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Stimulus-Response compatibility for absolute and relative spatial correspondence in reaching and in button pressing.

Stins, J.F.; Michaels, C.F.

published in

The Quarterly Journal of Experimental Psychology. Section A : Human experimental psychology
2000

DOI (link to publisher)

[10.1080/713755894](https://doi.org/10.1080/713755894)

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Stins, J. F., & Michaels, C. F. (2000). Stimulus-Response compatibility for absolute and relative spatial correspondence in reaching and in button pressing. *The Quarterly Journal of Experimental Psychology. Section A : Human experimental psychology*, 53A(2), 569-589. <https://doi.org/10.1080/713755894>

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Publisher Psychology Press

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

The Quarterly Journal of Experimental Psychology Section A

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713683590>

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Online publication date: 22 October 2010

To cite this Article Stins, John F. and Michaels, Claire F.(2000) 'Stimulus-response compatibility for absolute and relative spatial correspondence in reaching and in button pressing', The Quarterly Journal of Experimental Psychology Section A, 53: 2, 569 — 589

To link to this Article: DOI: 10.1080/713755894

URL: <http://dx.doi.org/10.1080/713755894>

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Stimulus–response compatibility for absolute and relative spatial correspondence in reaching and in button pressing

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Three experiments tested whether stimulus–response (S–R) compatibility might be a function of absolute (as opposed to relative) spatial correspondence—that is, the distance between a stimulus and the place of response. Experiment 1 studied reaching movements toward one of two targets in response to one of six visual stimuli. Stimulus–response pairs that shared relative position were faster than those that did not, and reaction time was faster when the stimulus and one of the potential targets were in close proximity. In Experiment 2 the same effects were found when the hands started from a different position, implicating stimulus–target distance, rather than stimulus–hand distance as the critical variable. Experiment 3 employed keypress responses instead of reaches, and the distance effect was nearly absent. The implications of these results are discussed in terms of categorical (e.g. left–right) vs. quantitative (e.g. distance) S–R variables in spatial compatibility.

The literature on spatial stimulus–response (S–R) compatibility suggests that reactions are speeded up when there is relative spatial (left–right) correspondence between the stimulus and the response, and that absolute correspondence is not important. For example, Proctor, Van Zandt, Lu, and Weeks (1993) argued that “the absolute physical locations of the stimuli and responses do not determine the degree of compatibility, but their relative locations do” (p. 82). In this article we entertain and test the thesis that the absolute positions of the stimuli and the responses can affect compatibility when participants are asked actually to reach to a place. More specifically, we tested whether compatibility might be understood in terms of just the *distance* between the position of the stimulus and the place toward which a reach is directed. If this can be shown to be the case, it might indicate that the apparent supremacy of relative spatial correspondence may be limited to the keypressing paradigm and, more generally, that compatibility effects depend in important ways on how an action is executed (Stins & Michaels, 1997a, 1997b).

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Spatial S–R compatibility refers to better performance (faster reaction times, fewer errors) with an S–R assignment that preserves the spatial correspondence between the stimulus and the response than with a mapping in which the spatial S–R correspondence is reversed (for overviews, see Hommel & Prinz, 1997; Proctor & Reeve, 1990). For example, left responses to left stimuli and right responses to right stimuli are emitted faster than those with the reverse combinations (left–right and right–left S–R pairs). Consider a simple binary S–R compatibility task, with left–right visual stimuli on a computer screen and left–right response buttons. The buttons are directly in front of the stimuli, and are operated by their respective hands. In this situation, there are at least four reasons why left–right and right–right S–R pairs might yield faster reaction times than the converse pairs: First, the left (right) stimulus is responded to by the anatomically left (right) hand. In other words, the *identity* of the responding hands is the response feature that enters into a compatibility effect with the stimulus. Second, the pairs share the same hemispace, in that the left (right) response button is on the same side as the left (right) stimulus. Third, the pairs share the same relative position, in that a given stimulus (and a given response) can be defined as left (or right) relative to the alternate stimulus (and response). Finally, the left (right) response button is *nearer* to the left (right) stimulus light than to the right (left) stimulus. The first three potential sources of compatibility have been studied extensively (for an overview, see Heister, Schroeder-Heister, & Ehrenstein, 1990). The majority of the studies seems to favour the third explanation—that is, an explanation based on relative spatial correspondence. However, there is evidence that the fourth factor (absolute spatial correspondence) can also sometimes induce compatibility. The purpose of the present paper is to explore further the conditions under which an effect (if any) of absolute correspondence shows up.

As stated, relative spatial S–R correspondence appears responsible for most compatibility effects, and absolute correspondence appears not to affect reaction time (RT). For example, Nicoletti, Anzola, Luppino, Rizzolatti, and Umiltà (1982), observed an effect of relative spatial correspondence that appeared unaffected by absolute correspondence. In their experiment, participants had to press a left or right key in response to a left or right visual stimulus. Within a block of trials, the responding hands were positioned on the same side of the body midline (either left or right), and the imperative (left–right) stimuli appeared—within a block of trials—with both either to the left or to the right of a fixation point. Nicoletti et al. (1982) found that left–right hand position and left–right field of presentation did not differentially affect RT. Instead, fast responding was a function solely of relative spatial correspondence. Thus, for example, when both hands were positioned to the right of the body midline, and the stimuli appeared in the left visual field, the left hand still responded faster to a left visual stimulus than to a right one, even though the hand was actually closer to the right stimulus than to the left stimulus. As further evidence of the predominance of relative spatial correspondence effects, Weeks, Proctor, and Beyak (1995) measured unimanual left–right toggle switch deflections in response to the up–down position of a visual stimulus. In their Experiment 2, they found that the preference for a given mapping could actually be reversed by positioning an inactive toggle switch to the left or to the right of the response switch. In other words, even though the *absolute* position of the response device (the toggle switch) remained fixed, its

relative position was modified by the mere presence of another (inactive) switch, thereby influencing the direction of the compatibility effect.

