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Egocentric and relative spatial codes in S-R compatibility

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Summary. It has been shown that spatial compatibility is due to a comparison between the spatial codes that describe stimulus and response positions. Such codes are often defined in right-left terms. There are, however, two types of right-left codes that can be used for describing a position in space. One is formed with relation to the egocentric axes and can be termed "side", whereas the other is formed with relation to an external reference location and can be termed "relative position". Five experiments were conducted to determine the role of these different codes in producing spatial compatibility effects. In Experiments 1 and 2 the position of the stimulus provided the relevant cue for choosing the correct response (i.e., the situation was typical of spatial compability proper), whereas in Experiments 3, 4, and 5 the stimulus provided a locational cue that was not necessary for choosing the correct response (i.e., the situation was typical of the Simon effect). The experimental manipulations concerned the task demands and the time elapsing between availability of the stimulus code and availability of the response code. The results showed that upon stimulus presentation, both stimulus codes (that concerning side and that concerning relative position) were formed, but experimental manipulations determined the one that was effective in yielding compatibility effects. When the task required the use of one type of code, then spatial compatibility depended on that code alone. When the two coding processes were separated in time, then spatial compatibility depended only on the code that was formed simultaneously with the response code.

Introduction

Several studies (Brebner, Shepard, & Cairney, 1972; Nicoletti, Anzola, Luppino, Rizzolatti, & Umiltà, 1982; Nicoletti & Umiltà, 1984; Umiltà & Nicoletti, 1985; Wallace, 1971) have shown that spatial compatibility is due to the correspondence (compatible pairings) or lack of correspondence (incompatible pairings) between the spatial codes that define stimulus-response (S-R) pairings. This applies to spatial compatibility in its two forms, *viz.*, spatial compatibility proper and the so-called Simon effect [see Nicoletti and Umiltà (1984), Simon, Sly, and Vilapakkam (1981), and Umiltà and Nicoletti (1985) for the distinction between the two kinds of spatial compatibility].

In the case of spatial compatibility proper, the positional codes must be processed attentionally because it is the right-left code of the stimulus that indicates the correct response. For example, if the stimulus is on the right side, then the right response code (compatible S-R pairing) or the left response code (incompatible S-R pairing) must be selected. Response latency is faster when the two codes are the same because no translation from the stimulus to the response code is needed, whereas such translation must take place when the two codes are different (Teichner & Krebs, 1974). Note that for simplicity it is assumed here, in accordance with Teichner and Krebs (1974), that compatibility effects are attributable to a lengthening of incompatible RTs rather than to a facilitation of compatible ones, even though this important issue is far from being clarified (Simon & Acosta, 1982; Simon, Acosta, Mewaldt & Speidel, 1976 a).

In the case of the Simon effect, it is a nonspatial code of the stimulus, like, say, color, that indicates the right-left code of the response. For example, if the light is red, then the right response code must be selected; if it is green, then the left response code must be selected. The lights, however, appear on either the right or left side and give rise automatically to the corresponding spatial code. Also in this instance then, when a right-left response code is being formed, a right-left stimulus code is available and can influence the speed with which the former is achieved. Hence, the red light is responded to faster when it is shown on the right than the left side and vice versa for the green light.

It may be noted in passing that there is a certain similarity between the Simon effect and the well-known Stroop effect [see Dyer (1973) and Jensen and Rohwer (1966), but see also Simon, Acosta and Mewaldt (1975) for a contrasting point of view]. Both arise because of the simultaneous availability of two similar and potentially conflicting codes. One is the response code (i.e., the name of the color in the Stroop effect, the side of the response in the Simon effect) that must be formed in order to perform the task. The other is a stimulus code (its meaning in the Stroop effect, its position in space in the Simon effect), which is of no relevance for performing the task, but nonetheless becomes automatically available. However, by noting a similarity between the Simon and the Stroop effects we do not mean to imply that the codes involved in the former are

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verbal in nature. In fact, there is good evidence that at least spatial compatibility proper is due to the use of nonverbal, most likely spatial codes (Nicoletti & Umiltà, 1984). Also note that the spatial codes are not necessarily of the right-left type. If the response code is in terms of above-below or near-far positions, then identical compatibility effects can be observed, which depend on the above-below or near-far positions of the stimulus (Nicoletti & Umiltà, 1984; Simon, Mewaldt, Acosta, & Hu, 1976 b).

One important issue to consider is that two types of right-left codes can be formed. The stimulus can be on either the right or left side in relation to an egocentric reference axis, like the body midline, the head midline, or the vertical retinal meridan. (Note that when an observer fixates a point in the visual field without turning the head or the body, the three axes are aligned and the stimulus is on the right or left side in relation to every axis.) Alternatively, the stimulus can be on either the right or left position in relation to an external reference point like the other stimulus. For brevity, here we will use the term *side* to indicate the right-left position in relation to the egocentric axes, which are assumed to be aligned, and the term *relative position* to indicate the right-left position of the stimulus with respect to the other.

