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The role of attention for the Simon effect

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Summary. It has been claimed that spatial attention plays a decisive role in the effect of irrelevant spatial stimulus–response correspondence (i.e., the Simon effect), especially the way the attentional focus is moved onto the stimulus (lateral shifting rather than zooming). This attentional-movement hypothesis is contrasted with a referential-coding hypothesis, according to which spatial stimulus coding depends on the availability of frames or objects of reference rather than on certain attentional movements. In six experiments, reference objects were made available to aid spatial coding, which either appeared simultaneously with the stimulus (Experiments 1–3), or were continuously visible (Experiments 4–6). In contrast to previous experiments and to the attentional predictions, the Simon effect occurred even though the stimuli were precued by large frames surrounding both possible stimulus positions (Experiment 1), even when the reference object's salience was markedly reduced (Experiment 2), or when the precueing frames were made more informative (Experiment 3). Furthermore, it was found that the Simon effect is not reduced by spatial correspondence between an uninformative spatial precue and the stimulus (Experiment 4), and it does not depend on the location of spatial precues appearing to the left or right of both possible stimulus locations (Experiment 5). This was true even when the precue was made task-relevant in order to ensure attentional focusing (Experiment 6). In sum, it is shown that the Simon effect does not depend on the kind of attentional operation presumably performed to focus onto the stimulus. It is argued that the available data are consistent with a coding approach to the Simon effect which, however, needs to be developed to be more precise as to the conditions for spatial stimulus coding.

Introduction

The Simon effect is characterized by the dependency of reaction time (RT) on task-irrelevant spatial correspondence of stimulus and response (e.g., Simon & Rudell, 1967). Suppose a subject is required to press a left-hand key in response to an X and a right-hand key in response to an O. The stimuli are presented randomly to the left or right side of a fixation point. Although the subject is instructed to ignore stimulus location, left-hand responses will be faster to an X on the left than to an X on the right, and right-hand responses will be faster to an O on the right than to an O on the left.

It was Simon himself who put forward the first attentional approach to the effect which was later on named after him. Simon (1969) proposed a primitive tendency to react toward the source of stimulation, a kind of orienting reflex (Sokolov, 1963), which facilitates actions towards, and interferes with actions away from the stimulus. Meanwhile, Simon has couched his approach in information-processing terms and views the Simon effect as a stimulus-induced bias in response selection (Mewaldt, Connelly, & Simon, 1980; Simon, 1990; Simon, Acosta, Mewaldt, & Speidel, 1976).

Empirical evidence of a perhaps critical role of spatial attention in the Simon task has been found by Nicoletti and Umiltà (1989). In their study, stimuli were presented in various spatial positions to the left and right of the subjects' focus of attention, the position of which was directed by peripheral or central cues. Regardless of fixation, left-hand responses were faster to stimuli to the left of the focus and right-hand responses were faster to stimuli to the right of the focus. According to the authors, these results suggest that the focus of spatial attention serves as a reference point for a left–right subdivision of space and, thus, determines whether a given left-hand or right-hand response is facilitated or impaired by the spatial position of a given stimulus.

Recently, Stoffer (1991) has proposed a more theoretically based attentional approach to the Simon effect, according to which a stimulus has to be attentionally focused before stimulus analysis can begin. In the Simon task, this is done by a lateral shift of spatial attention from a starting (e.g., fixation) point to stimulus location. In order to control this attentional shift, a spatial code has to be generated referring to the position of the stimulus in relation to the location last attended. The Simon effect is assumed to arise because the response-controlling action plan has to be specified by a spatial code as well, which in this case refers to response or key location. Thus, the spatial code, which controls the attentional shift, may intrude into action planning by unintentionally preselecting the right or wrong response, depending on spatial correspondence or noncorrespondence of stimulus and response.

According to this view, the Simon effect should disappear if only a lateral shift of spatial attention towards the stimulus is prevented. This is indeed what Stoffer (1991) found. He attempted to prevent lateral attentional shifts by not providing a visual "anchor" in between the two stimulus locations (e. g., a fixation point) which could be focused before the stimulus was presented. Instead, a large frame surrounding both stimulus locations appeared before, or simultaneously with, the stimulus. Thus, focusing the stimulus did not require a lateral attentional shift but, in Stoffer's words, attentional "zooming" into the visual structure consisting of the frame and the stimulus. Since zooming is assumed to be controlled by a spatially neutral code, no Simon effect was predicted, and, in fact, none was found.

