0 response box with the left and right index fingers. Stimuli were a red or green square (1.3×1.3 cm, $1.24^\circ \times 1.24^\circ$). They were presented approximately 3 cm (2.85°) above or below a fixation cross "+" (0.6×0.6 cm, $0.57^\circ \times 0.57^\circ$; see Figure 1a).

Procedure
Participants were told to align their body midline with the centre of the screen and to place their left index finger on the left key and their right index finger on the right key (see Figure 1b). The experiment consisted of one practice session of 60 trials, followed by three test sessions of 120 trials each. After completing each session, a 30-s rest period was given.

At the beginning of each trial, a white fixation cross was presented at the centre of the screen. Participants were asked to stare at it. After 1,000 ms, a red or green square was presented above or below the fixation cross. Participants were to press the left or right key to the colour of the square. Half of the participants were instructed to make the right response to the green square and the left response to the red square, and the other half were instructed to make responses in the opposite way. The fixation cross and the square remained on until the response was made. An incorrect response was followed by a 500-ms feedback tone. The fixation point for the next trial came on 1,500 ms after the response.

Results

RTs shorter than 125 ms and longer than 1,250 ms (a total of 0.30%) were removed from analysis as outliers. Mean RTs and percentage of errors (PE) were calculated for each participant as a function of stimulus location (up and down) and response (left and right). Analyses of variance (ANOVAs) were conducted on the mean RT and PE data, with the stimulus location and response as within-subject factors. The means of these data are shown in Table 1.

Table 1. *Mean reaction time and percentage of error in Experiment 1 as a function of response and stimulus position*

	Response	
Stimulus position	*Left*	*Right*
Up	461 (1.45)	451 (1.51)
Down	454 (1.11)	449 (1.65)

Note: Mean reaction time in ms. Percentage of error in parentheses.

Reaction time
RT was shorter when the square was presented below the fixation point (M = 452 ms) than when it was presented above the fixation point (M = 456 ms), $F(1, 39) = 5.18$, $p = .029$, $\eta^2 = .12$. RT tended to be shorter for the right response (M = 450 ms) than for the left response (M = 457 ms), though the main effect of response was not significant, $F(1, 39) = 2.36$, $p = .132$, $\eta^2 = .06$. Most important, the interaction of stimulus location and response was not significant, $F(1, 39) = 1.33$, $p = .257$, $\eta^2 = .03$. The mean data showed a 3-ms difference in the direction of an up–right/down–left advantage.

Percentage of error
Overall percentage of error (PE) was 1.43%. Although slightly more errors tended to be made when the square appeared above the fixation point (1.48%) rather than below (1.38%), the main effect of stimulus location was not significant, $F(1, 39) < 1.00$, $p = .704$, $\eta^2 = 0$. The main effect of response was not significant either, $F(1, 39) = 2.05$, $p = .160$, $\eta^2 = .05$, nor was the interaction of stimulus location and response, $F(1, 39) < 1.00$, $p = .456$, $\eta^2 = .01$.

Discussion

No significant orthogonal Simon effect was obtained, even though the stimulus appeared only above or below the fixation point, as in Nishimura and Yokosawa's (2006) Experiment 1, and 40 participants were tested rather than the 16 used in their study. Instead, there was a non-significant 3-ms up–right/down–left advantage similar to the result obtained for the condition of their Experiment 2 in which the response keys were centred at midline. This outcome implies that having stimuli occur only in up and down locations is not sufficient to obtain a clear orthogonal Simon effect with centred, left–right keypresses.

One important difference in the results between this experiment and Nishimura and Yokosawa's (2006) Experiment 1 is that mean RT was longer in the present experiment ($M = 453$ ms) than in theirs ($M = 343$ ms). Thus, the possibility exists that a clear orthogonal Simon effect would be evident for fast responses. To evaluate this possibility, we divided the RT distributions of each participant for the up–right/down–left pair and up–left/down–right pair into five bins, each containing 20% of the RTs in the distribution (e.g., Adam et al., 1998), and then performed an ANOVA with correspondence (up–right/down–left pair and up–left/down–right pair) and bin (1, 2, 3, 4, and 5) as factors. As determined by the analysis, RT was an increasing function of bin, being 340, 391, 431, 482, and 622 ms for the shortest to longest RT bins. However, the orthogonal Simon effect did not vary with bin, being 0, 2, 1, 2, and 5 ms, respectively. Thus, even though mean RT for the first bin was similar to the overall RT in Nishimura and Yokosawa's experiment, there was no evidence of an orthogonal Simon effect.