Despite the importance of relative spatial S–R correspondence, there is evidence that the absolute position of the stimulus or the response may influence RT. For example, Roswarski and Proctor (1996, Experiment 4) employed a spatial compatibility task with visual stimuli appearing in one of four locations on a horizontal array. Participants had to press a left or right key, spatially corresponding or non-corresponding to the left–right hemispace in which the stimulus appeared, regardless of relative position within a particular hemispace. The results showed a clear-cut spatial compatibility effect. In addition, hemispace and relative position interacted; stimuli at the outer locations (Positions 1 and 4) were responded to more quickly than stimuli at the inner locations (Positions 2 and 3). The same effect was also reported by Lamberts, Tavernier, and d'Ydewalle (1992). The apparent advantage for eccentric stimuli is not found in other paradigms; eccentric stimuli have also been shown to lead to slower RTs, arguably due to decreased visual acuity toward the periphery (e.g. Umiltà & Liotti, 1987). Other evidence for the importance of absolute position comes from the few experiments that studied unimanual reaching movements directed at (or in close proximity to) the imperative stimulus (Hendrikx, 1986; Spijkers et al., 1996).

Given the emphasis in the compatibility literature on relative spatial S–R correspondence, the observation of effects of absolute correspondence clearly deserves further study. In the present experiments we looked for effects of absolute correspondence when participants reach with the left or right hand to a target in response to a visual stimulus. Moreover, we varied the distance between the stimulus and the target of the reach, so that on some trials stimulus and target coincided, and on other trials the target was located at some distance from the imperative stimulus.

EXPERIMENT 1

In Experiment 1 we asked whether absolute spatial correspondence yields compatibility above and beyond that due to relative position. In the general paradigm, a visual stimulus could appear at one of six colinear places (three to the left and three to the right of the body midline) on a horizontal array (see Figure 1). If one of the three left stimuli was illuminated, the participant had to reach to a prespecified target with the left hand, and if one of the three right stimuli was illuminated, the participant had to reach to a different prespecified target with the right hand. In the other condition this mapping was reversed, so that left stimuli were to elicit right-hand movements, and right stimuli were to elicit left-hand movements. On some trials stimulus position and target coincided, and on other trials the stimulus and the target were separated by one of a number of distances. This paradigm permits us to study the effects of relative and absolute spatial correspondence on compatibility. An effect of relative spatial correspondence would be fast responding with left–left and right–right stimulus–hand pairs, and an effect of absolute spatial correspondence would be fast responding when the imperative stimulus is in close proximity to the target of the reach.

FIG. 1. The types of trials and their blocking in Experiment 1. There were four blocks of trials (two S-H mappings and two target eccentricities), as indicated by the numerals 1 to 4. The arrows denote the required movement in response to illumination of any of the three stimuli (the black squares). The white squares represent the unilluminated side.

Method

Participants

Twelve graduate and undergraduate students at the Vrije Universiteit participated, who were naive to the purpose of the experiment. All were right handed and were paid a small fee for their participation.

Apparatus and Stimuli

The participant was seated at a table. The table had six light-emitting diodes (LEDs) arrayed horizontally under a glass tabletop, at a distance of 50 cm from the proximal edge of the table. The distance between the LEDs was 15 cm. The LEDs had green plastic covers so that when an LED was lit, a green stimulus (1 cm $\times$ 1 cm) appeared. The unilluminated LEDs could still be perceived clearly as dark green squares against the white surface under the glass.

The participants inserted two or three figures (depending on finger size) in the side of two small boxes, which could be moved independently across the table. The boxes consisted of a base 5 cm wide $\times$ 3.5 cm deep, and three edges 1.5 cm high (two on each side and one at the front). The boxes each weighed 6 g. The bottoms of the boxes were covered with cloth so that they slid freely across the glass surface. Thin wooden C-shaped blocks were affixed to the table 25 cm proximal to, and oriented toward, LEDs 1, 3, 4, and 6. These blocks served as the starting positions of the movements.

An infrared light-emitting diode (IRED) was attached to the front of each box. A flexible wire connected the box to the computer. In addition, an IRED was positioned under the glass directly in front of each of the six stimulus LEDs. An infrared (SELSPOT) camera sampled the coordinates of the IREDs at 320 Hz. The IREDs on the boxes registered the movement, and the IREDs in front of the stimulus LEDs registered when the target had been reached (see the "Data Analysis" section). Because the reaches consisted of sliding over the surface, they could be measured in the x - z plane with only one camera. Data registration, illumination of the measurement IREDs, illumination of the stimulus LEDs, and control of camera onset and offset were performed by a computer.

Procedure and Design

On each block of trials two stimulus positions were designated as targets—one for the left hand and one for the right hand. As shown in Figure 1, these were either Positions 3 and 4 (the central targets) or Positions 1 and 6 (the eccentric targets). The illuminated stimulus indicated which of the two potential targets was the actual target and, thus, which one had to be reached. LEDs 1, 2, or 3 constituted a "left stimulus", and LEDs 4, 5, or 6 constituted a "right stimulus". Participants were told to make a rapid unimanual movement upon stimulus onset to the target LED. A *stimulus-hand (S-H) consistent mapping* required a reach with the left hand in response to a left stimulus and a reach with the right hand in response to a right stimulus. In the *S-H inconsistent mapping* condition, this mapping was reversed.