Stoffer's theoretical approach is not only consistent with his own results but can also be used to explain, as he does, the disappearing of the Simon effect in similar experiments by Umiltà and Liotti (1987), who themselves did not find a satisfying explanation of their results. Thus, a comprehensive theoretical account of the Simon effect may have to consider voluntary attention as a constituting factor. However, the available data do not allow for an unequivocal determination of the role attention may play in the emergence of the Simon effect, since at least two different interpretations of the available data are possible.

According to the first interpretation, already mentioned, which will be referred to as the *attentional-movement hypothesis*, the Simon effect is bound to a certain "movement" of spatial attention and caused by some processes necessary for programming this movement. Shifting the attentional focus to the left somehow leads to preselection of a left-hand response, while a right attentional shift leads to preselection of a right-hand response. According to this view, it is not a feature of the stimulus or its spatial relation to the response that is responsible for the Simon effect. Conversely, since it is only the direction of the attentional shift and its relation to the response that matters, the actual spatial position of the target stimulus (whether absolute or relative to some other object) should be completely irrelevant. If this were true, the Simon effect would arise from (non-)correspondence between the attentional shift's direction and the response location, but not – as is commonly assumed – from spatial (non-)correspondence between stimulus and response.

According to the second interpretation, which will be referred to as the *referential-coding hypothesis*, the stimulus code is not spatially coded in reference to, or depending on, the focus of spatial attention, but in reference to an intentionally defined object or frame of reference (or several of them). To be sure, the location of a reference object may often serve as a point of departure for explorational shifts of the attentional focus. For example, in the study of Nicoletti and Umiltà (1989), stimuli may not have been coded in relation to the focus of spatial attention, but in relation to a certain reference object that also happened to be the object to which spatial attention was currently directed. From this view, it also comes as no surprise that lateral stimulus coding (and, as a consequence, the Simon effect) can be prevented by the substitution of a central object or field by a frame surrounding both possible stimulus positions, as in Stoffer's (1991) study. In this case there is simply no central object that could be selected for referential coding of left and right stimuli. That is, while both stimulus coding and the directing of spatial attention may depend on an intentionally defined object or frame of reference (or several of them), spatial coding need not necessarily depend on spatial attention.

The purpose of the present study was to find empirical evidence that permits a decision between the attentional-movement hypothesis and the referential-coding hypothesis. The first three experiments all followed the same strategy. On the one hand, a design was chosen that renders a Simon effect impossible, provided that the attentional-movement hypothesis holds. On the other hand, additional coding aids were made available so that a Simon effect should be obtained, provided that the referential-coding hypothesis holds. In three further experiments, it was attempted not to prevent lateral attentional shifts, but to control their direction by preexposing attention-capturing lateral cues.

Experiment 1

In the study of Stoffer (1991: Experiment 1, large-cue condition), each target (i. e., command) stimulus was preceded not by the usual fixation point or by adjacent boxes, but instead by a large frame surrounding both possible stimulus locations. It was assumed that thus spatial attention would be attracted by the frame, that is, directed to a rather global representational level (Navon, 1977; Stoffer, 1988; Wandmacher & Arend, 1985). On presentation of the target, a common stimulus structure would be formed out of the target and the surrounding frame. This structure is assumed to be hierarchically represented, just like an object (frame) and a part of it (target stimulus). Thus, to focus onto the target stimulus proper, spatial attention would not need to be shifted horizontally but zoomed into the visual structure. The attentional shift would then not be performed from one object to another on the same representational level, but from a more global level to a hierarchically subordinate one instead. Since the Simon effect did not appear under these conditions, it may be concluded that the Simon effect does depend on a horizontal shift of the attentional focus.

A horizontal (within-level) shift of spatial attention logically requires at least two objects which are presumably represented on the same representational level. Note that the availability of more than one object is also required from a referential-coding hypothesis because an object has to be related to another in order to compute a spatial relation. The attentional-movement hypothesis, however, pos-

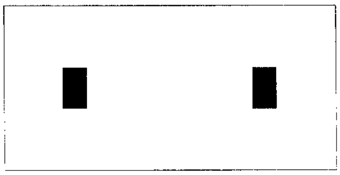

Fig. 1. Schematic diagram of the stimulus display in Experiment 1. The two rectangles (target stimulus and reference object) actually differed in color

tulates a second precondition for a Simon effect to occur, which is not necessary from a referential coding view, namely that spatial attention is really shifted from one of these objects to the other. Because both hypotheses share the assumption of multiple objects, a decision between them has to focus on the dependency of the Simon effect on attentional movements.