The lack of reliable orthogonal Simon effect could be due to either of two possible reasons. First, polarity codes for the stimulus locations may not be formed when location is task irrelevant, providing no basis for a Simon effect. That is, according to Cho and Proctor (2003), an orthogonal SRC effect should occur when stimulus and response locations are coded categorically, resulting in one alternative being coded positively and the other negatively. If stimulus locations are not coded categorically when they are task irrelevant, no orthogonal Simon effect would occur.

Second, the polarity codes for the stimulus locations may have been formed but not been sufficiently strong to yield a polarity correspondence effect. When stimulus and response sets are parallel, the Simon effect is less than half the size of the SRC effect obtained when stimulus location is relevant (see Proctor & Vu, 2006). Given that the orthogonal SRC effect for midline keypresses when stimulus location is relevant is itself relatively small (10–15 ms), any reduction in effect size due to location being irrelevant could render the effect too small to detect in most experiments. This possibility was favoured by Proctor et al. (2003), who noted that the mean differences in their study and Wallace's (1971, 1972), though nonsignificant, tended toward an up–right/down–left advantage, "suggesting that there may really be an advantage for the top–right/bottom–left relation" (p. 35). The results of Experiment 1 continue this trend.

EXPERIMENT 2

Orthogonal SRC is modulated by the position at which responses are made (e.g., Michaels, 1989). When responses are made at left, centre, or right positions relative to the stimulus display, the up–right/down–left advantage is largest at the right response position (Cho & Proctor, 2004). Also, the orthogonal SRC effect reverses at the left response position to an up–left/down–right advantage. This response eccentricity effect is obtained even when the up–right/down–left advantage is not significant at the centre position (e.g., Cho & Proctor, 2004). If, in Experiment 1, stimulus polarity was coded, and the orthogonal Simon effect was nonsignificant because the activation due to correspondence with the response code polarities was not very strong, then the orthogonal Simon effect should be evident when response position is manipulated.

In Nishimura and Yokosawa's (2006) Experiment 2, participants made bimanual keypresses to the colour of a square appearing above or below the fixation point, with the response apparatus located at body midline or 30 cm to the left or right of midline. The nonsignificant 4-ms up–right/down–left advantage at body midline increased to a significant 16-ms advantage at the right position and reversed to a significant 9-ms up–left/down–right advantage at the left position.

In our Experiment 2, as in Nishimura and Yokosawa's (2006) Experiment 2, we manipulated the response position. However, unlike in their experiment, participants responded to the stimulus colour by deflecting a toggle switch left or right with the left or right hand. The purpose was to replicate the results obtained by Nishimura and Yokosawa with a different response modality that allowed comparison between the two hands, as well as to test whether the polarities of the stimulus locations are coded when they are task irrelevant. If the polarity of the stimulus codes activates the response code of the corresponding polarity, a response eccentricity effect that is qualitatively similar to that obtained when stimulus location is task relevant should occur, and this response eccentricity effect should be similar for the left and right hands.

Method

Participants

A total of 40 new undergraduate students from the same subject pool as that in Experiment 1 participated. Participants were randomly assigned to two different response-hand groups: left and right.

Stimuli and apparatus

As in Experiment 1, MEL 2.01 software was used to programme the experiment, and stimuli were presented on the display screen of a personal computer at a viewing distance of approximately 60 cm. Responses were made by deflecting a toggle switch left or right in response to the colour of the stimulus at three different positions: body midline and 15 cm to the left and right of midline. The toggle switch was mounted on a panel (43 × 17.5 × 6 cm), placed on the table containing the computer display, interfaced with a MEL 2 response box. The height of the toggle switch was 7.5 cm (see Figure 1c). Stimuli were a red or green circle (1.2 cm, 1.14° in diameter). They were presented approximately 3 cm (2.85°) above or below a fixation row of three asterisks (0.2 × 0.7 cm, 0.19° × 0.67°).