Of course, the two types of spatial coding coincide if there are only two stimuli, which are shown to the right or left of the egocentric axes. In this case, the stimulus on the right side also occupies the right relative position and the stimulus on the left side is also relatively on the left. Consider, however, a display like that in Figure 1. There are only two possible locations (i.e., those marked by the two boxes) where the stimulus can appear, and both are on the right side. Here side and relative position are unconfounded at the location nearer the fixation mark, which is on the right side but occupies the left relative position. There is also no confound for the location nearer to fixation on the left side (not shown in Figure 1). The same reasoning applies to the response code: For the location of the response there is also a right-left side and a right-left relative position, and they can be partially unconfounded by positioning the two responses on the same side in relation to the egocentric axes.

In a series of previous experimets we (Nicoletti et al., 1982; Nicoletti, Umiltà, & Ladavas, 1984; Umiltà & Nicoletti, 1985) have shown that spatial compatibility depends on the relative positions of the stimuli (and responses) and not on the side where they are shown (or emitted). It appeared that the only type of right-left coding that mattered for spatial compatibility was the one performed with reference to the location of the other stimulus or response. In a condition like that in Figure 1, therefore, the position closer to fixation was coded as left even though it was on the right side. Such a finding, even though supported by unequivocal evidence, is surprising. After all, the observer was well aware of the fact that the position closer to fixation was on the right side egocentrically. Why, then, did this type of spatial coding not seem to have any effect on the speed of response?

An important characteristic of those previous experiments was that the side position was blocked, that is, the stimuli were shown on one side for about 30 trials and then the stimulation side was switched for another block of trials. This way the side could be coded once for all, whereas coding of the relative position took place during each trial upon stimulus presentation. If one assumes that in order to be effective right-left coding of the stimulus must occur at nearly the same time as the selection of the right-left response code, then the above finding becomes less surprising. The side of the stimulus was in fact coded, but this operation took place well before the stage of translation from the stimulus to the response code and hence did not affect it. This explanation is in accordance with the observation that compatibility effects disappear if the response is delayed for 300 ms or so (Simon et al., 1976 a). In some sense, if the side is blocked, the response is simply delayed quite a bit with respect to when the coding of the side took place. Therefore, the stimulation side could not affect RT. Note that in those studies in which the side was not blocked (see, e.g., Simon, 1969; Wallace, 1971), it was always confounded with relative position since the two stimuli were shown on opposite sides of the body midline and the other egocentric axes.

Before outlining the aims of the present study it might be useful to summarize the points raised so far.

a. In two-choice RT paradigms, a right-left coding of the response occurs because this is, either explicitly or implicitly, one of the task demands.
b. Upon stimulus presentation, right-left positional codes are formed either attentionally (i.e., in the case of spatial compatibility proper) or automatically (i.e., in the case of the Simon effect).
c. There are two types of right-left codes. One concerns the location of the stimulus or response in relation to the egocentric axes (i.e., *side* as defined here). The other is formed with reference to the location of the other stimulus or response (i.e., *relative position*).
d. Previous studies have shown that the type of codes to which compatibility effects are due is that regarding relative position. However, in those studies, *side* was confounded with *relative position* or blocked. In the latter case, the outcome of its coding might have become ineffectual by the time the response code was formed.

In conclusion, it seems fair to say that while the role of relative position in spatial compatibility is well established, the role of stimulation side has yet to be properly tested. The present study addressed this issue. In the first two experiments it was the location of the stimulus that provided the relevant cue for choosing the response code (i.e., the situation was that of spatial compatibility proper). In Experiment 1 the instructions were couched in terms of right-left stimulus relative position, whereas side was irrelevant. In contrast, Experiment 2 required the subject to use right-left stimulus side as the relevant spatial cue, whereas relative position was irrelevant. Hence, the two experiments together attempted to demonstrate spatial compatibility effects attributable to either type of stimulus coding alone.

In the last three experiments, the stimulus provided a locational cue that was not necessary for choosing the response code (i.e., the situation was that of the Simon effect). What was manipulated was the time course of the two types of right-left stimulus coding. In Experiment 3, side could be coded prior to stimulus presentation, whereas relative positional codes could be formed only after stimulus presentation. In Experiment 4, the situation was exactly the opposite: Relative position could be coded in advance, whereas side could be coded only after the stimulus had appeared. In Experiment 5, both types of coding could take place prior to stimulus presentation. The prediction was that only the stimulus coding that occurred while the response code was formed would prove effective in yielding compatibility effects. Accordingly, compatibility effects due to relative position were expected in Experiment 3, compatibility effects due to side were expected in Experiment 4, and no compatibility effects were expected in Experiment 5.

Experiment 1

This experiment was essentially a repetition of previous experiments that had demonstrated the role of relative position in spatial compatibility proper (Nicoletti et al., 1982). The relative position of the stimulus indicated the location of the correct response but the side was not relevant. Therefore, compatibility effects were predicted that were exclusively attributable to the coding of relative position.

Method

Subjets. Twelve right-handed students from the University of Parma served as paid subjects. They had normal or corrected-to-normal visual acuity and were naive as to the purpose of the experiment.