The design of the present experiment was similar to that of Stoffer (1991: Experiment 1, large-cue condition, 500 ms), who found no evidence for a Simon effect with large preexposed frames. However, there were three modifications (see Figure 1). First, only relative stimulus position was varied, since in the Stoffer study the Simon effect did not interact with the side of stimulus presentation. Second, and perhaps more important, simultaneously with the target stimulus, a reference object appeared that was easily discriminable from both alternative target stimuli by its color. There were only two possible stimulus locations, so that each left-side target stimulus was accompanied by a right-side reference object and each right-side target stimulus was accompanied by a left-side reference object.

Reference objects were introduced to aid spatial-stimulus coding. As the results of Hommel (1993c) suggest, stimuli appearing inside a large free field may be mislocated, so that (some) left-hand stimuli would be erroneously perceived as being right-hand and vice versa. Under conditions of very low stimulus eccentricity, this may even result in a complete disappearance of the Simon effect (Hommel, 1993c: Experiment 2), presumably because localization becomes random. Since, in the present study, presentation of a fixation point had to be avoided for theoretical reasons, other ways to ensure proper spatial coding were required.

A third modification resulted from considerations based on findings from visual search. In search tasks, single-feature targets (i.e., stimuli that are discriminable from their visual context on a single feature dimension) are commonly distinguished from conjunctive targets (i.e., stimuli differing from context only by a specific combination of features). It is well established that reaction times for single-feature searches (e.g., a red X among green Xs) do not systematically depend on the number of distractors, while reaction times for conjunction searches (e.g., a red X among green Xs and red Os) do (e.g., Quinlain & Humphreys, 1987; Treisman & Gelade, 1980). This suggests that a serial component is involved in conjunction, but not in single-feature search.

It is relevant to the present study that in both experiments in which no Simon effect was found with simultaneous presentation of cueing frames and stimuli (Stoffer, 1991; Umiltà & Liotti, 1987), the stimuli were conjunctively defined, that is, were discriminable from each other and from the cue only regarding the combination of their features. For example, one stimulus was a square that differed from the alternative stimulus in width only and from the cues in surface area only, while stimuli and cues were indistinguishable in terms of simple features (e.g., horizontal and vertical lines). Thus, the subjects actually had to solve conjunction-search tasks in these studies that might have induced special coding strategies not needed in a standard Simon task. This is suggested by results of Lamberts, Tavernier, and d'Ydewalle (1992), and of Hommel (1993a), who obtained normal Simon effects by using easily discriminable single-feature target stimuli in experiments that were otherwise very similar to the studies of Stoffer and of Umiltà and Liotti.

Thus, it is reasonable to assume that the specific combinations of stimuli and cues chosen by Stoffer and by Umiltà and Liotti were of critical importance in their failure to find a Simon effect. In our experimental series we were not concerned with the question why the Simon effect did not appear in these studies, but rather whether an attentional approach is tenable in general and, specifically, whether certain attentional movements are necessary for a Simon effect to occur. For this reason, exclusively single-feature (i.e., color) stimuli were used. Our choice would not have been of critical importance for any really general theory of the Simon effect – which the current attentional approaches of course claim to be – because Simon effects have mostly been found and investigated by the use of single-feature stimuli (e.g., Craft & Simon, 1970; Hedge & Marsh, 1975; Simon & Small, 1969). Therefore, any reasonable explanation of the Simon effect must be applicable to every kind of single-feature stimulus.

Following the attentional-movement hypothesis, no Simon effect – that is, no interaction of stimulus location and response location – is expected in Experiment 1. According to Stoffer (1991), spatial attention would be drawn first to the preexposed frame and then, at the timepoint of stimulus presentation, zoomed into the visual structure now consisting of both frame and stimulus. In contrast to lateral shifts, zooming is not assumed to be controlled by parameters in left/right terms and thus should not interfere with left-hand or right-hand responses. That is, the preconditions for the occurrence of the Simon effect are not met. At first sight, one would not assume that the addition of a discriminable reference object should change anything in this picture, except that the emerging visual structure would be somewhat more complex. (Second-sight considerations as to this aspect will be mentioned in the Discussion). Conversely, according to the referential-coding hypothesis, the addition of a reference object should be crucial. As this modification makes a same-level object available for use to compute the relative spatial code of the accompanying target stimulus, a Simon effect is clearly predicted, no matter which kind of precue is presented. In sum, the presence of a Simon effect would lend some support to the referential-coding hypothesis, while its absence would further strengthen the attentional-movement hypothesis.