Procedure

Participants were instructed to align their body midline with the centre of the screen and to hold the toggle switch with the thumb and index finger of the responding hand. The experiment consisted of one practice session of 20 trials and three test sessions of 140 trials, one for each response position. Half of the participants began at the 15-cm position in the right hemispace and progressed to the left. The other half began at the 15-cm position in the left hemispace and progressed to the right. The practice trials were performed with the response position used for the first test session. After completing each of the first two test sessions, a 30-s rest period was given before beginning the next session.

At the beginning of each trial, a row of three asterisks was presented at the centre of the screen as a fixation point. Participants were asked to stare at it. After 500 ms, the row of asterisks disappeared, and the red or green circle was presented above or below the fixation row. Participants were instructed to deflect the toggle switch left or right to the colour of the circle. Half of participants were told to make the right response to the green circle and the left response to the red circle, and the other half to make responses in the opposite way. The circle remained visible until the response was made. An incorrect response was followed by a 500-ms feedback tone. The fixation point for the next trial came on 1,000 ms after the response.

Results

A total of 0.59% of the trials were removed from analysis using the same criteria as those in Experiment 1. Mean RTs and PEs were calculated for each participant as a function of response position (left, midline, and right) and compatibility (up−right/down−left and up−left/down−right). ANOVAs were conducted on the mean RT and PE data, with response position and mapping as within-subject factors and response hand (left or right) as a between-subjects factor. The means of these data are shown in Table 2.

Reaction time

Although RT tended to be shorter when responding with the right hand than with the left hand, the main effect of response hand was not significant, $F(1, 38) = 1.84$, $p = .183$, $\eta^2 = .05$. The two-way interaction of response hand and response

Table 2. *Mean reaction time and percentage of error in Experiment 2 as a function of response hand, response position, and compatibility*

	Response position		
Compatibility	*Left*	*Centre*	*Right*
Left hand			
Up–right/down–left	456 (2.58)	465 (1.15)	455 (1.22)
Up–left/down–right	446 (1.30)	463 (1.07)	481 (2.08)
Right hand			
Up–right/down–left	444 (2.72)	433 (1.23)	429 (1.08)
Up–left/down–right	440 (2.44)	439 (2.67)	447 (2.94)

Note: Mean reaction time in ms. Percentage of error in parentheses.

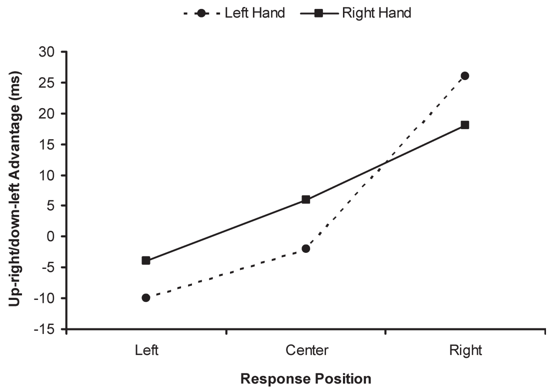

Figure 2. *The orthogonal Simon effect as a function of response position and response hand in Experiment 2.*

position approached statistical significance, $F(2, 76) = 2.92$, p=.060, η^2=.07. When participants responded using the right hand, RT was longer at the left response position ($M = 442$ ms) than at the other two positions (Ms = 436 and 438 ms for the midline and right response positions, respectively). However, when participants responded using the left hand, RT was shorter at the left response position ($M = 451$ ms) than at the other two positions (Ms = 468 and 464 ms for the right and midline response positions, respectively). That is, responses for both hands were faster at the ipsilateral position than at the other positions.

An overall up–right/down–left advantage of 6 ms was obtained, $F(1, 38) = 4.83$, $p = .034$, $\eta^2 = .11$. Most important, the interaction of compatibility and response position was significant, $F(2, 76) = 17.70$, $p < .0001$, $\eta^2 = .32$. The nonsignificant up–right/down–left advantage of 2 ms at the midline response position increased to 22 ms at the right response position, $F(1, 38) = 27.95$, $p < .001$, $\eta^2 = .42$, and reversed to a 6-ms up–left/down–right advantage at the left response position, $F(1, 38) = 3.78$, $p = .059$, $\eta^2 = .09$. This response eccentricity effect did not interact with response hand (see Figure 2), $F(2, 76) = 1.58$, $p = .213$, $\eta^2 = .04$. When responding with the right hand, the up–right/down–left advantage was 18, 6, and −4 ms at the right, midline, and left response positions, respectively. When responding with the left hand, it was 26, −2, and −10 ms, respectively. No other main effect or interaction was significant.