Apparatus and display. The subject sat in front of a CRT screen driven by an Apple II microcomputer. The head was positioned in an adjustable head-and-chin rest, so that the distance between the eyes and the screen was approximately 50 cm. The visual display (see Figure 1) comprised the following items: one fixation cross 0.5 × 0.5 deg in size shown at the geometrical center of the screen; two boxes 1.5 × 1.5 deg in size shown at 3 and 5 deg from the fixation cross (center to center); one small square (the stimulus) 0.25 × 0.25 deg in size shown at the geometrical center of one of the two boxes. The responses were emitted by pressing one of two keys on the computer keyboard ("Z" and "/"), about 17 cm apart.

Procedure. At each trial the timing of the random sequence of events was as follows. The fixation cross was presented first and left on until the end of the trial. After a 500-ms

Fig. 1. Schematic diagram of stimulus display and response keys for Experiment 1. In the delay condition the two boxes preceded the stimulus by 500 ms. *RVF*, right visual field or right side; *LVF*, left visual field or left side

interval, a warning beep (25 ms in duration) was delivered, followed by a further interval of 1 s. When this interval was over, the two boxes were shown, half of the time to the right and half to the left of fixation. In half of the trials the boxes were followed by a 500-ms interval and then the stimulus was shown with equal probability in one of them. In the other half of the trials there was no interval; hence the boxes and the stimulus appeared simultaneously. In both instances, they stayed on until a response was emitted. Upon emission of the response, a 500-ms visual feedback about speed and accuracy was provided and the trial ended with a 2-s intertrial interval. Every subject was run in three sessions on consecutive days, and each session comprised four blocks of 80 trials separated by 5-min rest periods. Therefore, overall there were 960 experimental trials for every subject, plus about 80 practice trials at the beginning of the first session.

The subject was instructed to maintain good fixation and to be as fast as possible while trying to keep the error rate below 5%. The instructions were couched in terms of relative position of the stimulus. In the compatible condition (two blocks of trials in each session) the subject was to press the right key if the stimulus was shown within the right box (i.e., the box close to fixation on the left side and the more peripheral one on the right side) and to press the left key if it was shown within the left box. In the incompatible condition (the other two blocks in each session) the assignment was reversed, namely, the right key was used for the left stimulus and the left key for the right. Note that the two relative positions were always clearly marked since both boxes were always present from stimulus onset through response execution. Order of condition was counterbalanced across sessions and subjects. Trials for which RT was less than 150 ms or longer than 1000 ms were considered errors, and all types of errors were discarded and replaced at the end of each block.

Results and discussion

Errors were very few (about 2% in the compatible condition and about 3% in the incompatible condition) and were not analyzed. Mean correct RTs were entered into a repeated-measures analysis of variance with four factors: delay between the boxes and the stimulus (0 or 500 ms), relative position of the stimulus, side of the stimulus, and response position (all right or left).

Two sources of variability proved significant. One was the interaction between stimulus relative position and response position, $F(1,11) = 23.27$, $P < 0.001$. It showed that the right stimulus was responded to faster by the right than the left key (459 vs 533 ms), whereas the left stimulus was responded to faster by the left than the right key (470 vs 524 ms). Pair-wise comparisons performed by the Newman-Keuls procedure confirmed the significance of the two differences (both $P < 0.001$). Overall there was a compatibility effect of about 65 ms, which was attributable to the coding of the relative position of the stimulus. In contrast, the side yielded no compatibility effect: If anything, contralateral responses were about 10 ms faster than ipsilateral ones. These findings corroborate those of previous experiments (Nicoletti et al., 1982) and confirm that the subject can make use of relative positional cues while disregarding side of stimulation. The other significant source was the main effect of delay, $F(1,11) = 90.99$, $P < 0.001$. Responses were much faster in the delay condition than when the stimulus was presented along with the boxes (457 vs 537 ms). This can be explained by considering that the two boxes could have supplied a more effective warning than the beep alone and, in addition, allowed the subject to direct attention to the side where the stimulus was to be shown.

Experiment 2

This experiment tested whether the coding of stimulus side could be as effective as the coding of relative position in bringing about compatibility effects. Accordingly, in it the instructions were couched in terms of right-left stimulus side and response position, whereas stimulus relative position was irrelevant.

Method

Subjects. An additional 12 students served as paid subjects.

Apparatus and display. These have already been described; there was only one difference concerning the display (see Figure 2). There were four boxes, two on each side of fixation. The stimulus was, however, shown always within one of the two with solid contours. The two with broken contours had the only purpose of marking the relative position of the stimulus.

Procedure. The timing of the events was identical to that of the previous experiment. Note that the four boxes were shown simultaneously and the solid ones occurred with equal probability in the right or left relative positions. In the compatible condition the subject pressed the right key if the stimulus appeared on the right side and the left key if it appeared on the left. The assignment was just the opposite in the incompatible condition. The instructions also made it clear that the stimulus could only appear within one of the two solid boxes, while relative position was of no use in choosing the correct response.

Results and discussion

The errors (about 1% for compatible trials and 3% for incompatible ones) were not analyzed. Mean correct RTs were submitted to an analysis of variance identical to that employed in Experiment 1, which yielded three significant sources.

