Psychological Research (2004) 69: 106–114
DOI 10.1007/s00426-003-0158-1

ORIGINAL ARTICLE

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Stimulus-set location does not affect orthogonal stimulus-response compatibility

Received: 18 May 2003 / Accepted: 27 August 2003 / Published online: 22 November 2003

Abstract In two-choice tasks for which stimuli and responses vary along orthogonal dimensions, one stimulus-response mapping typically yields better performance than another. For unimanual movement responses, the hand used to respond, hand posture (prone or supine), and response eccentricity influence this orthogonal stimulus-response compatibility (SRC) effect. All accounts of these phenomena attribute them to response-related processes. Two experiments examined whether manipulation of stimulus-set position along the dimension on which the stimuli varied influences orthogonal SRC in a manner similar to the way that response location does. The experiments differed in whether the stimulus dimension was vertical and the response dimension horizontal, or vice versa. In both experiments, an advantage of mapping up with right and down with left was evident for several response modes, and stimulus-set position had no influence on the orthogonal SRC effect. The lack of effect of stimulus-set position is in agreement with the emphasis that present accounts place on response-related processes. We favor a multiple asymmetric codes account, for which the present findings imply that the polarity of stimulus codes does not vary across task contexts although the polarity of response codes does.

Introduction

In two-choice tasks, reaction time (RT) is shorter and error rate lower with a compatible mapping for which the spatially corresponding response is made to each stimulus than for an incompatible mapping in which the responses do not correspond (see Proctor & Reeve, 1990). This stimulus-response compatibility (SRC) effect is obtained when the stimulus and response dimensions are both horizontal or both vertical (Vu, Proctor, & Pick, 2000). A similar benefit of spatial correspondence is found when a stimulus feature other than its location is relevant. This benefit is known as the Simon effect (Hommel & Prinz, 1997; Lu & Proctor, 1995). The SRC and Simon effects are typically attributed to an advantage of situations in which spatial stimulus and response codes correspond compared with ones in which they do not.

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Although the vast majority of studies have examined situations in which the stimuli and responses vary along the same spatial dimension (usually horizontal), SRC effects also occur when the stimulus dimension is orthogonal to the response dimension (called orthogonal SRC effects). When the stimulus dimension is vertical and the response dimension horizontal, performance is often better with the mapping of up to right and down to left than with the alternative mapping (Adam, Boon, Paas, & Umiltà, 1998; Bauer & Miller, 1982; Weeks & Proctor, 1990). This up-right/down-left advantage has been obtained not only with physical up-down locations, but also with upward and downward pointing arrows and the written words "above" and "below". There has been widespread agreement that the advantage of the up-right/down-left mapping is due to asymmetric coding of the stimulus and response sets (Lippa & Adam, 2001), with the only issue being whether this asymmetry is restricted to verbal codes (Adam et al., 1998; Umiltà, 1991) or not (Weeks & Proctor, 1990, 1991). Specifically, up and right are coded as the salient, or polar, referents of the respective dimensions (see, e.g., Clark, 1973; Olson & Laxar, 1973, 1974), and performance is better when the positive member of the stimulus set is mapped to the positive member of the response set.

When responses are unimanual movements of a switch or of a finger to a target location, the orthogonal SRC effect is modulated by response position (Cho & Proctor, 2002; Michaels, 1989; Michaels & Schilder, 1991; Weeks, Proctor, & Beyak, 1995). Specifically, the up-right/down-left advantage obtained when responses are made at body midline is larger when responding in the right hemispace and reverses to an up-left/down-right advantage when responding in the left hemispace. This response eccentricity effect on orthogonal SRC occurs regardless of whether the left or right hand is used for responding (Weeks et al., 1995), but for the typical situation in which responses are made with the hand in a prone posture, the overall up-right/down-left advantage is larger with the left hand than with the right hand. The relative magnitude of the advantages for the two hands reverses when the responding hand is in a supine posture (Cho & Proctor, 2002; Michaels & Schilder, 1991), revealing a hand posture effect on orthogonal SRC.