The combinations of S-H mapping (consistent vs. inconsistent) and target eccentricity (central vs. eccentric) are shown in the four panels of Figure 1. Panel 1 shows the situation designating an S-H consistent mapping, with reaches directed at central targets: When a left stimulus was illuminated (LEDs 1, 2, or 3) the left hand had to move to LED 3, and when a right stimulus was illuminated (LEDs 4, 5, or 6) the right hand had to move to LED 4. Panel 3 shows the situation designating an S-H consistent mapping, with reaches directed at eccentric targets. Panels 2 and 4 show the reverse situations designating an S-H inconsistent mapping.

The starting position of each hand was always the starting block in front of that hand's target. Regardless of target eccentricity and S-H mapping, participants always were to make a direct ipsilateral movement to the target.

The experiment was divided into four blocks (the panels of Figure 1) of 72 trials (12 trials for each of the six stimulus LEDs). Each block was preceded by three to five practice trials, which were not analysed.

Half of the participants performed the first two blocks of trials with reaches to central targets and the next two blocks of trials with reaches to eccentric targets. This order was reversed for the other participants. Under both target eccentricities, half of the participants started with a block of trials requiring a consistent S-H mapping, followed by a block of trials requiring an inconsistent S-H mapping. This order was reversed for the other participants.

Prior to each trial, the participant positioned the moveable boxes at their starting points. Each trial started with a warning signal: The six stimulus LEDs were illuminated simultaneously. After 500 msec, the LEDs went off for 500 msec, at which time one of the six LEDs was illuminated for 500 msec. The participants were instructed to make a fast reaching movement¹ toward the target LED and then to return to the home location. They were also instructed to cover the target LED with the box, but a small amount of overshoot was deemed acceptable. The position of the stimulus light, in combination with the instructions for that block to make a particular response, defined the correct response. Participants were told not to lift the boxes from the table during the movement but to slide them over the surface of the table.

Movement recording began at stimulus onset, and lasted 1,500 msec. Only the position data of the hand that had to make the required response and the position data of the IRED in front of the to-be-reached target were sampled. Thus, no data were obtained for the other hand that, on some occasions, erroneously started to move. At the end of each trial, the computer determined whether the IRED in front of the required target LED had been covered. If the IRED was not covered within 1,500 msec, the trial was counted as an error and was not further analysed. The intertrial interval was about 5 sec (the time that it took the computer to store the data and generate the next trial).

Data Analysis

The movement data were low-pass filtered with a cut-off frequency of 30 Hz (second-order recursive Butterworth). The RTs (i.e. the time interval between stimulus onset and start of the movement) were calculated from the movement data: An algorithm searched backward in time from the peak velocity to the point at which the velocity dropped below 25 cm/sec; this point was called the *start of the movement*. For calculation of the movement time (MT), a movement was said to be completed when the IRED in front of the target LED was covered. In addition to these temporal measures (RT and MT), we also derived a spatial measure—namely, the maximum lateral deviation from the straight line connecting the starting position of the box and the end position of the box. The end position of the box was taken as the box IRED at the time the target IRED was covered.² Positive values are defined as deviations away from the body midline, whereas negative values are deviations toward the body midline (cf. our earlier measure of initial movement direction, Stins & Michaels, 1997b).

¹ Although the responses solicited from the participants would be more properly considered to be sliding movements, we will simply refer to them as reaching movements.

² Note that the box was wider than the to-be-covered LED (5 cm vs. 1 cm), so that the box could cover the IRED within a range of a few centimetres.

Results and Discussion

Incorrect trials (i.e. the ones in which the reach did not arrive at the required target position) and trials on which the RT was not within the range of 150–1,000 msec were not analysed. Also excluded were trials on which the approach movement, after an initial acceleration phase, decelerated and subsequently started accelerating again (presumably as a result of hesitation or an abrupt change in direction). Less than 4% of the trials were excluded.

We performed four-factor, within-subjects analyses of variance (ANOVAs) on the RTs, the MTs, and the lateral deviations, using the following factors: mapping (consistent vs. inconsistent S–H mapping), hand (left vs. right hand), target eccentricity (central vs. eccentric target), and stimulus eccentricity (eccentric, LEDs 1 and 6; intermediate, LEDs 2 and 5; central, LEDs 3 and 4, stimulus positions).

The RTs averaged over participants, hands, and trials are shown in Figure 2. The cell means for all three experiments are presented in the Appendix. Three main effects and two interactions reached significance. First, the main effect of S–H mapping was significant, $F(1, 11) = 14.18$, $p < .01$; there was a 27-msec advantage for S–H pairs that were on the same side over S–H pairs that were on opposite sides (345 msec vs. 372 msec, respectively). In other words, relative spatial S–H correspondence speeded up RT.

Second, we observed a Target Eccentricity $\times$ Stimulus Eccentricity interaction, $F(2, 22) = 30.93$, $p < .001$. This interaction indicates that reaches directed at central targets (Targets 3 and 4) were initiated faster in response to central stimuli (LEDs 3 and 4) than to more eccentric stimuli (see, in Figure 2, the negative slope for central targets). Conversely, reaches directed at eccentric targets (Targets 1 and 6) were initiated faster in response to eccentric stimuli (LEDs 1 and 6) than to more central stimuli (see, in Figure 2, the positive slope for eccentric targets). In other words, if a reach is directed at Target 1, for example, then responding is fast with stimuli at LEDs 1 and 6, slower with LEDs 2

FIG. 2. Mean RTs (in msec) for Experiment 1, given as a function of stimulus eccentricity (eccentric, intermediate, or central). The four lines represent the combinations of target eccentricity (eccentric or central) and S–H mapping (consistent vs. inconsistent).

and 5, and slower still with LEDs 3 and 4. Thus, responding is fast when the imperative stimulus is in close proximity to one of the potential targets.