This time, the response position did not interact with the relative position of the stimulus, but it did interact with the stimulus side, $F(1,11) = 43.70$, $P < 0.001$. As attested also by pair-wise comparisons (both $P < 0.001$), when the stimulus was on the right side, the responses were faster with the right than the left key (325 vs 363 ms), whereas just the opposite occurred for the left-side stimulus (320 vs 367 ms). Overall, the compatibility effect was of about 44 ms. Taken at face value, this seems to show a spatial compatibility effect due to the coding of side alone. However, some further considerations are in order.

If attention was focused on the two boxes with continuous contours, as the instructions implicitly suggested, while the two broken boxes were somehow filtered out, then it is possible that side and relative position were confused. In other words, one could argue that here the S-R mapping was identical to that of Experiment 1, and here also spatial compatibility was due to the coding of relative position. There is, however, an important aspect of the results that suggests that different codes were employed in the two experiments. Here, overall RT was much faster than in the previous experiment: 344 versus 497 ms, namely, a difference of 153 ms, which turned out to be highly significant [$t(22) = 13.34$, $P < 0.001$]. It is apparent that the stimulus positional code needed to select the correct response was much faster to form in Experiment 2 than in Experiment 1. The alternative interpretation, i.e., that in both experiments only relative codes were formed, but those of Experiment 2 were achieved more easily because the two positions were farther apart and/or crossed the midline, can be discarded since previous experiments have shown that for relative codes neither the distance (Nicoletti & Umiltà, 1984) nor the crossing of the midline (Nicoletti et al., 1982; Umiltà & Nicoletti, 1985) matters. In brief, it can also be concluded that the side undergoes a right-left coding, which can be used for mapping stimuli into responses and consequently causes spatial compatibility effects.

In this experiment there was also a significant main effect of delay, $F(1,11) = 118.28$, $P < 0.001$, which confirmed that RT was faster if there was an interval between the boxes and the stimulus (310 vs 377 ms). Another significant source was the interaction between the side and relative position [$F(1,11) = 19.75$, $P < 0.005$]. It showed that RT was about 12 ms faster for stimuli presented within the inner than the outer boxes. This is understandable if one considers that retinal acuity decreases towards the periphery. It is not clear, however, why this effect was not present in Experiment 1.

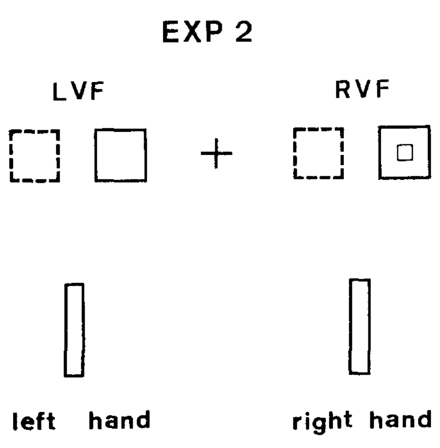

Fig. 2. Schematic diagram of the stimulus display and response keys for Experiment 2. In the delay condition the four boxes preceded the stimulus by 500 ms. The stimulus was always shown in one of the *solid boxes*. The *dashed boxes* marked the relative positions

Experiment 3

Experiments 1 and 2 showed that both kinds of right-left codes can be utilized for mapping stimuli onto responses. In the following three experiments, the time course of the two coding processes was manipulated to test whether differential timing influenced their role in producing compatibility effects.

Remember that the hypothesis is that only the stimulus coding that occurs while the response code is in the process of being formed can be effective. In Experiments 3, 4, and 5, the stimulus property relevant for selecting the response code was shape (i.e., the situation was paradigmatic of the Simon effect), and there was no apparent reason why the subject should process the position of the stimulus. In contrast, in the two preceding experiments the subject was explicitly required to process the relative position of the stimulus (Experiment 1) or the side (Experiment 2) in order to choose the correct response.

Method

Subjects. Twelve new students participated in exchange for a small fee.

Apparatus and display. These aspects were identical to those in Experiment 1, the only difference concerning the display (see Figure 3). There were two stimuli instead of one: a square (0.25 × 0.25 deg) and a rectangle (0.25 × 0.75 deg).

Procedure. There was only one difference with respect to that of Experiment 1. Half of the subjects were instructed to use the right key when the rectangle was shown and the left key for responding to the square, whereas the other half were given the reverse assignment. The instructions made it clear that neither side nor relative position was of any relevance for choosing the correct response.

Results and discussion

Accuracy was somewhat lower than in the previous experiments, but errors (about 7% overall) were nearly evenly distributed among conditions and were not analyzed. The increase in error rate was undoubtedly due to the rather difficult pattern discrimination the subject had to show.

Mean correct RTs were entered into the usual four-way repeated-measures analysis of variance. The main effects of delay [F (1,11) = 127.97, P < 0.001], stimulus side [F (1,11) = 20.41, P < 0.001], and stimulus relative position [F (1,11) = 34.12, P < 0.001] were all significant.