Because the response eccentricity effect, as well as those of hand and hand posture, involves a motor variable, hand position, several authors have proposed explanations for it and the other effects in terms of the state of the motor system. Bauer and Miller (1982) put forward a movement-preference account of the orthogonal SRC effects that attributes them to the left hand preferring clockwise rotations and the right hand preferring counterclockwise rotations. Michaels (1989; Michaels & Schilder, 1991) accepted the basic premise of Bauer and Miller's movement-preference account but proposed that the hands have different movement preferences in the left and right hemispaces from those at body midline. Her account, which takes an ecological approach, emphasizes that action "sets up" perception. Lippa and Adam (2001) developed an end-state comfort account, which can be viewed as an elaboration of the action-sets-up-perception account, according to which the mental representation of the response set is rotated into alignment with the stimulus set. Consequently, as with standard SRC effects, performance is better for the mapping in which the stimulus locations and the represented response locations correspond than for the one in which they do not. The preferred mapping is determined by the direction in which the response set is rotated, which is the direction in which physical rotation of the limb would result in the most comfortable end-state posture.

Lippa and Adam's (2001) end-state comfort account is a hybrid motor-coding explanation in which the state of the motor system determines the coding of the response set. Two other explanations also place an emphasis on response coding. Lippa's (1996) referential coding account assumes that the response dimension is coded along the same dimension as the stimuli. However, according to Lippa, this alignment is accomplished by using the intrinsic axis of the hand from fingertip to wrist as a frame of reference when the hand and arm are placed at an angle of about 45–90°, which is the normal placement unless hand positioning is explicitly controlled. Cho and Proctor's (2003a) multiple asymmetric codes account attributes the response eccentricity, hand, and hand posture effects to correspondence of asymmetric stimulus and response codes, as in the explanations for the overall up-right/down-left advantage. The responses are presumed to be signified by multiple codes, one for each reference frame in which the response position relative to an object is represented. Within each frame, the response that is consistent with the representation of the response position as left or right is coded as positive and the other response as negative. The response eccentricity effect is due primarily to coding the response position as left or right relative to the display (Cho & Proctor, 2003b), whereas the hand and hand posture effects are due primarily to coding the response position as left or right relative to the main part of the hand (Cho & Proctor, 2002). The overall direction and size of the orthogonal SRC effect reflect the combined contributions of correspondence of the asymmetric stimulus codes with the asymmetric response codes for the respective reference frames.

All of these explanations of the effects of response eccentricity, hand, and hand posture on orthogonal SRC emphasize response-related factors. The first three accounts attribute the effects to properties of the motor system and, therefore, directly imply that manipulations of stimulus-set location should not have a similar influence on orthogonal SRC. The latter two accounts attribute the effects to relative-location coding of the responses and, although they do not preclude an influence of stimulus-set location on orthogonal SRC, the emphasis is on response-related factors.

The first purpose of the present study was to determine whether, as implied by the accounts of the response eccentricity effect, manipulations of stimulus-set location along the same dimension as the stimuli do not produce effects on orthogonal SRC similar to those produced by manipulations of response-set location. The second purpose was to consider the implications of the detailed patterns of results for the alternative accounts that have been proposed. Because the multiple asymmetric codes account applies to bimanual key press and vocal response modes, as well as to unimanual responses, whereas the other accounts do not, response mode was manipulated to determine whether qualitatively similar result patterns are obtained for the different modes.

In Experiment 1, participants made left-right responses to stimuli presented above or below a row of plus signs shown in the upper or lower half of the display screen 500-ms prior to the stimulus. Experiment 2 was similar to Experiment 1, except that the stimulus and response dimensions were reversed. Stimuli and the stimulus set varied along the horizontal dimension, whereas the responses varied along the vertical dimension. In both experiments, the primary concerns were whether an overall advantage of up-right/down-left mapping would be obtained and whether the orthogonal SRC effect would vary as a function of the relative position of the stimulus set.

Experiment 1

Experiment 1 examined whether, when vertically arrayed stimuli are mapped to horizontally arrayed responses, variation of stimulus-set position along the vertical dimension influences orthogonal SRC. The imperative stimulus was presented above or below a fixation row, and this display was shown on the upper or lower half of the screen. Left-right responses were made in one of four response modes: unimanual switch movements made with the left or right hand, bimanual key presses, and the vocal utterances "left" and "right."

Based on prior studies, we expected to obtain an overall up-right/down-left advantage. If the position of the stimulus set influences the orthogonal SRC effect in the same way that response position does, then the up-right/down-left advantage should be larger when the stimulus set is in the upper half of the screen than when it is in the lower half. However, if stimulus-set location does not affect orthogonal SRC, the up-right/down-left advantage should be the same when the stimulus set is in the upper or in the lower screen half.