Third, this two-way interaction was modified by the factor S–H mapping, captured as the three-way S–H Mapping $\times$ Target Eccentricity $\times$ Stimulus Eccentricity interaction, $F(2, 22) = 4.428$, $p < .05$. A post hoc analysis revealed that the effect of S–H mapping with eccentric targets was significant with eccentric and intermediate stimuli, but not with central stimuli (compare in Figure 2 the distance between the squares at different stimulus positions). In other words, reaches to eccentric targets did not show relative position compatibility to the central stimuli; they were made with equal speed to medial stimuli in left and right relative positions.

Finally, two other main effects reached significance. The main effect of target eccentricity, $F(1, 11) = 26.71$, $p < .001$, revealed a 41-msec advantage for movements directed at central targets over movements directed at eccentric targets (338 msec vs. 379 msec, respectively). In addition, the main effect of stimulus eccentricity, $F(2, 22) = 9.22$, $p < .01$, revealed a net RT disadvantage for the two central stimuli over the intermediate and eccentric stimuli (370 msec vs. 353 msec and 352 msec, respectively).

For the MTs, the main effect of target eccentricity was significant, $F(1, 11) = 25.03$, $p < .001$; movements directed at central targets had a duration that was 20 msec shorter than movements directed at eccentric targets (211 msec vs. 231 msec, respectively). One interaction reached significance: The Target Eccentricity $\times$ Stimulus Eccentricity interaction, $F(2, 22) = 7.35$, $p < .005$, indicated that MT was fastest with stimulus–target (S–T) pairs that were both central (LEDs 3 and 4) or that were both eccentric (LEDs 1 and 6). This effect is in the same direction as in the two-way interaction observed with the RTs, although the effect was very small; the MTs for S–T pairs that were both central or eccentric were, on average, 3 msec faster than MTs for S–T pairs that were central–eccentric or eccentric–central.

With respect to maximum lateral deviation, we note first that the movements showed a deviation toward the body midline; the overall deviation was -0.48 cm. An ANOVA revealed only one significant effect: the main effect of stimulus eccentricity, $F(2, 22) = 6.61$, $p < .01$. The mean deviations for stimuli at the eccentric, intermediate, and central locations were -0.43 , -0.52 , and -0.49 cm, respectively. The tendency for the reaching movements to deviate slightly toward the body midline was weaker with eccentric stimuli (LEDs 1 and 6) than with the more central ones. Small deviations from linearity are common in reaching (e.g. Morasso, 1981), and the finding of a deviation toward the body midline with ipsilateral reaching movements, which was unaffected by mapping, corroborates our earlier findings (Stins & Michaels, 1997b).

To summarize, the results from Experiment 1 indicate that RT was strongly influenced by the experimental manipulations, and that MT and the deviation scores showed fewer and weaker effects (see also Stins & Michaels, 1997b). As to RT, we found a compatibility effect based on relative spatial correspondence; responses emitted on the same side as the stimulus (consistent S–H mapping) were initiated faster than those on the opposite side to the stimulus. Second, we found clear effects of S–T distance: Reaches directed at central targets were initiated fastest in response to central stimuli and were slower with increasing stimulus eccentricity. Similarly, reaches directed at eccentric targets were initiated fastest in response to eccentric stimuli and were slower with decreasing stimulus eccentricity.

The combination of the effects of absolute and relative spatial correspondence resulted in fastest RTs when stimulus position and target position coincided.

We emphasize, however, that the effect of distance is not simply a monotonic function of how far away the imperative stimulus is from the to-be-reached target. In the case of reaching to a left eccentric target, for example, the RT is fast to the stimulus at that target and increases to the central stimuli, but then it decreases again with increasing eccentricity on the opposite side. Thus, we are careful to label the distance effect in terms of how far away the imperative stimulus is to either of the potential targets. We defer a consideration of the implications of this observation until after we have determined further the conditions under which it occurs.

EXPERIMENT 2

In Experiment 1, the starting positions of the hands were directly in front of the to-be-reached targets, so that the factor S–T distance was confounded with the distance between the stimulus and the starting positions of the hands. That is, the observed effect of absolute spatial correspondence might not be related to the spatial proximity between the stimulus and the target but, instead, to the proximity between the stimulus and the starting position of the hands. If the interaction of stimulus eccentricity with target eccentricity was due to S–T proximity, then changing the starting position of the hands but employing the same targets ought to yield essentially the same results as did Experiment 1. If, on the other hand, the distance between the starting position of the hands and the stimulus was responsible for the interaction then the effect should be reversed; S–H pairs that are close to each other will yield fastest RTs. This pattern of results might be expected on the basis of the findings of Tipper, Lortie, and Baylis (1992), who observed that distractors between the hand and a to-be-reached place caused greater interference than distractors at other places in the workspace. To determine whether it is S–H proximity or S–T proximity that matters, we studied a situation where eccentric targets had to be reached from a central starting position and central targets had to be reached from an eccentric starting position.

Method

The method of experiment was similar to that of Experiment 1, with the exception of the movement direction of the hands (see Figure 3). In Experiment 2, when the hands were positioned in front of stimulus Positions 3 and 4, they always reached to Positions 1 or 6, whereas when the hands were positioned in front of stimulus Positions 1 and 6, they reached to Positions 3 or 4, respectively.

Participants and Analyses

Twelve students at the Vrije Universiteit participated in this experiment. All were right-handed and were paid a small fee for their participation. Apparatus and stimuli were the same as those in Experiment 1, as was the procedure. Data analysis was the same as that in Experiment 1, although positive and negative deviation values now take on a different meaning, due to the fact that the reaching movements are now directed either inward or outward. We define positive deviation values

FIG. 3. The types of trials and their blocking in Experiment 2. There were four blocks of trials (two S-H mappings and two target eccentricities), as indicated by the numerals 1 to 4. The arrows denote the required movement in response to illumination of any of the three stimuli (the black squares). The white squares represent the unilluminated side.

as deviations toward the stimulus array and negative values as deviations away from the stimulus array, regardless of inward–outward movement direction.