Again the 500 ms delay yielded a substantial shortening of RT (468 vs 539 ms). The finding that RT was faster on the right than the left side (499 vs 509 ms) might corroborate the notion of a preferential tendency to orient attention toward the right side or, alternatively, might indicate a left-hemispheric specialization for that kind of pattern discrimination [see Umiltà & Nicoletti (1985), who discussed a similar finding and favored the attentional explanation]. Note, however, that an attentional bias does not explain why the tendency did not manifest itself in Experiments 1 and 2, whereas an explanation in terms of hemispheric specialization encounters no difficulties because in those experiments no pattern discrimination was required. There is no apparent explanation for why RT was faster in the right than the left relative position (again, 499 vs 509 ms), a finding not replicated in any other experiment. Stimulus side interacted significantly with stimulus relative position [F (1,11) = 68.37, P < 0.001]. As expected, the stimuli closer to fixation were responded to about 27 ms faster than the more peripheral ones. This effect is no doubt attributable to differential retinal acuity.

The most interesting finding was, however, the significant three-way interaction (see Table 1) that regarded delay, stimulus relative position, and response position [F (1,11) = 8.02, P < 0.025]. It showed that in the delay condition there was a compatibility effect of about 21 ms: The stimuli presented in the right relative position were responded to faster by the right than the left key, whereas the reverse happened for the stimuli presented in the left relative position (448 vs 475 ms and 468 vs 483 ms, respectively; both P < 0.05). In contrast, in the absence of the delay there was no compatibility effect (the difference between compatible and incompatible RT was less than 2 ms overall). It must be pointed out that there was not even a hint of significant interactions involving the side of the stimulus and response position (F < 1.32).

When the two boxes precued the side of the stimulus, there was time for that code to be completed before the response code began to be formed [see Simon et al. (1976 a), who found that compatibility effects disappeared if the response was delayed between 250 and 350 ms]; therefore, as predicted, this type of code did not affect RT. On the contrary, the coding of relative position could not begin until the stimulus was shown; hence it was formed simultaneously with the response code and, as predicted, brought about clear-cut compatibility effects. Probably what happened was that the two boxes directed the subject's attention to the side where the stimulus was going to appear and this, in turn, caused the side to be automatically encoded while the relative position was left unspecified. It

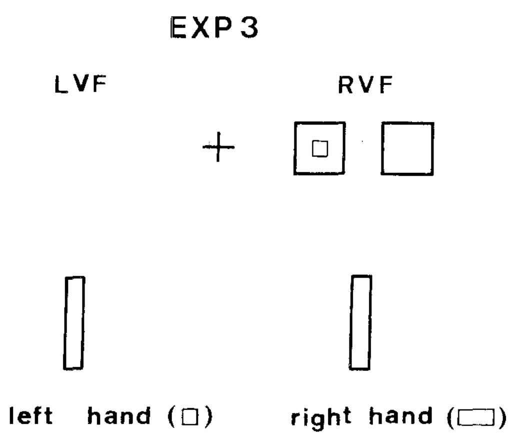

Fig. 3. Schematic diagram of stimulus display and response keys for Experiment 3. There were two stimuli

Table 1. Experiment 3: Mean RT in milliseconds as a function of delay, stimulus relative position, and response position

Delay condition	Stimulus	
	Right	Left
Response Right	448	483
Response Left	475	468
No-delay condition	**Stimulus**	
	Right	Left
Response Right	546	542
Response Left	537	530

must be stressed that we are not suggesting that the side was coded through an attentional process, as is the case of spatial compatibility proper. We suggest instead that it was the orienting of attention that brought about automatic coding of the side.

Admittedly, the compatibility effect found here was smaller than that observed in the two previous experiments. This difference in magnitude, however, was to be expected because it is known that spatial compatibility proper, that is, that measured in Experiments 1 and 2, is larger than the Simon effect, that is, that measured in the present experiment (e.g., Nicoletti et al., 1982; Umiltà & Nicoletti, 1985).

The absence of the Simon effect in the no-delay condition merits careful consideration because it represents a most unusual finding. To the best of our knowledge, this is the first time that the Simon effect failed to manifest itself, despite the fact that positional cues were clearly available for both stimuli and responses.

There can be little doubt that the reason for the disappearance of the effect is to be found in those features that differentiated the present experiment from all the previous ones. One such feature is that here the two relevant positions were specified, among four possible ones, only when the stimulus was shown. This could have prevented the formation of relative positional codes. However, this explanation can be rejected because in other experiments (Nicoletti & Umiltà, in preparation) the Simon effect could be observed even though the two relevant positions were specified upon stimulus presentation among up to six possible positions.

The other possibility is that our experimental manipulations were successful in providing two independent pairs of right-left codes. In other words, the Simon effect vanished in the no-delay condition because both side and relative position were coded simultaneously and independently when the response code was being formed. Possibly the subject did not have enough time to direct attention to the cued side and because of this the side could not be coded in advance, as instead happened in the delay condition.

It is difficult to be specific about the mechanism that caused the disappearance of the Simon effect. An obvious possibility is that the two coding operations yielded conflicting outcomes and the effects cancelled each other out. Alternatively, it might be that the conflict resulted in a delay in the formation of the codes and the response, being determined by shape only, was emitted before any of them became available. However, the codes for the side and relative position were in conflict only for the inner boxes, whereas they were congruent for the outer boxes. In spite of that, no interaction was found that supported such a differential effect.