Method

Participants

Ninety-six undergraduate students enrolled on the Introductory Psychology course at Purdue University participated in partial fulfillment of a course requirement. All of the participants were right-handed and had normal or corrected-to-normal visual acuity as determined by self-report. Participants were randomly assigned to the four response modes: vocal, bimanual key press, and left- and right-hand unimanual joystick-movement responses.

Apparatus and stimuli

The experiment was controlled by software developed with the Micro Experimental Laboratory (MEL 2.1) system. Stimuli were presented on the 14-inch display screen of a personal computer, viewed from a distance of approximately 60 cm. For all response modes, the response device was placed at the participant's sagittal midline. For vocal responses, the word "left" or "right" was spoken into a microphone interfaced with the computer through a MEL response box. For the bimanual key presses, the leftmost or rightmost response button on the MEL response box (which contains five buttons) was pressed with the left or right index finger. The unimanual responses were made with a unidimensional joystick, 5.5 cm high and 1.4 cm in diameter, mounted on the 16 × 16 cm surface of a box 11.5 cm in height. The joystick was grasped between the thumb and index finger of the appropriate hand, with the arm held in a comfortable position so that the wrist-to-fingertip axis was slightly off of vertical, and required a movement of 1.2 cm in one direction or the other to close a switch. The joystick was pushed left or right with the left hand for the left-hand unimanual response mode and with the right hand for the right-hand unimanual response mode.

Stimuli were uppercase Xs (0.3 × 0.4 cm, approximately 0.29° × 0.39° of visual angle). They were presented as white characters on a dark background, 2 cm (1.91°) above or below a fixation row '+ + +' (0.9 × 0.3 cm, 0.86° × 0.29°) on either the upper or lower part of the screen.

Procedure

Each participant performed the task with both the up-right/down-left and up-left/down-right mappings, with the order of the mappings counterbalanced among participants. Each participant performed 20 practice trials and 200 test trials for each mapping condition. The test trials were presented in two blocks of 100 (50 randomly assigned to each stimulus position), with a 1-min interval between trial blocks and a 2-min interval between mapping conditions.

Each trial began when a single asterisk flashed in the center of the screen. Participants were asked to focus on this asterisk. After 250 ms it disappeared and the fixation row of plus signs was presented 4.5 cm (4.30°) above or below the asterisk's location. After 500 ms the stimulus 'X' appeared above or below the fixation row, and both remained on until the participant responded. The asterisk for the next trial appeared 1 s after the response. An incorrect response was followed by a 500-ms feedback tone and then the 1-s intertrial interval.

Results

Reaction times shorter than 125 ms and longer than 1,250 ms were removed as outliers in this and all subsequent experiments. These criteria resulted in 1.09% of the trials being excluded. Mean RT and percent error (PE) were calculated for each participant as a function of mapping (up-right/down-left, up-left/down-right), stimulus-set location (up, down), and response (left, right). Analyses of variance (ANOVAs) were conducted on the RT and PE data, with those variables as within-subject factors and response mode as a between-subject factor (see Table 1).

Reaction time

The main effect of response mode was significant, $F(3, 92) = 17.96$, $p < .0001$, $MSE = 36{,}161$, with RT shortest for bimanual key presses ($M = 396$ ms),

Table 1 Mean reaction time (in ms) and percentage of error (in parentheses) in Experiment 1 as a function of mapping, location of stimulus set, and response mode

Mode	Stimulus-set location					
	Upper			Lower		
	Up-left/down-right	Up-right/down-left	Mapping effect	Up-left/down-right	Up-right/down-left	Mapping effect
Vocal	464 (1.09)	451 (1.17)	13 (−.08)	468 (1.26)	457 (1.30)	11 (−.04)
Bimanual	407 (4.23)	381 (2.38)	26 (1.85)	411 (3.72)	383 (3.35)	28 (.37)
Right-hand	525 (2.45)	516 (2.15)	9 (.30)	522 (3.28)	516 (2.93)	6 (.35)
Left-hand	538 (4.50)	497 (2.91)	41 (1.59)	534 (4.01)	493 (2.97)	41 (1.04)
Mean	461 (2.15)	484 (3.07)	23 (.92)	462 (2.64)	484 (3.07)	22 (.43)