Method

Subjects. Ten female and five male subjects aged 21 – 33 years took part for pay. All had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Apparatus. The same apparatus was used throughout Experiments 1 – 6. Stimulus presentation and data acquisition were controlled by a Hewlett Packard Vectra RS20 computer. The stimuli were presented on an Eizo VGA monitor on a dark background. Responses were made by pressing the left or right SHIFT key on the computer keyboard with the corresponding index finger.

Stimuli. The precue was a thin 4.3°- wide and 2.0°-high rectangular frame surrounding both possible stimulus locations. The reference object and the target stimuli were 0.3° × 0.6° solid rectangles, appearing 1.1° to the left or right of the center of the screen. The precue frame was white (114 cd/m^2), the reference object was gray (42 cd/m^2), and the target stimuli were green (26 cd/m^2) and red (12 cd/m^2).

Procedure. The experiment took place in a dimly lit room. Subjects were instructed to press the left-hand key in response to the red target stimulus and the right-hand key in response to the green target stimulus. The sequence of events in each trial was as follows. After an intertrial interval of 2,000 ms, the precue frame was presented alone for 500 ms. Then one of the target stimuli and the reference object appeared inside the frame and stayed on the screen for 150 ms, after which the screen went blank. Each target stimulus was accompanied by a reference object that occupied the alternative position – that is, a left-side stimulus was accompanied by a right-side reference object and a right-side stimulus was accompanied by a left-side reference object. The next intertrial interval began as soon as the response was given, but no later than after 1,000 ms. In case of an error, a short auditory feedback was inserted. Subjects could delay the next trial by holding the key pressed down if they felt confused or inattentive.

The experiment was run in single sessions lasting about 30 min. A session was composed of 6 warming-up blocks and 48 experimental blocks. Each block consisted of four randomly mixed trials, whose type resulted from the factorial combination of target color (red or green) and side of target presentation (left or right). Responses with the wrong key were counted as errors and responses with latencies above 1,000 ms were considered missing. In both cases, the trial was recorded and then repeated at some random position in the remainder of the block.

Results

Responses faster than 180 ms (<0.5%) were considered as anticipations and excluded from analysis, as were missing trials (<0.5%). Valid and error trials were analyzed separately. For each subject, mean RTs and error rates were calculated for each combination of stimulus location and response location (i.e., stimulus color). A repeated-measurement analysis of variance (ANOVA) of mean RTs revealed a highly significant interaction of stimulus location and response location, $F(1,14) = 23.29$, $p < .001$. Left responses were faster to left than to right stimuli (473 vs. 497 ms), while right responses were faster to right than to left stimuli (467 vs. 501 ms), thus amounting to a Simon effect of 29 ms. A similar ANOVA of the (root-transformed) error percentages gave rise to two effects. First, a significant main effect of response location, $F(1,14) = 8.46$, $p < .05$, indicated less frequent errors with the left as compared with the right response (3.2 vs. 5.7%). Second, there was a highly significant interaction of stimulus location and response location, $F(1,14) = 13.16$, $p < .005$. Errors were less frequent when the left response followed a left rather than a right stimulus (2.4 vs. 4.0%), and when the right response was to a right rather than to a left stimulus (3.4 vs. 8.0%).

Discussion

Obviously, the Simon effect shows up even under conditions that make lateral shifts of spatial attention unlikely. While supporting the referential-coding hypothesis, this result does not favor the attentional-movement hypothesis. However, there may be two objections to this conclusion: these relate to the way we modified the experimental design used by Stoffer (1991). First, it is possible that attention is only attracted by a preexposed frame when the side of presentation varies, as was the case in Stoffer's experiment, but not in the present one. This hypothesis will be discussed later and was tested in Experiment 3. Second, it may have been difficult or impossible to zoom directly from the more global frame level onto the target stimulus. The reference object could have been too salient to avoid zooming onto it first and only then shifting laterally to the target proper. If this were the case, a right-side target stimulus would always have been approached by a rightward attentional shift coming from the left-side reference object first attended to, while a left-side target would have been reached by a leftward attentional movement. That is, rightward attentional shifts would have preceded focusing right-side target stimuli and leftward attentional shifts would have preceded focusing left-side target stimuli. Because this is exactly what the attentional-movement hypothesis assumes to happen in a standard Simon task, the resulting effect would come as no surprise. Thus, in order to provide a fair test of the attentional-movement hypothesis, strict experimental control of the absolute and relative salience of the reference object is required.