Results and Discussion

One participant showed an error rate of over 20%. The data from this participant were not further analysed. We performed a four-factor ANOVA on the RTs, the MTs, and the lateral deviations, using the same factors as in the previous experiment. Incorrect trials (less than 2%) were not analysed.

The RTs averaged over participants, hands, and trials are shown in Figure 4, a figure remarkably similar to Figure 2. The main effect of S–H mapping was again significant, $F(1, 10) = 8.391$, $p < .05$; there was a 27 msec advantage for S–T pairs that were on the same side over S–T pairs that were on opposite sides (389 msec vs. 416 msec, respectively). In addition, the Target Eccentricity $\times$ Stimulus Eccentricity interaction was significant, $F(2, 20) = 49.852$, $p < .001$; as in Experiment 1, S–T pairs that were either both central or both eccentric yielded fastest RTs (remember that eccentric targets are reached from a central hand position, and vice versa). No other effects reached significance.

For the MTs, two main effects and no interactions reached significance. The main effect of target eccentricity, $F(1, 10) = 47.95$, $p < .001$, revealed a 26 msec advantage for hand movements that started from the central hand position and moved outward, over hand movements that started from the eccentric position and moved inward (235 msec vs. 262 msec, respectively). Second, the main effect of stimulus eccentricity, $F(2, 20) = 3.62$, $p < .05$, showed a small (3 msec) MT advantage for stimuli appearing at an eccentric location (LEDs 1 or 6) over stimuli appearing at more central locations.

There were several effects involving lateral deviation. To begin, note that the lateral deviation averaged about +1 cm, indicating that the reaches slightly deviated in the

FIG. 4. Mean RTs (in msec) for Experiment 2, given as a function of stimulus eccentricity (eccentric, intermediate, or central). The four lines represent the combinations of target eccentricity (eccentric or central) and S–H mapping (consistent vs. inconsistent).

direction of the stimulus array. We observed one main effect and three interactions. The main effect of S-H mapping, $F(1, 10) = 7.924$, $p < .05$, indicated that the amount of deviation was slightly larger for the inconsistent than for the consistent S-H mapping. There were 2 two-way interactions: the Stimulus Eccentricity $\times$ Target Eccentricity interaction, $F(2, 20) = 14.571$, $p < .001$, and the Stimulus Eccentricity $\times$ S-H Mapping interaction, $F(2, 20) = 7.653$, $p < .01$; and a three-way interaction involving these three factors, $F(2, 20) = 3.844$, $p < .05$. The latter interaction can be seen in Figure 5: The amount of deviation in the direction of the stimulus array increases with decreasing stimulus eccentricity, but only in one condition—namely, the consistent S-H mapping, involving reaches directed at eccentric targets. Thus, for example, with a hand movement directed at target LED 1 the amount of deviation in the direction of the stimulus array is smallest with a stimulus at LED 1 and largest with a stimulus presented at LED 3. In other words, movements directed at an eccentric target appear to deviate slightly toward the imperative stimulus.

The RT results from this experiment again demonstrated an effect of relative spatial correspondence; S-H pairs that were on the same side speeded up RT. Moreover, we again found an effect of absolute correspondence. This effect, together with the results of Experiment 1, suggests that the effect of absolute correspondence is a function of the destination of the movement and not of its starting position. In other words, fast responding appears to be a function of the proximity between the stimulus and the target. The observation that the proximity of stimulus and target, rather than the proximity of stimulus and hand, determines the speed of movement initiation appears at odds with the findings of Tipper et al. (1992). As stated, they observed that the position of distractors relative to the hand was more important than the position of the distractor relative to the target. However, the present task requires a conjoint selection of hand and prespecified target, whereas Tipper et al.'s task has a single hand moving to one of several possible targets. It is known that such a difference in task can determine which

FIG. 5. Mean maximum lateral deviation (in cm) for Experiment 2, given as a function of stimulus eccentricity (eccentric, intermediate, or central). The four lines represent the combinations of target eccentricity (eccentric or central) and S-H mapping (consistent vs. inconsistent).

correspondence relations (among stimulus, hand, and target) enter into compatibility effects (Stins & Michaels, 1997b).

MT was again essentially unaffected by our experimental manipulations, but we found an interesting effect on the deviation scores; the path of the movements that were directed outward (i.e. from a central starting position to an eccentric target) tended to deviate in the direction of the stimulus that appeared on the same side. A similar effect was found by Tipper, Howard, and Jackson (1997), who found that reaching movements directed at target objects sometimes deviated toward distractor objects. However these authors also observed the opposite effect, as did Rizzolatti, Riggio, and Sheliga (1994) for eye movements. At present, it is unclear why movements directed at a target sometimes deviate toward and other times deviate away from distractors.

EXPERIMENT 3

The results of Experiments 1 and 2 demonstrated clear effects of relative spatial correspondence and of S–T distance. In Experiment 3, we tested whether the distance effect depends on the use of reaches as responses. Given that explanations of results from the button-pushing paradigm have not found a need to invoke the concept of absolute position, we expect that if no reaching movements to a target have to take place then the effect will disappear. In Experiment 3, we asked participants simply to press a left or a right key in response to the imperative stimulus. We expect no effect of stimulus eccentricity (i.e. essentially flat RT profiles) and only an effect of S–H correspondence.