In conclusion, we believe that the absence of the Simon effect is so unusual as to be taken in itself as evidence in favory of two independent coding operations, even though we cannot be explicit about the mechanism involved. It is important to note that in Experiment 1, in which experimental conditions were identical, spatial compatibility proper was also present in the no-delay condition. No doubt this was because in the case of spatial compatibility proper, the task required that one type of code be formed (i.e., that concerning relative position) through an attentional process in order to guide the selection of the correct response.

Experiment 4

In a certain sense, this experiment was the mirror-image version of the previous one. Whereas in Experiment 3 the stimulus side could be coded prior to, and stimulus relative position along with, response position, in Experiment 4 the opposite happened: Stimulus relative position could be coded before response position, and stimulus side was coded simultaneously with response position. Therefore, we predicted compatibility effects attributable to side but not to relative position.

Method

Subjects. Twelve new subjects took part in the experiment in exchange for a small fee.

Apparatus and display. These were the same as described for Experiment 2 (see Figure 4), with the exception that the stimuli were the two patterns employed in Experiment 3.

Procedure. The timing of the events was the same as in Experiment 1, while the instructions used were those given in Experiment 3. It is worth noting that, as in Experiment 2, the subjects were fully informed of the fact that the stimuli could appear only within the boxes with solid contours and the two boxes with broken contours were simply meant to mark the relative positions. For instance, in the example given in Figure 4, with the delay, the subject knew in advance that the stimulus was going to appear in the right relative position. What was uncertain was whether it was to be shown to the right or left side of fixation.

Results and discussion

The errors (again about 7% overall) were evenly distributed among the conditions and were not analyzed. Mean correct RTs were entered into an analysis of variance with the usual four factors, and three sources proved significant. The main effect of delay, $F(1,11)=122.59$, $P<0.001$, showed that RT was much shorter with than without delay (445 vs 516 ms). The interaction between stimulus side and stimulus relative position, $F(1,11)=158.12$, $P<0.001$, showed that the stimuli closer to fixation were responded to about 20 ms faster than the more peripheral ones.

More interestingly, there was also the expected interaction regarding delay, stimulus side, and response position, $F(1,11)=21.59$, $P<0.001$. The figures of this interaction

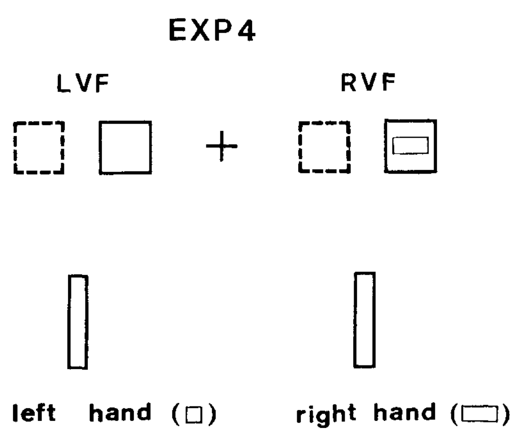

Fig. 4. Schematic diagram of stimulus display and response keys for Experiment 4

Table 2. Experiment 4: Mean RT in milliseconds as a function of delay, stimulus side, and response position

Delay condition		Stimulus	
		Right	Left
Response	Right	427	453
	Left	457	442
No-delay condition		**Stimulus**	
		Right	Left
Response	Right	513	521
	Left	516	517

can be seen in Table 2. With the delay there was a compatibility effect of about 21 ms due to stimulus side: The stimuli presented on the right side were responded to faster by the right than the left key, whereas the reverse was true of the stimuli presented on the left side (427 vs 457 ms and 442 vs 453 ms, respectively, both $P<0.01$). On the other hand, without delay there was no compatibility effect (the difference between compatible and incompatible trials was very close to 0). It is important to note that there was no compatibility effect attributable to the coding of stimulus relative position, as attested by the nonsignificant interactions involving stimulus relative position and response position ($F<1.12$).

Let us consider the results of the delay condition first. If one accepts that the broken boxes were effective in providing information about relative position, then it is apparent that our prediction was fully confirmed. This time the delay allowed the advance coding of stimulus relative position; hence this kind of code did not influence the speed of response. The coding of the stimulus side instead took place while the response code was formed; hence it affected the response latency and brought about clear-cut compatibility effects.

This interpretation, however, is open to the same criticism we considered where dicussing the results of Experiment 2: It could be that the subject managed to filter out the broken boxes and, by doing so, confounded the side and relative position. In other words, one can argue that the two broken boxes did not provide any positional information and, here, as in the delay condition of Experiment 3, what mattered was relative position. Note also that now the small and nonsignificant advantage in overall RT of Experiment 4 over Experiment 3 (480 vs 504 ms) does not tell us much about the codes because they did not determine the response as they did in Experiments 1 and 2.

We must turn to the no-delay condition to find evidence that the side and relative position were coded independently. If the positional information supplied by the broken boxes had been eliminated, this condition should have become identical to those of all previous experiments, in which a clear-cut Simon effect was found. In contrast, here there was no trace of such an effect.