Right-hand denotes the right-hand unimanual response mode, and left-hand denotes the left-hand unimanual response mode intermediate for vocal responses ($M = 460$ ms), and longest for unimanual responses (Ms = 516 ms and 520 ms with the left and right hands, respectively). The mapping main effect was significant, $F(1, 92) = 16.73$, $p < .0001$, $MSE = 5{,}521$, with RT shorter for the up-right/down-left mapping ($M = 462$ ms) than for the up-left/down-right mapping ($M = 484$ ms). This up-right/down-left advantage did not differ significantly among response modes, $F(3, 92) = 1.98$, $p = .1220$, $MSE = 5{,}521$, although separate ANOVAs showed the advantage to be significant for bimanual key presses (27 ms), $F(1, 23) = 7.74$, $p = .0106$, $MSE = 4{,}491$, and left-hand unimanual responses (41 ms), $F(1, 23) = 12.75$, $p = .0016$, $MSE = 6{,}312$, but not for vocal responses (12 ms), $F(1, 23) = 1.44$, $p = .2420$, $MSE = 5{,}010$, or right-hand unimanual responses (7 ms), $F(1, 23) = 0.44$, $p = .5114$, $MSE = 6{,}271$. The main effect of response was significant, $F(1, 92) = 17.46$, $p < .0001$, $MSE = 1{,}794$, with right responses ($M = 466$ ms) faster than left responses ($M = 479$ ms). This effect did not differ significantly across response modes, $F(1, 92) = 2.22$, $p = .0912$, $MSE = 1{,}794$.

Most important, neither the Mapping × Stimulus-Set Location interaction nor the three-way interaction of these variables with response mode was significant, Fs < 1.0. The up-right/down-left advantage was 23 ms for the upper stimulus set and 22 ms for the lower set. The up-right/down-left advantages for the upper and lower stimulus sets were 13 and 11 ms for vocal responses, 26 and 28 ms for bimanual key presses, 9 and 6 ms for right-hand unimanual responses, and 41 and 41 ms for left-hand unimanual responses respectively.

The only other significant effect was the three-way interaction of mapping, response, and stimulus-set location, $F(1, 92) = 4.00$, $p < .05$, $MSE = 740$. This interaction can be interpreted as a correspondence effect between the location of the stimulus set and the location of the imperative stimulus. With the up-left/down-right mapping, the left response (up stimulus) was faster when the stimulus set was presented on the upper half of the screen ($M = 489$ ms) than on the lower half ($M = 494$ ms), whereas the right response (down stimulus) was faster when the stimulus set was presented on the lower half ($M = 474$ ms) than on the upper half ($M = 479$ ms). With the up-right/down-left mapping, the left response (down stimulus) was faster when the stimulus set was presented on the lower half of the screen ($M = 466$ ms) than on the upper half ($M = 468$ ms), whereas the right response (up stimulus) was faster when the stimulus set was presented on the upper half ($M = 455$ ms) than on the lower half ($M = 458$ ms).

Percent error

Overall PE was 2.73%. Only the main effect of response mode was significant, $F(3, 92) = 7.93$, $p < .0001$, $MSE = 28.63$. PE was 1.21% for vocal responses, 2.70% for right-hand unimanual responses, 3.41% for bimanual key presses, and 3.60% for left-hand unimanual responses. The main effect of mapping approached significance, $F(1, 92) = 3.35$, $p = .0705$, $MSE = 26.18$, with PE tending to be lower for the up-right/down-left mapping (2.78%) than for the up-left/down-right mapping (3.70%).

Discussion

All response modes showed the up-right/down-left advantage, at least numerically. The up-right/down-left advantage was larger for left-hand unimanual responses (41 ms) than for right-hand responses (7 ms). This difference is in agreement with previous findings and consistent with the proposition that the response hand provides a frame of reference for coding response location (Cho & Proctor, 2002), e.g., with left-hand unimanual responses, the response location is represented as 'right' relative to the main part of the hand, causing the right response to be coded as positive in this reference frame and thus increasing the size of the up-right/down-left advantage. With this interpretation, the unbiased estimate of the overall up-right/down-left advantage for unimanual responses is the average of the two conditions, or 24 ms, compared with 28 ms for bimanual key presses and 12 ms for vocal responses.

Stimulus-set location had no effect on orthogonal SRC. For each response mode, the overall up-right/down-left advantage was of similar magnitude for the upper and lower stimulus sets. This outcome suggests that stimulus-set location does not affect orthogonal SRC in a manner analogous to the way that response-set location does. However, there is an alternative explanation for the difference in results obtained for stimulus-set location in this experiment and response-set location in others. The dimension along which the stimulus set varied was vertical, whereas the dimension along which the response set varied in previous studies was horizontal. Thus, it could be that the vertical dimension is more rigid than the horizontal dimension, making it insensitive to relative-location effects. This possibility is consistent with evidence from sentence-picture verification tasks, which shows that the coding asymmetry for the vertical dimension is more robust than that for the horizontal dimension (Clark, 1973; Olson & Laxar, 1973, 1974), probably because there is an unambiguous referent, the ground, for the vertical dimension but not for the horizontal dimension.