Method

This experiment was similar to Experiments 1 and 2, with the exception of the type of response. In Experiment 3 the hands again assumed a central or eccentric position, but participants responded to the stimulus by pressing the key on one of two stationary computer mice on which the hands rested. The positions of the mice coincided with the starting positions of the hands (central or eccentric) in the previous experiments. The mice were connected to an interface card that permitted direct readout of the RT. Participants pressed the mouse keys with the index finger of their left or right hands. Twelve new right-handed graduate and undergraduate students participated. The stimuli and procedure were the same as those in Experiment 2 but now the intertrial interval was about 3 sec, and no movement registration took place.

Results and Discussion

Errors (less than 2% total) were not analysed. The RTs averaged over participants, hands, and trials are shown in Figure 6. We performed the same ANOVA on the RTs as that in Experiments 1 and 2 but we used the factor hand eccentricity (instead of target eccentricity) to refer to the position of the responding hands (central vs. eccentric). The analysis revealed that there was a main effect of S–H mapping, $F(1, 11) = 32.523$, $p < .001$; S–H pairs that were on the same side had a 50-msec RT advantage over pairs that were on opposite sides (344 msec vs. 394 msec, respectively). In addition, the factor stimulus eccentricity interacted with hand eccentricity, $F(2, 22) = 4.371$, $p < .05$: With

FIG. 6. Mean RTs (in msec) for Experiment 3, given as a function of stimulus eccentricity (eccentric, intermediate, or central). The four lines represent the combinations of hand eccentricity (eccentric or central) and S-H mapping (consistent vs. inconsistent).

the hands at the eccentric positions, participants responded more slowly to central stimuli (LEDs 3 and 4) than to the more eccentric stimuli, whereas stimulus eccentricity did not matter if responses were given at the central hand position. This yielded a net main effect of stimulus eccentricity, $F(2, 22) = 10.878$, $p < .01$, indicating somewhat higher RTs for central stimuli. Finally, stimulus eccentricity interacted with hand, $F(2, 22) = 4.077$, $p < .05$ (not graphed), indicating that the left hand responded relatively slowly to central LEDs.

The results of Experiment 3 essentially confirmed our predictions. First, as in Experiments 1 and 2, we observed an effect of relative spatial correspondence; keypress responses were initiated faster when the stimulus was presented on the same side as the responding hands (consistent S-H mapping) than when they were on different sides. Second, we observed no effect of stimulus eccentricity with the central hand placement, as evidenced by essentially flat RT profiles. However, with the eccentric hand position, keypresses were slow in response to central stimuli. This effect is in the same direction as that observed in Experiment 1, where we found, with the eccentric hand-target position, slower RTs with decreasing stimulus eccentricity. That an effect of stimulus eccentricity shows up with one hand placement but not the other suggests to us that static hand position can indeed affect compatibility (see also Michaels & Schilder, 1991). More generally, Experiment 3 provides further evidence (Stins & Michaels, 1997b) that the manner of response execution can figure significantly in compatibility (see also Michaels, 1989; Michaels & Schilder, 1991). Even though all three experiments involved a left-right response dimension, we found that different movement types yielded different RT advantages.

GENERAL DISCUSSION

In three experiments we studied the contribution of absolute spatial S-R correspondence to compatibility in the case of reaching movements (Experiments 1 and 2) and in the case of keypress responses (Experiment 3). First, we found a spatial compatibility effect for

relative position in all three experiments; S–R pairs that were on the same side gave rise to faster response initiation than S–R pairs that were on different sides. Second, comparison between the reaching tasks (Experiments 1 and 2) and the keypressing task (Experiment 3) showed that not only a place but also the type of action figures in compatibility; left–right reaches gave rise to different compatibility effects than left–right keypresses. A related observation was made by Stins and Michaels (1997a; Experiment 1), who demonstrated that pushing proximal or distal keypresses vs. moving a joystick in a proximal or distal direction gave rise to compatibility effects of different sizes (see also Adam et al., 1996; Michaels & Stins, 1997). Third, a comparison of Experiments 1 and 2 indicated that compatibility was a function of the target of the reach and not of the starting positions of the hands. Finally, the RT data in the reaching tasks indicated that movement onset was fastest when the stimuli and the targets were both at central locations or both at eccentric locations. To reiterate, a movement directed at the extreme left target (target LED 1) was initiated fast with an extreme left stimulus (LED 1), was also fast with an extreme right stimulus (LED 6), and became slower with the more central stimuli. This suggests that absolute spatial correspondence (i.e. the proximity between the imperative stimulus and the potential targets of the reach) yields compatibility effects above and beyond those found with relative spatial correspondence.

We begin our discussion with a consideration of how compatibility related to absolute correspondence fits with three influential accounts of spatial compatibility and Simon effects: the attention-shifting account (and its precursor, premotor theory), the referential coding account, and the dimensional overlap model. We give a very brief (and necessarily incomplete) description of these accounts, and we assess the extent to which they might explain our observations.

Attention-shifting Account

According to the attention-shifting account (e.g. Stoffer, 1991; Stoffer & Umiltà, 1997), selecting an object in the visual field requires that attention be directed from its current position (e.g. a fixation point) to the object's position. Directing of attention can occur automatically (e.g. due to an abrupt stimulus onset or offset) or intentionally. The account holds that if the direction of the lateral attentional shift is left, for example, then a left stimulus code³ is formed. No spatial code will be formed when no shifting of attention occurs—for example, when attention “zooms” in or out (Eriksen & St. James, 1986; Stoffer, 1991). The account predicts fast RTs when the spatial stimulus code is congruent with the spatial left–right code of the response. A given stimulus might thus have induced a leftward attentional shift, a rightward shift, or even no attentional shift at all. Let us assume, for present purposes, that prior to stimulus onset attention was directed somewhere at the centre of the stimulus array.⁴ The attention-shifting theory would have to

³ Within the language of information processing, a code can be thought of as some sort of a cognitive “tag” that represents a particular stimulus (or response) attribute, such as its colour, position, orientation, etc.