Experiment 2

In this experiment, it was ensured that the target stimuli were much more salient than the accompanying reference objects. In Experiment 1, the stimulus serving as reference object was much brighter than either target stimulus, so that there is reason to assume that spatial attention has often, or always, been attracted by the reference object before the focus could have reached the target stimulus. Thus, it may be that target stimuli were brought into the focus by lateral shifts, but not by zooming. To rule out such

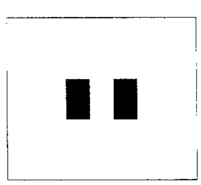

Fig. 2. Schematic diagram of the stimulus display in Experiment 2. The two rectangles (target stimulus and reference object) actually differed in color

an interpretation, the luminance of the reference object was drastically reduced in the present experiment. To retain good discriminability between the stimuli, the colors of target and reference stimuli were also changed.

Furthermore, the eccentricity of the targets was reduced (see Figure 2). This was to ensure that both reference object and stimulus were always projected to nearby retinal areas to provide for comparable color discrimination. From a referential-coding view, this manipulation should not matter as long as the spatial relations are discriminable and computable, since the spatial code of a given stimulus should depend on relative spatial position, but not on the distance between coded stimulus and reference object. Conversely, an eccentricity reduction could further favor the attentional-movement hypothesis by reducing the costs of possible misallocations of spatial attention to the location of the reference object. On the assumption that the attentional focus extends in space (e.g., Downing & Pinker, 1985; Eriksen & St James, 1986; Posner, 1980), the chances are good that an attentional focus erroneously shifted to the reference object also encompasses a target located near by. An additional lateral shift would then be superfluous, which again should lead to an elimination of the Simon effect. In sum, the experiment was modified to provide optimal conditions for the elimination of the Simon effect from an attentional-movement view. In all other respects, it was a replication of Experiment 1.

Method

Subjects. Six female and nine male subjects aged 21–31 years took part for pay. Again, all had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Stimuli. The precue frame was 2.6° wide and 2.4° high. The reference object and the target stimuli were of the same sizes as in Experiment 1, but appeared 0.1° to the left or right of the center of the screen. The precue frame was white (114 cd/m^2), the reference object was dark green (0.8 cd/m^2), and the target stimuli were blue (13 cd/m^2) and red (30 cd/m^2).

Procedure. The procedure was the same as in Experiment 1, with only one exception – that, here, left-hand responses were mapped onto the blue target stimulus and right-hand responses were mapped onto the red target stimulus.

Results

Valid, error, and missing trials (<0.5%) as well as anticipations (<0.5%) were treated as in Experiment 1. Again, a repeated-measurement ANOVA was performed on mean RTs and transformed error percentages. The RT data revealed two effects. First, right responses were significantly faster than left responses (404 vs. 415 ms). Second, the interaction of stimulus location and response location was highly significant, $F(1,14) = 149.64$, $p < .001$. Left responses were faster to left than to right stimuli (403 vs. 427 ms), whereas right responses were faster to right than to left stimuli (387 vs. 420 ms), thus amounting to a Simon effect of 29 ms. The error analysis yielded two effects, as well. First, right stimuli produced a highly significant lower error rate than left stimuli (2.0 vs. 2.8%), $F(1,14) = 13.66$, $p < .005$. Second, the highly significant interaction of stimulus location and response location, $F(1,14) = 26.40$, $p < .001$, indicated fewer left-hand errors following left as compared to right stimuli (1.1 vs. 3.5%), and fewer right-hand errors following right than left stimuli (0.4 vs. 4.5%).

Discussion

The results were clear-cut. Even with extremely reduced salience of the reference object and only a very small distance between reference object and target, a Simon effect showed up in response speed and in errors. Thus, the data do not justify the attempt to save the attentional-movement hypothesis by the application of a first-zooming-then-shifting hypothesis to the results of Experiment 1. In the present experiment, there is neither logical reason nor empirical evidence that the reference should have attracted attention first. Nonetheless, the size of the effect is identical to that in Experiment 1. Let us now consider the possibility that the variation of absolute position (i.e., side of presentation) is required for the elimination of the Simon effect with preexposed frames.