Experiment 2

To test whether the absence of an effect of stimulus-set location on orthogonal SRC in Experiment 1 was due to the stimuli varying along the vertical dimension or to orthogonal SRC being insensitive in general to relative location, the stimulus and response dimensions were reversed in Experiment 2. Left-right stimuli were mapped to up-down responses, and the location of the stimulus set was manipulated horizontally. All response modes from Experiment 1 were used except bimanual key presses, since the up-down responses would also differ with respect to left-right hand for this response mode. If the absence of a stimulus-set location effect in Experiment 1 was due to rigidity of coding along the vertical dimension, then stimulus-set location should affect orthogonal SRC in Experiment 2 because the stimuli varied along the horizontal dimension. However, if the absence was due to a general lack of influence of stimulus-set location on orthogonal SRC, then no effect should be found.

Not many experiments have been conducted with a horizontal stimulus dimension and vertical response dimension, and the results of these studies have been mixed. Weeks and Proctor (1990) obtained a right-up/left-down advantage for vocal "above" and "below" responses to left-right stimulus locations, but no such advantage has been reported for unimanual responses to physical locations (Bauer & Miller, 1982; Lippa, 1996; Michaels & Schilder, 1991). Thus, Experiment 2 allows evaluation of whether a right-up/left-down advantage occurs when the stimulus dimension is horizontal and the response dimension vertical.

Method

Participants

Seventy-two new students, from the same pool as Experiment 1 and satisfying the same criteria, participated in order to fulfill a course requirement. They were randomly assigned to three different response modes: Vocal responses, and left-hand and right-hand unimanual responses.

Apparatus, stimuli, and procedure

The method was similar to that for the unimanual and vocal conditions in Experiment 1, with the following exceptions. At the offset of the center asterisk, a column of three plus signs (0.9 × 0.3 cm, 0.86° × 0.29°) was presented approximately 6 cm (5.73°) to the right or left. After 500 ms, a stimulus (an uppercase X, as in Experiment 1) was presented approximately 2 cm (1.91°) to the left or right side of the column.

For the vocal responses, the word "up" or "down" was spoken into the microphone. For the unimanual responses, the joystick, placed at the participant's sagittal midline, moved in the vertical dimension of the transverse plane. The switch was grasped with the thumb and index finger of the left or right hand, and responses were made by pushing the joystick up or down with the responding hand. Participants were allowed to position their responding hand comfortably, with the arm at an angle of 45–90° with respect to the vertical response dimension.

Results

Using the same criteria as in Experiment 1, 1.88% of the trials were excluded as outliers. Mean RT and PE were calculated for each participant as a function of mapping (right-up/left-down, left-up/right-down), stimulus-set location (left, right), and response (up, down). ANOVAs were conducted on the RT and PE data, with those variables as within-subject factors and response mode as a between-subject factor (see Table 2).

Reaction time

The response mode main effect was significant, $F(2, 69) = 17.91$, $p < .0001$, $MSE = 24{,}087$: RT was shorter with vocal responses ($M = 424$ ms) than with unimanual responses (Ms = 488 ms and 517 ms for the left- and right-hand responses respectively). Down responses ($M = 466$ ms) were faster than up responses ($M = 487$ ms), $F(1, 69) = 19.83$, $p < .0001$, $MSE = 3{,}439$, and response interacted with response mode, $F(1, 69) = 3.14$, $p = .0496$, $MSE = 3{,}439$. Down responses were 29 ms faster than up responses for right-hand unimanual responses, 17 ms faster for left-hand unimanual responses, and 9 ms faster for vocal responses.