Percentage of error

Overall PE was 1.87%. The main effect of response position was significant, $F(2, 76) = 5.11$, $p = .008$, $\eta^2 = .12$. Fewer errors were made at the midline response position (1.53%) than at the right and left response positions (1.83% and 2.26%, respectively). Although the data showed a 0.41% up–right/down–left advantage, the main effect of compatibility was not significant, $F(1, 38) = 2.85$, $p = .100$, $\eta^2 = .07$. However, the two-way interaction of compatibility and hand was significant, $F(1, 38) = 5.57$, $p = .024$, $\eta^2 = .12$. The up–right/down–left advantage was 1.00% when responding with the right hand, but it was −0.17% when responding with the left hand. Most important, the response eccentricity effect was also obtained in the PE data, $F(2, 76) = 10.22$, $p < .0001$, $\eta^2 = .21$. A 0.68% up–right/down–left advantage at the midline response position increased to 1.36% at the right position and reversed to a 0.78% up–left/down–right advantage at the left position. This response eccentricity effect was not modulated by response hand, $F(2, 76) < 1.0$. The other terms were not significant.

Discussion

Both RT and PE showed no significant orthogonal Simon effect at the centre response position, but such an effect was evident in the interaction of compatibility with response position. In the RT data, a 2-ms orthogonal Simon effect at the centre position increased to 22 ms at the right response position and reversed to a 6-ms up–left/down–right advantage at the left response position. In the PE data, a similar pattern of results was obtained. As in Experiment 1, the orthogonal Simon effect was not significant at the centre position. However, the response eccentricity effect was obtained for both the left and the right hands, and response hand did not interact significantly with this influence of response eccentricity on the orthogonal Simon effect. Thus, response position is the factor that systematically influences the orthogonal Simon effect.

The response eccentricity effect obtained with unimanual responses in this experiment and with keypress responses in Nishimura and Yokosawa's (2006) Experiment 2 is important because it indicates that stimulus positions are being coded as positive and negative polarity even when stimulus location is irrelevant to the task. According to the multiple asymmetric codes account (Cho & Proctor, 2003), though the left–right responses were coded asymmetrically when responding at a centred position, the contribution of polarity correspondence to response selection was not sufficiently strong to unambiguously affect performance. Because response position is coded in terms of the stimulus display and/or body midline, an additional positive polarity code for the right response was formed when responding at the right response position, resulting in the right response being coded as more strongly positive. This increase in asymmetry for the left and right response alternatives resulted in a stronger benefit from correspondence of the right response with the positive polarity up stimulus code and the left response with the negative polarity down stimulus code, resulting in a larger up–right/down–left advantage. In contrast, when responding at the left response position, the response position is coded as left, which adds a positive polarity to the left response. Thus, the up stimulus position now corresponds relatively more with the left response and the down stimulus position with the right response than when responding at the centre position, and the preferred mapping shifts toward up–left/down–right.

The size of the response eccentricity effect in this experiment (28 ms), which is comparable to that obtained in Nishimura and Yokosawa's (2006) Experiment 2 (25 ms), is smaller than that obtained when stimulus location is task relevant (60–80 ms; Cho & Proctor, 2002, 2004). This smaller size is to be expected because the Simon effect obtained when the stimuli and responses are arrayed along parallel dimensions is smaller than the effect of SRC proper (see Proctor & Vu, 2006). Thus, polarity correspondence across stimulus dimensions seems to act much like spatial correspondence within stimulus dimensions.

In the PE data, the orthogonal Simon effect was larger when responding with the right hand than with the left hand. This outcome is contrary to the usual finding of a larger up–right/down–left advantage with the left hand than with the right hand for the prone posture in previous studies of orthogonal SRC effects (e.g., Cho & Proctor, 2003, 2005). The discrepancy in the results could be due to stimulus location being relevant in those studies versus irrelevant in the present experiment, or to response hand being manipulated within subjects in the previous experiments but between subjects in Experiment 2.