It is true that there were four possible positions and that the relevant two were specified only upon stimulus presentation. Yet, as already pointed out in discussing the results of Experiment 3, the available empirical evidence is against the possibility that the number of stimulus positions influenced the Simon effect (Nicoletti & Umiltà, in preparation). Al considered, the best explanation for the disappearance of the Simon effect in the no-delay condition seems to be (as in Experiment 3) that of the simultaneous availability of two independent pairs of right-left positional codes.

One could still argue that the focusing of attention on the continuous boxes and/or the filtering out of the broken boxes took time and could be achieved only in the delay condition. However, this interpretation can be very easily translated into the coding hypothesis. Since the stimulus could appear only within one of the continuous boxes, the subject focused attention on them and, by doing so, automatically coded the pre-cued relative position, while leaving the side unspecified. In the delay condition in Experiment 3, however, the opposite occurred: The subject coded the side in advance by directing attention to the pre-cued side and left the relative position unspecified.

We do not mean to imply that the pre-cued location, whether side or relative position, was coded attentionally. We simply mean that, in the delay condition, the subject focused attention on the two relevant positions and, because of that, automatically coded the side (Experiment 3) or relative position (present experiment). In contrast, in the no-delay condition there was not enough time to focus attention on the relevant positions, and no right-left code could be formed in advance. Therefore, both codes became automatically available along with the response code. Recall also that in the identical no-delay conditions of Experiments 1 and 2 the effect of spatial compatibility proper did not vanish because the procedure forced the subject to process attentionally one of the two types of right-left positional cues, namely, the relative position (Experiment 1) or side (Experiment 2).

Having said all that, we must concede that, while invoking the absence of the Simon effect to support the notion of independent coding of both pairs of positional cues, we have no specific suggestion as to why the effect disappeared, apart from those discussed and rejected for Experiment 3.

Experiment 5

This experiment differed from all the previous ones because both the stimulus side and relative position were precued in the delay condition. If one considers that in Experiment 3 and 4 compatibility effects were absent for those stimulus codes that were formed prior to that of the response, it is logical to predict that now no compatibility effects should be found in either the delay or the no-delay condition. This is because in the former there should be time for both stimulus codes to be achieved prior to the coding of the response position, and in the latter, as in the two preceding experiments, the two independent codes should have no effect on RT.

The rationale of Experiment 5, therefore, implied acceptance of the null hypothesis, but this problem did not seem serious since very similar experimental conditions had yielded reliable compatibility effects in all of the preceding experiments.

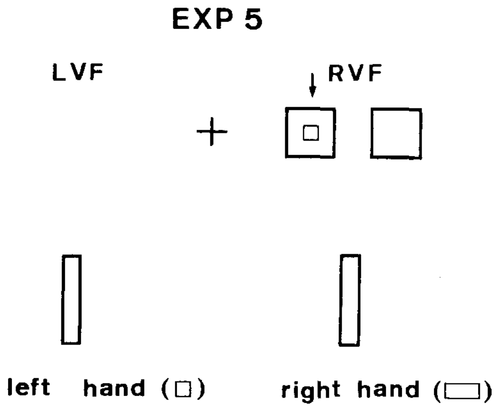

Fig. 5. Schematic diagram of stimulus display and response keys for Experiment 5. The *arrow* indicated the box in which the stimulus was to be shown. In the delay condition the two boxes and arrow preceded the stimulus by 500 ms

Method

Subjects. An additional 12 paid subjects participated.

Apparatus and display. These were the same as in Experiments 1 and 3, with the exception of an arrow that precued the relative position of the stimulus by pointing towards one of the two boxes, the one where the stimulus was to appear (see Figure 5). Therefore, in the delay condition, the stimulus side was precued by the two boxes, while the relative position of the stimulus was precued by the arrow. In other words, there was no uncertainty whatsoever about the location of the stimulus. Of course, the stimulus shape was not known in advance and so the response code could not be formed prior to stimulus presentation.

Procedure. The procedure was the same as that already described for Experiment 3. The subjects were fully informed of the fact that the stimulus could appear only within the box indicated by the arrow.

Results and discussion

Errors were fewer than in the two previous experiments (about 3% overall), probably because of the exhaustive precuing of stimulus location, and were not analyzed. The usual analysis of variance was instead performed on mean correct RTs, and three main effects as well as one interaction proved significant.

Not surprisingly, delay [$F(1,11)=106.60$, $P<0.001$] speeded up RT (394 vs 465 ms). The main effect of stimulus side [$F(1,11)=9.25$, $P<0.01$], showed that RT was faster on the right than on the left side (426 vs 433 ms). As already pointed out, this might be due to either a propensity to orient attention to the right side or to a hemispheric specialization for discriminating between the two patterns. At any rate, it appears that the right-side advantage comes and goes without any apparent reason. The main effect of response position [$F(1,11)=17.35$, $P<0.005$] showed that RT was faster with the right than the left key (421 vs 438 ms). There does not seem to be any obvious explanation for this difference either: While it is true that the subjects were all right-handed and so a right-hand advantage might be conceivable, it is also true that right-handers were tested in the other experiments where the effect was absent.