Reaction time was shorter for the right-up/left-down mapping ($M = 466$ ms) than for the left-up/right-down mapping ($M = 487$ ms), $F(1, 69) = 7.21$, $p = .0091$, $MSE = 8{,}285$. The interaction of mapping with response mode was not significant, $F(2, 69) = 2.54$, $p = .0861$, $MSE = 8{,}285$, although the right-up/left-down advantage was significant for the right-hand unimanual responses (44 ms), $F(1, 23) = 8.43$, $p = .0080$, $MSE = 11{,}164$, but not for the left-hand responses (12 ms), $F < 1.0$, or the vocal responses (6 ms), $F < 1.0$. The three-way interaction of mapping and response mode with response was also significant, $F(2, 69) = 5.10$, $p = .0086$, $MSE = 866$. The right-up/left-down advantage was larger for up responses (50 and 24 ms for

Table 2 Mean reaction time (in ms) and percentage of error (in parentheses) in Experiment 2 as a function of mapping, location of stimulus set, and response mode

Mode	Stimulus-set location					
	Left			Right		
	Left-up/right-down	Right-up/left-down	Mapping effect	Left-up/right-down	Right-up/left-down	Mapping effect
Vocal	428 (1.76)	421 (1.60)	7 (.16)	426 (1.96)	422 (1.39)	4 (.57)
Right-hand	537 (5.49)	493 (2.49)	44 (3.00)	540 (5.15)	496 (2.15)	44 (3.00)
Left-hand	497 (3.44)	485 (2.28)	12 (1.16)	492 (2.46)	480 (2.65)	12 (−.19)
Mean	487 (3.56)	466 (2.13)	21 (1.43)	486 (3.19)	466 (2.07)	20 (1.12)

Right-hand denotes the right-hand unimanual response mode, and left-hand denotes the left-hand unimanual response mode the right- and left-hand unimanual response modes respectively) than for down responses (39 and −1 ms respectively) for the unimanual response modes, whereas for the vocal mode it was larger for down responses (11 ms) than for up responses (−1 ms).

Most importantly, stimulus-set location did not influence the mapping preference, $F < 1.0$. A 20-ms right-up/left-down advantage occurred when the stimulus set was presented on the right and a 21-ms advantage when the stimulus set was presented on the left of the screen. This term did not interact with response mode, $F < 1.0$. No other main effect or interaction was significant.

Percent error

Overall PE was 2.73%. The main effect of response mode was significant, $F(2, 69) = 6.56$, $p = .0025$, $MSE = 33.38$. PE was 3.81% for right-hand responses, 2.71% for left-hand responses, and 1.68% for vocal responses. The PE was less for the right-up/left-down mapping (2.10%) than for the left-up/right-down mapping (3.37%), $F(1, 69) = 10.14$, $p = .0022$, $MSE = 23.11$. This right-up/left-down advantage interacted with response mode, $F(2, 69) = 4.54$, $p = .0141$, $MSE = 23.11$, being 0.36% for vocal responses, 0.48% for left-hand responses, and 2.98% for right-hand responses. The interaction between mapping and response was significant, $F(1, 69) = 4.92$, $p = .0298$, $MSE = 3.80$. The right-up/left-down advantage was 1.64% for up responses, but only 0.91% for down responses.

Stimulus-set location did not affect the orthogonal mapping preference, $F(1, 69) < 1.0$ (see Table 2). When the stimulus set was presented on the right side of the screen, a 1.12% right-up/down-left advantage occurred, and when it was presented on the left side of the screen, a 1.42% advantage. No other main effect or interaction was significant.

Discussion

The RT and PE data showed an overall right-up/left-down mapping advantage that was significant for right-hand unimanual responses and evident numerically in the means for left-hand unimanual responses and vocal responses. The finding of an overall right-up/left-down advantage is important because previous studies of orthogonal SRC effects for horizontal stimuli mapped to vertical responses have suggested that there may be no overall advantage comparable to that for vertical stimuli mapped to horizontal responses (Bauer & Miller, 1982; Lippa, 1996; Michaels, 1989). The fact that the advantage for pairing right with up and left with down that occurred in this experiment (21 ms) was similar to that in Experiment 1 (22 ms) suggests that explanations based on the more widely investigated version of vertical stimuli mapped to horizontal responses may be directly applicable to horizontal stimuli mapped to vertical responses.

Stimulus-set position had no influence on the orthogonal SRC effect for any response mode, as in Experiment 1. Thus, the results of the two experiments converge to indicate that manipulating the position of the stimulus set along the dimension on which the stimuli vary does not influence the mapping preference. This outcome verifies that the emphasis current accounts of the response eccentricity effect place on response-related processes is warranted.