EXPERIMENT 3

Orthogonal SRC is modulated by the posture of the hand used to operate the response switch (e.g., Michaels & Schilder, 1991). When a response switch is held in a prone posture, as in Experiment 2, the up–right/down–left advantage is larger with the left hand than with the right hand. However, when the switch is held in a supine posture, the advantage is greater with the right hand than with the left hand. According to the hand-referent hypothesis proposed by Cho and Proctor (2003), this hand posture effect is a consequence of the body of the hand providing a frame of reference relative to which a spatial code for response position is formed. That is, if the body of the hand is to the right, the response position is coded as left, and vice versa. If polarity correspondence is affected by the response hand when stimulus location is task irrelevant, the orthogonal Simon effect should be affected by hand posture similar to the way that it is when stimulus location is task relevant.

In Experiment 3, participants made responses to the colour of the stimulus by deflecting a toggle switch at body midline left or right, operating the switch with the left or right hand in one of two hand postures, prone or supine. The purpose was to test the influence of hand posture on the orthogonal Simon effect. If stimulus polarity is coded when stimulus location is irrelevant, a hand posture effect, qualitatively similar to the effect obtained when the stimulus location is task relevant, should be obtained.

Method

Participants

A total of 40 new undergraduate students from the same subject pool as that in the previous experiments participated. Participants were randomly assigned to the two different hand posture groups: prone and supine.

Apparatus, stimuli, and procedure

The apparatus and stimuli were identical to those of Experiment 2 except that only the body midline position for the response switch was used. Participants aligned their body midline with the centre of the screen and placed the response hand with the palm down in the prone condition and the palm up in the supine condition (see Figure 1d). For both hand postures, the toggle switch was held between the thumb and index finger. The experiment consisted of two blocks of three sessions, one practice and two test, with a 1-min rest period between them. Participants performed the first block with one hand and the second block with the other hand. The order of the responding hand was counterbalanced across participants. Each participant performed 10 practice trials using the response hand for the trial block before performing the test sessions of 100 trials each. After completing each session, a 30-s rest period was given.

Results

A total of 0.86% of trials were removed from analysis using the same criteria as those in the previous experiments. Mean RTs and PEs were calculated for each participant as a function of response hand (left and right) and compatibility (up–right/down–left and up–left/down–right). ANOVAs were conducted on the mean RT and PE data, with hand and compatibility as within-subject factors and hand posture (prone, supine) as a between-subjects factor. The means of these data are shown in Table 3.

Reaction time

RT was shorter with the prone posture (M = 463 ms) than with the supine posture (M = 519 ms), $F(1, 38) = 8.08$, $p = .007$, $\eta^2 = .18$. Mean RT was 2 ms shorter when the spatial relation was up–right/down–left (M = 490 ms) than when it was up–left/down–right (M = 492 ms), and this difference was not significant, $F(1, 38) < 1.0$. However, the two-way interaction of compatibility and response hand was significant,

Table 3. *Mean reaction time and percentage of error in Experiment 3 as a function of response hand, hand posture, and compatibility*

	Hand posture	
Compatibility	*Prone*	*Supine*
Left hand		
Up–right/down–left	467 (1.51)	524 (1.47)
Up–left/down–right	467 (1.56)	518 (0.66)
Right hand		
Up–right/down–left	460 (1.45)	508 (0.91)
Up–left/down–right	458 (1.45)	526 (1.60)

Note: Mean reaction time in ms. Percentage of error in parentheses.

$F(1, 38) = 8.11$, $p = .007$, $\eta^2 = .18$. When participants made responses with the right hand, an 8-ms up–right/down–left advantage was obtained, $F(1, 38) = 5.95$, $p = .0195$, $\eta^2 = .14$, but when they made responses with the left hand, a 2-ms up–left/down–right advantage occurred, $F(1, 38) < 1.0$. Most important, the hand-posture effect was evident (see Figure 3). The three-way interaction of compatibility, response hand, and hand posture was significant, $F(1, 38) = 13.86$, $p < .001$, $\eta^2 = .27$. The right hand showed a 2-ms up–left/down–right advantage in the prone posture, $F(1, 38) < 1.0$, and 18-ms up–right/down–left advantage in the supine posture, $F(1, 19) = 15.77$, $p = .0008$, $\eta^2 = .45$, whereas the left hand showed a 0-ms up–right/down–left advantage in the prone posture, $F(1, 38) < 1.0$, and a 6-ms up–left/down–right advantage in the supine posture, $F(1, 38) < 1.0$. No other main effect or interaction was significant.