The most important finding was the absence of any compatibility effect, as attested by the nonsignificance of all interactions involving stimulus relative position and response position or stimulus side and response position (all $F<2.06$). In the absence of the delay, this negative finding corroborated those for Experiments 3 and 4. After three converging results there can be little doubt that the two independent ways of coding the stimulus spatially yield a null effect on RT. Of greater interest was the lack of compatibility effects in the delay condition, a finding that was unique to the present experiment. It supported the prediction that those stimulus codes that are completed before the process of forming the response code has begun cannot influence response latency. Again, it can be suggested that both codes were formed in advance because the subject had time to focus attention on the only relevant position, as opposed to two positions in Experiments 3 and 4.

Conclusions

In the present study we assumed, in accordance with previous studies (Brebner, 1973; Brebner et al., 1972; Nicoletti et al., 1982; Nicoletti et al., 1984; Umiltà & Nicoletti, 1985; Wallace, 1971, 1972), that spatial compatibility is due to the comparison of the codes that describe the position in space of the stimulus and the response [but see the work by Simon and colleagues for a different hypothesis (e.g., Simon, 1969, 1982; Simon et al., 1975, 1976 a)] and tried to determine how those codes are formed. This question seemed interesting because there are two spatial codes for classifying the position of either stimulus or response along the right-left dimension. One code is formed with relation to some egocentric reference axes, which are usually aligned. We have used the term *side* for this egocentric code. The second code is formed with relation to the other stimulus and response. The term used here for this environmental code was *relative position*. It is clear that each code, if consistently applied to the description of the spatial characteristics of the stimulus and the response set, is apt to lead to an unambiguous identification of a right or left stimulus and a right or left response. Therefore, both codes could in principle bring about compatibility effects.

The few experiments (Nicoletti et al., 1982, 1984; Umiltà & Nicoletti, 1985) that disentangled side and relative position demonstrated that the coding of relative position was only responsible for spatial compatibility effects. The demonstration of the role of relative position was important in itself because it supported the notion that spatial compatibility is due to the comparison of S-R spatial codes (Nicoletti et al., 1982; Wallace, 1971) and disproved the view that attributed it to an attentional and/or response bias (Simon, 1969; Heilman & Valenstein, 1979). However, the finding that the coding of stimulus side had no role in spatial compatibility runs counter to the well-established fact that the relationships between the side of stimulation and side of response affect RT (e.g., Bradshaw, Nathan, Nettleton, Pierson, & Wilson, 1983; Pierson, Bradshaw, & Nettleton, 1983).

The experiments reported here clarified this issue by showing that upon stimulus onset, both spatial codes, that is the one regarding side and the one regarding relative position, were formed; however, experimental manipulations could determine which code caused the compatibility effects. These experimental manipulations were the task demands and the time that elapsed between the moment the stimulus code became available and when the response code was formed. It is important to keep in mind that the task demands also determined whether the phenomenon under consideration was spatial compatibility proper or the Simon effect.

First, let us consider spatial compatibility proper. When the task required that the stimuli were mapped onto the responses on the basis of relative position, then spatial compatibility proper depended on the relative codes and the side had no effect (Experiment 1). Conversely, if the S-R pairings were defined on the basis of side, then spatial compatibility proper depended on the egocentric codes and the relative position was not effectual (Experiment 2). This was true regardless of the time interval between the spatial cues and the command stimulus. The differential consequences of the two kinds of coding on spatial compatibility proper are likely to be due to the difference between controlled, attentional processes and automatic, nonattentional processes (e.g., Schneider, Dumais, & Shiffrin, 1984; Shiffrin & Schneider, 1977). The stimulus code required for selecting the correct response was no doubt achieved through a controlled process, whereas the non-relevant one was achieved automatically. It thus seems that the outcome of a controlled process prevailed over the outcome of an automatic process.

Let us now consider the Simon effect, where both kinds of spatial coding took place automatically because neither was relevant for selecting the correct response. For clarity, it is preferable to discuss first what happened when the two coding processes were separated in time. The crucial factor was the type of stimulus coding that took place simultaneously with the coding of the response position. If the side was coded in advance, whereas stimulus relative position and response position were coded at the same time, then the Simon effect was due to relative position alone (Experiment 3). Conversely, if it was the relative position that was coded prior to stimulus presentation, whereas information concerning side became available upon stimulus presentation, then the Simon effect was due to the side alone (Experiment 4). If information about both the relative position and side could be processed prior to stimulus onset, then the Simon effect was absent (Experiment 5). It might be suggested that the automatic coding of the precued positions occurred because the subject focused attention on the positions where the stimulus was to be presented.

Something different happened when both codes were formed simultaneously: The outcome of the two independent coding processes was the absence of the Simon effect (Experiments 3, 4 and 5, no-delay condition). Even though no convincing explanation could be offered, the phenomenon was considered to be of great importance in itself because this was the only case in the literature in which the Simon effect did not occur, despite the fact that the response code was defined in right-left terms and right-left stimulus cues were clearly available.

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