The right-up/left-down advantage was larger with the right hand than with the left hand. This pattern is the opposite of that for vertical stimuli mapped to horizontal responses (e.g., Experiment 1; Cho & Proctor, 2002), in which the up-right/down-left advantage was larger for the left than for the right hand. Because the main part of the hand was above the switch location for both hands, the pattern is not predicted on the basis of the view that the hand serves as a frame of reference relative to which response location is coded. The interaction pattern is, however, similar to one found by Lippa (1996, Experiment 1) for unimanually-aimed movements when the hands were placed at a comfortable angle of about 45–90°, as in the present study. Whereas she found a 41-ms right-up/left-down advantage with the right hand that reversed to a 49-ms left-up/right-down advantage with the left hand, we found a 44-ms right-up/left-down advantage with the right hand that was reduced to a 12-ms right-up/left-down advantage with the left hand. Because Lippa (1996, Experiment 2) did not obtain such an interaction when the hands were in line with the vertically arranged response keys, she attributed the interaction to participants coding the response alternatives as left or right relative to the wrist-to-fingertip axis. Such referential coding may be responsible for the interaction observed in Experiment 2.

The vocal responses showed a numerical advantage for the right-up/left-down mapping in both the RT and PE data, but this advantage was small and not statistically significant. The fact that the right-up/left-down advantage was smaller with vocal responses than with manual responses is counter to the hypothesis that asymmetric coding is restricted to verbal codes (Adam et al., 1998; Umiltà, 1991). This hypothesis was initially based on the fact that the mapping effects for vocal responses tended to be larger than those for manual responses in Weeks and Proctor's (1990) study. However, this tendency has not been evident in subsequent experiments in which stimuli were vertical and responses horizontal (Experiment 1 of this paper; Cho & Proctor, 2001; Proctor & Cho, 2001), consistent with the present findings obtained with horizontal stimuli and vertical responses.

General discussion

In agreement with previous studies, Experiment 1 showed an overall advantage of the mapping of up stimulus to right response and down stimulus to left response over the alternative mapping, and this up-right/down-left advantage did not interact significantly with response mode. Although the up-right/down-left advantage of 12 ms was not significant for the vocal responses in this experiment, a significant advantage has been obtained with this response modality in other experiments (e.g., Adam et al., 1998; Proctor, Wang, & Vu, 2002). Experiment 2 showed an overall advantage of the mapping of right stimulus to up response and left stimulus to down response that also did not interact significantly with response mode, although it was again small for the vocal responses (6 ms in RT and 0.36% in PE). The overall right-up/left-down advantage in Experiment 2 is consistent with Weeks and Proctor's (1990, Experiment 3) finding that the left and right stimulus locations mapped to "above" and "below" vocal responses showed an RT advantage for the right-"above"/left-"below" mapping.

In contrast to the results of Experiment 2, though, previous studies that have used unimanual up-down responses to right-left stimuli have found no overall advantage of right-up/left-down mapping (Bauer & Miller, 1982; Lippa, 1996; Michaels, 1989). Bauer and Miller (1982) and Lippa (1996) used finger movements aimed from a start key at one of two response keys, and thus their different results may be due to differences in the configuration of the response device, the positioning of the hand and fingers, the way in which a response was effected, and so on. Michaels used toggle-switch responses, which are more similar to the joystick movements used in our Experiment 2. However, our experiment and hers differed in several other respects, including whether the stimulus set appeared randomly in a left or right location or whether it was constantly in a centered position, and it is not obvious which of these factors might have been responsible for the different results in the two studies.

Even though an overall up-right/down-left advantage was obtained in Experiment 1, the location of the stimulus set in the upper or lower half of the display screen had no effect on the orthogonal SRC effect for all response modes. Experiment 2 showed that this lack of effect of stimulus-set location was not due to the dimension along which the set varied being vertical, because the overall right-up/left-down advantage in that experiment was not affected by the location of the stimulus set along the horizontal dimension. Thus, the results of Experiments 1 and 2 indicate that stimulus-set position does not affect orthogonal SRC, in contrast to the consistent effect of response-set position that has been found. This outcome supports the emphasis placed on response-related factors in all accounts of the effects of response eccentricity, hand, and hand posture on orthogonal SRC.