PE

Overall PE was 1.33%. The three-way interaction of compatibility, response hand, and hand posture only approached statistical significance, $F(1, 38) = 3.75$, $p = .060$, $\eta^2 = .09$, but the trend was consistent with a hand posture effect. The right hand showed a 0% up–left/down–right advantage in the prone posture and a 0.70% up–right/down–left advantage in the supine posture, whereas the left hand showed a 0.05% up–right/down–left advantage in the prone posture that was reversed to 0.81% up–left/down–right advantage in the supine posture. None of the other main effects or interactions was significant.

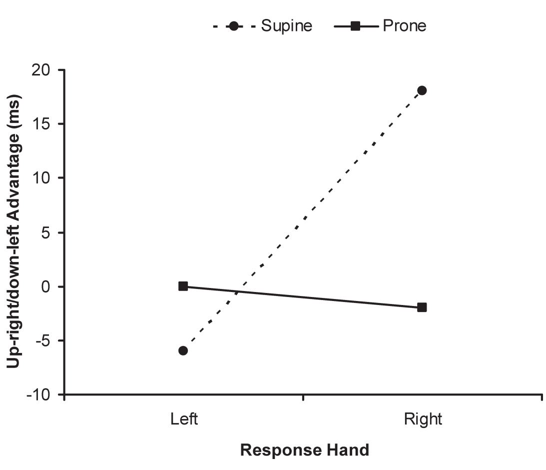

Figure 3. *The orthogonal Simon effect as a function of hand posture and response hand in Experiment 3.*

Discussion

Hand posture influenced orthogonal SRC even when the stimulus location was task irrelevant. As in Experiment 2, there was little difference between the up–right/down–left and up–left/down–right relations when the hand operating the switch was in a prone position. However, when hand posture was supine, the left hand showed a shift in the direction of an up–left/down–right advantage and the right hand a shift to an up–right/down–left advantage. This shift was evident in both the RT and PE data, although the interaction did not quite attain statistical significance for the latter. Like the response eccentricity effect, the hand posture effect was qualitatively similar but smaller in this experiment, for which stimulus location was irrelevant, than the effect obtained in studies for which stimulus location was task relevant (Cho & Proctor, 2002; Michaels & Schilder, 1991). Thus, when stimulus location is irrelevant, polarity correspondence influences response selection in the way predicted by the multiple asymmetric codes account of orthogonal SRC effects. The effect sizes are just smaller than they are when stimulus location is relevant.

GENERAL DISCUSSION

When participants make left–right responses to the location of a stimulus appearing above or below the fixation point, an overall up–right/down–left advantage is usually obtained (e.g., Weeks & Proctor, 1990). This orthogonal SRC effect is modulated by response position and hand posture (e.g., Michaels & Schilder, 1991). Cho and Proctor (2003) summarized evidence indicating that these orthogonal SRC effects are due to correspondence between the polarities of stimulus- and response-location codes. These asymmetric, categorical codes may be formed automatically as a consequence of having stimuli occur in up and down locations and responses being left and right choices. However, inconsistent results have been reported as to whether an orthogonal Simon effect, indicative of a polarity correspondence effect when stimulus location is task irrelevant, occurs and, if so, the conditions under which it does (Cho & Proctor, 2004; Nishimura & Yokosawa, 2006; Proctor et al., 2003; Wallace, 1971, 1972).

Three experiments investigated whether polarity correspondence affects performance when the stimulus location is task irrelevant. In Experiment 1, a nonsignificant 3-ms up–right/down–left advantage was obtained when participants made left–right keypresses to the colours of stimuli presented above or below a fixation point. This outcome differs from the significant 12-ms up–right/down–left advantage reported by Nishimura and Yokosawa (2006) for their similar experiment, but it is in agreement with the nonsignficant 4-ms effect they found for the centred response position in their Experiment 2 and with the nonsignificant effects of a few milliseconds reported in other studies. Thus, polarity correspondence has at most a very small effect on participants' performance when keypress responses are made at a centred position, even when there are just two stimulus positions varying along the vertical dimension.