⁴ This assumption seems reasonable, because attending to an eccentric position (prior to stimulus onset) would cause more difficulty for detecting a stimulus appearing at the other eccentric position than when attention is focused at the centre of the stimulus array.

explain why a large amplitude shift to the extreme left position, for example, resulted in fast responding to the extreme right target. It is unclear how the account would deal with this observation. It is interesting to note that a precursor to the attention-shifting theory, the *premotor theory* of spatial attention (e.g. Rizzolatti, Riggio, Dascola, & Umiltà, 1987; Rizzolatti et al. 1994), links attention to the programming of eye movements and might offer a means of dealing with the eccentricity effect.⁵ Given that eye movements have both direction and amplitude, the premotor theory might argue that a large amplitude code associated with programming an eye movement to an eccentric stimulus might be compatible with a large amplitude motor response, albeit with the opposite direction. This would then constitute an instance of response–response compatibility. However, given that premotor theory has (to our knowledge) dealt only with eye movements, we are not sure how it would link the presence of a stimulus to the organization of a reaching movement.

Referential Coding Account

The second account, the referential coding account, is similar to the attention-shifting account; it assumes that a left–right stimulus code is formed with respect to an intention–ally defined spatial frame of reference (see e.g. Hommel, 1993b). Thus, a stimulus obtains its leftness or rightness when its position is coded relative to the position of another object, such as a fixation point. Some (e.g. Lamberts et al., 1992; Roswarski & Proctor, 1996; Umiltà & Liotti, 1987) have proposed that a stimulus can even have multiple simultaneous spatial codes when there are multiple frames of reference. For example, a stimulus can be defined as left with respect to one object in the visual field, and (simultaneously) as right with respect to another object. According to this view, compatibility is a function of the extent to which these multiple stimulus codes correspond with each other and with the response code. Stimuli that are, for example, coded as left with respect to more than one frame of reference would then give rise to a stronger effect of mapping than stimuli that are coded as both left and right (Roswarski & Proctor, 1996). This model does not fare well with our data either: In our Experiments 1 and 2 we found that an extreme right reaching movement was very fast in response to the extreme left stimulus (presumed to have multiple left codes) and slow with stimuli that were more central (i.e. those that presumably also had a right code). One might invent a new referential code that can explain the results, for example, that eccentricity is coded with respect to the middle locations on each side; Positions 3 and 4 might be coded as “nearer” and Positions 1 and 6 as “farther”. Again, the advantage accruing to eccentric reaches in response to (ipsilateral or contralateral) stimuli would follow from this relative code. As compelling as this may seem at first sight, it goes without saying that a position along any continuum can be represented in terms of categorical relationships. Thus, a falsifiable referential coding account would have to offer explicit limits on numbers of codes, types of codes, and what can constitute a reference point.

⁵ We thank Bernhard Hommel for calling this interpretation to our attention.

Dimensional Overlap Model

Finally, the dimensional overlap (DO) model formulated by Kornblum and coworkers (e.g. Kornblum, 1992; Kornblum, Hasbroucq, & Osman, 1990) deals with compatibility in terms of overlapping dimensions between the stimulus set and the response set. Briefly, the model assumes that mapping differences emerge when the stimulus set and the response set have attributes (such as colour, position, etc.) in common—that is, when there is, at some level, similarity between the set. The model postulates that, when there is overlap between the stimulus set and the response set, presentation of a stimulus element automatically activates the congruent response. If, for example, one has a stimulus set consisting of four visual stimuli on a horizontal array and a response set consisting of four response keys on a horizontal array that are operated by four different fingers, then the stimulus set and the response set are similar with respect to position. Upon presentation of the extreme left stimulus, for example, the corresponding response (i.e. responding with the extreme left key) will be automatically activated. If the activated response happens to be the correct response, RT will be fast. If, on the other hand, the activated response has to be aborted in order to produce another response, RT will be slow. The model explicitly allows for stimulus and response sets to be similar along more than one dimension; for example, the sets can be similar with respect to both their position and their colour (cf. Hedge & Marsh, 1975, who used left–right stimuli that were also red or green, and left–right keypress responses with red or green coloured keys).

This model, too, might be applied to our data if it is assumed that the stimulus and response sets are overlapping not only with respect to their left–right relative position but also with respect to a new dimension—eccentricity (remember that S–T pairs that were either both eccentric or both central yielded fast RTs). Thus, if eccentricity were considered a dimension, then it would allow for the possibility of dimensional overlap. In the DO terminology, task-relevant left–right (stimulus) position would be said to overlap with task-relevant left–right (target) position, and task-irrelevant stimulus eccentricity would be said to overlap with task-irrelevant target eccentricity. But how would the DO model deal with target eccentricity? Is it a response characteristic or a stimulus characteristic? If target eccentricity is a response characteristic, then according to the model (task-irrelevant) stimulus eccentricity would automatically activate the congruent response. That is, a central stimulus, say, would automatically activate a response directed at a central target. This situation would be comparable to the Hedge and Marsh (1975) experiment and constitute—in the taxonomy of the DO model—a *Type 5 ensemble*. However, it seems unlikely that a central stimulus automatically activates a central response when the response set consists, within a block of trials, only of eccentric responses. That is to say, it only makes sense to assume activation of a particular response by a stimulus pattern when, on a given trial, an alternative stimulus pattern can potentially activate the alternative response. If both response keys in a spatial compatibility task were green, for example, then it would make little sense to assume that a green stimulus pattern would activate both responses. The DO model might work for a situation where, on each trial, a left reach is directed at a central target and a right reach is directed at an eccentric target (or vice versa), but arguably not when target eccentricity is fixed within a block of trials.