Although the lack of influence of stimulus-set location on the orthogonal SRC effect in Experiments 1 and 2 is consistent with all proposed accounts of those aspects of orthogonal SRC that vary as a function of response properties, we favor an explanation in terms of multiple asymmetric codes for several reasons. First of all, the multiple asymmetric codes account is the only one that is able to explain the overall advantage for the mapping of up with right and down with left that was present not only in both Experiments 1 and 2 but also in numerous other studies. Lippa and Adam (2001), who advocate the end-state comfort account for the effects of response eccentricity, hand, and hand posture, explicitly acknowledge this point and, consequently, propose that the overall up-right/down-left advantage has a different basis from the response eccentricity, hand, and hand posture effects. Secondly, the explanations that attribute these latter effects to properties of the motor system focus on unimanual movements and do not make straightforward predictions for bimanual key press responses. Yet in Experiment 1, the bimanual key presses showed an up-right/down-left advantage (28 ms) of similar magnitude to the average for the left- and right-hand unimanual switch responses (24 ms). If the position that the up-right/down-left advantage bears no relation to the response eccentricity, hand, and hand posture effects is taken, as Lippa and Adam have done, then the motor-system accounts remain viable. However, bimanual key presses yield a response eccentricity effect of similar magnitude to that for unimanual switch responses (Proctor & Cho, 2003), which not only creates difficulty for the motor-system accounts but implies that the response eccentricity effect and overall up-right/down-left advantage are not fundamentally distinct phenomena.

Thirdly, numerous other results are problematic for the end-state comfort account and others that emphasize the state of the motor system. Specifically, the orthogonal SRC effect for unimanual responses varies systematically as a function of whether an inactive response apparatus is placed to the left or right of the active response apparatus (Proctor & Cho, 2003; Weeks et al., 1995), a manipulation that should not affect the motor system. Also, whereas the end-state comfort account, and motor system explanations in general, attribute the response eccentricity effect to the position at which the responding hand is placed, an experiment dissociating this factor from the response location relative to the display showed that the latter factor was of primary importance (Cho & Proctor, 2003b). Both of these results were evident with bimanual key press responses, as well as unimanual switch movements (Cho & Proctor, 2003b; Proctor & Cho, 2003).

The present results, when interpreted in terms of the multiple asymmetric codes account, suggest that asymmetric coding of responses is more malleable than asymmetric coding of stimuli. Relative to several reference frames, performance is affected in a manner consistent with the view that the response corresponding to the position of the response set influences is coded as of positive polarity. However, manipulations of stimulus-set position have no comparable effect. The reason for this difference may be that response-set position has to be coded to prepare to execute the motor responses, whereas the position of the stimulus set is an irrelevant variable. Regardless of the exact reason, factors relating to response-set position appear to be more important indetermining the direction and magnitude of orthogonal SRC effects than factors related to stimulus-set position.

Although the overall up-right/down-left advantage was not statistically significant for all response modes, stimulus-set position along the dimension on which the stimuli varied had no effect on orthogonal SRC for any response mode in either Experiment 1 or 2. This lack of effect is consistent with the results of other recent studies that have shown the effects of response-set position to be similar across response modes (Cho & Proctor, 2003b; Proctor & Cho, 2003). This similarity of result patterns across unimanual movements, key press responses, and vocal responses implies that the orthogonal SRC effects for the different response modalities are of a similar nature, as assumed by the multiple asymmetric codes account. Across the numerous studies of orthogonal SRC that have been conducted, all three response modes show an overall up-right/down-left advantage, similar effects of variables affecting the relative position of the response set, and no effect of the variables affecting the relative position of the stimulus set along the dimension on which the stimuli vary. These results provide little evidence to suggest that there are two fundamentally different types of orthogonal SRC effects—the overall up-right/down-left mapping advantage and those effects that vary as a function of response factors—which require different types of explanations.

One finding that is somewhat problematic for the asymmetric coding account is the interaction of hand and orthogonal SRC for unimanual, up-down switch responses in Experiment 2. In both cases the main part of the hand was located above the switch, meaning that the location of the switch relative to the hand was the same when responding with the left or right hand, and, consequently, that the orthogonal SRC effect should not have varied with hand. As noted previously, the interaction pattern we obtained is similar to that found by Lippa (1996, Experiment 1) for unimanually-aimed movements when the hands were placed at a comfortable angle of about 45–90°. Lippa (1996, Experiment 2) found no such interaction when the hands were placed in line with the vertically arranged response keys, which led her to conclude that the interaction was due to participants coding the responses as left or right relative to the wrist-to-fingertip axis. Because the responding hand was placed at a 45–90° angle in our experiment, the interaction we observed may have been due to such referential coding. The possibility that the effect is a consequence of coding the responses as left or right relative to the fingertip-to-wrist axis for the responding hand is in agreement with the more general message of our research: Responses are coded relative to various frames of reference, and these response codings determine the direction and magnitude of the orthogonal SRC effect.

Acknowledgements We thank Yvonne Lippa, Thomas Kleinsorge, Carolo Umiltà, and an anonymous reviewer for helpful comments on a previous version of the paper.

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