Experiments 2 and 3, which used unimanual toggle-switch movements, similarly showed small, nonsignificant orthogonal Simon effects for responses made with a normal, prone hand posture at a midline position. Thus, small Simon effects are obtained for centred positions regardless of whether the responses are bimanual keypresses or unimanual switch movements. Despite the tenuous evidence for an orthogonal Simon effect when response position is centred, clear evidence for such an effect as a function of polarity correspondence was evident when response eccentricity and hand posture were varied in Experiments 2 and 3. When participants made left–right toggle-switch movement responses at left, centre, and right positions in Experiment 2, the nonsignificant 2-ms up–right/down–left advantage at body midline increased to a 22-ms up–right/down–left advantage at the right response position and a reversed 6-ms up–left/down–right advantage at the left response position. This response eccentricity effect did not interact significantly with responding hand (left or right), in agreement with previous findings indicating that the response eccentricity effect is mainly a function of response position (e.g., Cho & Proctor, 2004, 2005; Weeks et al., 1995). This pattern of results indicates that stimulus location is coded asymmetrically when it is irrelevant to the task, and this asymmetric coding yields a polarity correspondence effect with the asymmetrically coded responses under conditions in which this asymmetry is strong.

When participants made unimanual responses at body midline using a prone or supine hand posture in Experiment 3, a significant hand posture effect was found. Though little difference between up–right/down–left and up–left/down–right was found in the prone posture, the right hand showed an up–right/down–left advantage and the left hand an up–left/down–right advantage in the supine posture. These shifts in effects from prone to supine postures are in the directions expected if response position is coded relative to the body of the hand. For the right hand, the switch is coded left relative to the hand in the prone position but right in the supine position, leading to the right response alternative being more positive polarity. For the left hand, the switch is coded as right relative to the hand in the prone position but left in the supine position, leading to the left response alternative being more positive polarity. The pattern of hand posture and response eccentricity effects is qualitatively similar to that obtained when stimulus location is task relevant (e.g., Cho & Proctor, 2002; Michaels & Schilder, 1991), though of smaller magnitude (see also Cho & Proctor, 2004). Both effects indicate unambiguously that correspondence of asymmetric stimulus and response codes influences response selection when the stimulus location is irrelevant.

The results of Experiments 2 and 3 are in agreement with predictions of Cho and Proctor's (2003; Proctor & Cho, 2006) multiple asymmetric codes account. According to the account, the locations of the stimulus and response alternatives are coded asymmetrically, as positive and negative polarity, in terms of multiple frames of reference. These multiple spatial codes determine the summed polarities of the stimulus and response alternatives, accordingly causing polarity correspondence effects such as the orthogonal SRC effect. Thus, the multiple asymmetric codes account predicts that the orthogonal mapping preference is primarily influenced by response position relative to multiple frames of reference, such as display and responding hand, causing the response eccentricity and hand posture effects. The fact that the response eccentricity and hand posture effects obtained in Experiments 2 and 3 are qualitatively similar to those obtained from the previous studies, in which the stimulus location was task relevant, indicates that spatial information of the stimulus alternative is coded asymmetrically, and that the polarity code of a stimulus activates the response code of corresponding polarity, even when the spatial stimulus information is not task relevant.

Although an orthogonal Simon effect based on polarity correspondence can be obtained, the effect was not evident statistically for centre position responses in any of the experiments, including Experiment 1, which used keypresses. This result is not in accord with Nishimura and Yokosawa's (2006) explanation, according to which an orthogonal Simon effect should be clearly evident when stimuli vary only on the vertical dimension. Those researchers attributed the lack of a significant orthogonal Simon effect in other studies to their using methods in which the imperative stimuli appeared in left and right locations as well as up and down locations. They argued that on trials following a right or left stimulus, an up or down stimulus could be coded as left or right of the preceding stimulus, overriding any effects of coding along the vertical dimension. If such sequential coding of relative location were occurring and eliminating the orthogonal Simon effect, the effect should have been unambiguously evident in the present Experiment 1 since stimuli occurred in only up and down locations. Yet it was not; nor was it apparent when responses were made at the centre position in Nishimura and Yokosawa's (2006) Experiment 2, which yielded a nonsignificant effect of the similar size as the present Experiment 1 and other experiments (Cho & Proctor, 2004; Proctor et al., 2003; Wallace, 1971, 1972). Thus, it is unlikely that the orthogonal Simon effect is impacted much, if any, by coding of horizontal location relative to a preceding left or right stimulus. Rather, the orthogonal Simon effect obtained when responding at a centred position is at most very weak, regardless of the specific context in which the up and down stimuli are presented.