The other alternative is that target eccentricity is not a response characteristic but a stimulus characteristic. Reaction time would then be influenced by how well one stimulus characteristic (stimulus eccentricity) overlaps with another stimulus characteristic (target eccentricity). Thus, when the task involves reaches directed at either of the two central targets, for example, then stimuli that are presented centrally would be identified more quickly than stimuli that are presented at more eccentric positions. In the taxonomy of the DO model, this situation would constitute a *Type 4 ensemble*—that is, a Stroop-like task where two stimulus dimensions overlap with each other but neither of the two dimensions overlaps with the response dimension. However, then the model would have to assume that places that have the potential of becoming a target constitute a stimulus characteristic, which may or may not overlap with the imperative stimulus. It is unclear whether the DO model allows for this possibility.

Conclusion

To summarize, our effects of absolute spatial correspondence seem to pose problems for existing accounts of compatibility, unless these accounts posit additional codes. However, even a flexible conceptualization of codes may not be enough; these theories deal with stimulus and response characteristics (such as position) in purely categorical terms. They appear to assume that the purpose of coding is to assign stimuli and responses to categories—like left and right, front and back, far and near—which, in turn, form the basis of all spatial compatibility phenomena. Indeed, most compatibility studies deal with the coding of stimulus and response location exclusively in terms of left and right. Quantitative variables, such as the distance between an effector and a target of a reach, have attracted little attention in compatibility experiments and models.⁶ We believe that the repeated observations in the literature of effects of relative spatial correspondence and the lack of effects of absolute correspondence are actually due to the paradigms—such as button pressing—which leave no room for effects of absolute spatial correspondence to show up in the first place (Michaels & Stins, 1997). This is unfortunate, because in everyday situations absolute position is clearly very important for goal-directed actions. For example, grasping an object or reaching to a place requires information about its position relative to the body and arguably not about its leftness or rightness with respect to something else in the environment.

In our experiments, successful reaches required information about the absolute position of the target, and the speed of movement initiation appeared to be a function of how well an imperative stimulus signalled a place toward which to move. To reiterate,

⁶ Interestingly, the study by Georgopoulos, Lurito, Petrides, Schwartz, and Massey (1989) showed clear effects of distance on RT. In that study a monkey was trained to move its arm at a certain angle away from a visual stimulus. They found that the neuronal population vector gradually rotated away from the stimulus and towards the required movement direction. Moreover, the time it took the monkey to initiate the movement increased with angle. In contrast, in our experiment, movements directed at a large angle away from the stimulus (e.g. the right hand moving to the extreme right position with the extreme left stimulus) were initiated faster than movements at a smaller angle (e.g. the right hand moving to the extreme right position with the central left stimulus). However, in the Georgopoulos et al. (1989) study, no selection of an arm had to take place, which makes it difficult to compare their study directly with ours.

responses were initiated fast when the stimulus was close to the potential target, so that a reach to the extreme left target, for example, was initiated fast when the stimulus appeared at the extreme right position. We tentatively interpret this finding in terms of our earlier (ecological) account of S–R compatibility (Michaels & Stins, 1997): In order to produce successful movements, such as reaching to a place, the redundant degrees of freedom of the motor system somehow need to be constrained (e.g. Bernstein, 1967), and these constraints can be supplied by the actor's intentions and by information. The intention to perform a certain action "sets up" perception to task-relevant information—the stimulus—which can be used to guide the action (see also Hommel, 1993a). Fast responding thereby reflects the effectiveness of stimulus information in constraining the action. With respect to our findings, we believe that the intention to reach to either of the two targets sets up perception to information specifying the actual targets. A stimulus light appearing in close proximity to either of the targets is highly effective in constraining either of the two reaching movements, and selecting the subsequent response was fast. We therefore propose a conceptualization of "stimuli" in terms of possible constraints on an upcoming action, instead of left–right stimulus "codes" to be compared to response codes (Michaels & Stins, 1997).

We conclude that spatial compatibility is (under some circumstances) related to absolute spatial correspondence, and that an a priori categorical scheme for stimuli and responses in terms of left and right is not rich enough to explain the perception–movement relationships that are evidenced in spatial compatibility. It must be the case that selecting a left or a right hand to reach to a place is a function not only of the left–right correspondence between the hand and the position of target, but also of action system variables that are unrelated to left and right, such as the distance between the target and the respective hands, the end-state comfort of the hands (e.g. Rosenbaum et al., 1990), and so on. If so, the work required for an understanding of spatial compatibility has only just begun.

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Original manuscript received 14 April 1998

Accepted revision received 12 April 1999

APPENDIX

Mean RTs in msec, averaged over trials and participants, for each combination of stimulus position, eccentricity (of target or hand), and hand (left and right) of Experiments 1, 2, and 3

Experiment	Stimulus	Response			
		Left		Right	
		C	E	C	E
1	1	331	333	371	365
	2	316	348	357	388
	3	310	419	348	424
	4	343	416	288	413
	5	356	370	326	359
	6	365	358	341	352
2	1	372	377	427	412
	2	377	393	407	413
	3	363	423	395	452
	4	394	439	355	443
	5	413	411	381	401
	6	431	400	397	391
3	1	343	343	397	390
	2	336	339	383	388
	3	349	387	383	411
	4	415	417	334	358
	5	375	386	335	334
	6	391	387	336	340

Note: Left and Right indicate the left and the right hand, respectively. C and E indicate the central and eccentric target position (Experiments 1 and 2), or the central and eccentric hand position (Experiment 3).