Cho and Proctor (2004) obtained results similar to those of the present Experiments 2 and 3 when the task required responding to the location of a stimulus relative to a fixation row, with the entire display occurring in the upper or lower half of the display screen. They suggested that the lack of a significant overall orthogonal Simon effect coupled with significant interactions with response eccentricity and hand posture could be explained as follows in terms of dual-route models of SRC and Simon effects (e.g., Hommel & Prinz, 1997). The overall up–right/down–left advantage, which is clearly evident only when stimulus location is relevant, is due to short-term, task-defined associations of the intentional response selection route. If such is the case, there truly should be no orthogonal Simon effect when stimulus location is irrelevant, and responses are keypresses at a centred position, because there would be no basis for polarity coding of the responses. The response eccentricity and hand posture effects, on the other hand, which are evident regardless of whether stimulus location is relevant, are due to long-term associations of the automatic route.

It is important to note that the response eccentricity and hand posture effects in Experiments 2 and 3 were at most half the size of those obtained with unimanual toggle-switch movement responses in studies for which stimulus location was task relevant (Cho & Proctor, 2002; Weeks et al., 1995), though they were similar in size to those obtained by Cho and Proctor (2004) for irrelevant location of the entire display. This difference in effect sizes, which is in agreement with results obtained for the Simon and SRC effects with parallel stimulus and response dimensions (Lu & Proctor, 1995; Proctor & Vu, 2006), implies that even though the correspondence effects evident for different response eccentricities and hand postures reflect automatic activation produced by correspondence of polarity codes, intentions defined by the task instructions play a role as well. This suggests, as an alternative to Cho and Proctor's (2004) interpretation described in the preceding paragraph, that even the overall up–right/down–left advantage may reflect a contribution of the automatic route. According to this alternative, which we think more likely, there is in fact an orthogonal Simon effect when responding at a centred position, but it is just too weak to reliably attain statistical significance.

In summary, this study demonstrates that polarity correspondence contributes to the response selection process when stimulus location is task irrelevant in a manner similar to that for experiments in which it is task relevant. Qualitatively similar patterns of the response eccentricity and hand posture effect were obtained. These results imply that the response position relative to the stimulus display (the response eccentricity effect) or responding hand (the hand posture effect) is spatially coded and that this spatial code determines the polarity of the response alternatives. When an imperative stimulus appears, the polarity code of this stimulus activates the corresponding stimulus polarity code. These processes seem to occur automatically, because the polarity correspondence effect was obtained even when the stimulus location was task irrelevant.

Recently, Proctor and Cho (2006) argued that the contribution of polarity correspondence is not restricted to situations in which both stimulus and response dimensions are spatial, such as the orthogonal SRC effect and the orthogonal Simon effect. They provided evidence that polarity correspondence is an important contributor to mapping effects more generally, including the linguistic markedness association of response codes (MARC) effect (for numerical parity judgements, faster responses with the mapping of even–right/odd–left than for the opposite mapping; e.g., Cho & Proctor, in press), spatial–numerical association of response codes (SNARC) effect (faster responses for low numbers with the left hand and high numbers with the right hand than for the opposite relation; e.g., Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006), and the implicit association test (IAT; faster responding when a positive target concept is mapped to the same response as a pleasant attribute concept and a negative target concept to the same response as an unpleasant attribute concept than vice versa; e.g., Kinoshita & Peek-O'Leary, 2005). Proctor and Cho claimed that "code polarities are a fundamental aspect of stimulus and response representations in binary classification tasks" (p. 439). Their polarity correspondence principle predicts that a stimulus code automatically activates the response code of the same polarity. The obtained results are consistent with the prediction of Proctor and Cho's polarity correspondence principle that the polarity of the stimulus produces automatic activation of the response of corresponding code polarity.

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