Experiment 3

In both of the preceding experiments only the relative stimulus position was manipulated (with side confounded). Because of this, the preexposed frame was much less informative than in Stoffer's (1991) experiment in which the side of presentation could vary from trial to trial. One may argue, therefore, that our subjects could have somehow managed not to focus on the more or less uninformative frame. If so, they may have focused their attention somewhere else before stimulus presentation, possibly on the center of the screen. This again would have led to conditions which – according to the attentional-movement hypothesis – are necessary for the Simon effect. That is, spatial attention would have been shifted laterally toward the target stimuli. Of course, this *ad hoc* assumption runs counter to the two main arguments of Stoffer (1991) that first, abrupt-onset stimuli attract attention not only automatically (cf., Lambert, Spencer, & Mohindra, 1987; Müller & Rabbitt, 1989; Posner & Cohen, 1984), but also at a global level (cf., Navon, 1977; Stoffer, 1988; Wandmacher & Arend, 1985) and that second, focusing is impossible without an object to be focused. Nevertheless, it was felt that the relevance of this methodical difference between the preceding experiments and the Stoffer study should be determined empirically. Therefore, Experiment 2 was replicated with an additional variation of presentation side.

Method

Subjects. Eight female and eight male subjects aged 18–50 years took part for pay. All had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Stimuli. These were as in Experiment 2, with only one exception. Instead of surrounding the center of the screen, the frame was presented with either its right or its left edge aligned to screen center, thus extending 2.6° to the left or to the right of the median plane. The target stimulus and the accompanying reference object always appeared inside the area surrounded by the preexposed frame, so that their spatial positions in relation to the frame were as in Experiment 2.

Procedure. The procedure was the same as in Experiment 2, with the following exceptions. Here, a session was composed of 3 warming-up blocks and 24 experimental blocks. Each block consisted of eight randomly mixed trials, whose type resulted from the factorial combination of target color (red or blue; i. e., left-hand or right-hand response), side of presentation (left of right; in relation to screen center), and relative spatial position of the stimulus (left or right in relation to frame center).

Results

Missing trials (<0.5%) and anticipations (<0.5%) were excluded from analysis. Mean RTs and error percentages were computed for each combination of stimulus/frame side (left or right in relation to screen center), relative stimulus position (left or right in relation to frame center), and response location (left or right). A $2 \times 2 \times 2$ ANOVA of mean RTs revealed only a highly significant interaction of relative stimulus position and response location, $F(1,15) = 27.72, p < .001$, while the remaining effects were far from significance ($.15 > p > .9$). Left responses were faster to left than to right stimuli (400 vs. 424 ms), and right responses were faster to right than to left stimuli (392 vs. 415 ms). Overall, this Simon effect amounted to 24 ms. The error analysis produced a very similar result pattern, in that there was only a highly significant interaction of relative stimulus position and response location, $F(1,15) = 33.50, p < .001$. Errors were less frequent with left responses to left than to right stimuli (2.7 vs. 7.9%) and with right responses to right rather than to left stimuli (3.1 vs. 9.5%).

Discussion

Again, a full-blown Simon effect was obtained under conditions that the attentional-movement hypothesis assumes to be favorable for its elimination. This time, the frame presented served as a completely valid spatial cue, so that there is every reason to assume that the subjects did attend to the frame before the stimulus was presented. Nonetheless, the results of Stoffer (1991) could not be replicated.

General discussion of Experiments 1–3

The first three experiments all followed the same rationale: provide coditions that require attentional zooming to focus onto the stimulus, but make sure that information about relative location is easily extractable. Their results seem to pose serious problems for an attentional-movement approach as put forward by Stoffer (1991). Contrary to attentional predictions, robust Simon effects occurred in all three experiments. Indeed, there is still a difference between our experiments and the otherwise mainly identical study of Stoffer, who successfully eliminated the Simon effect: spatial coding was aided by reference objects (and possibly by the choice of color stimuli) in our experiments, but not in Stoffer's. However, it is not easy to see why and how this difference should have made any change in the way attention is shifted or zoomed to extract stimulus information. But if it did not, we would have to conclude that the attentional-movement hypothesis is incorrect, at least in its current formulation.

Before rejecting the attentional-movement account altogether, let us consider two arguments that might be put forward in its support.[1] The first is based on the idea that attentional zooming may require directional (i.e., left/right) parametrization just as shifting does, despite Stoffer's (1991) claim of the contrary. The second argument questions whether the present experiment was successful in inducing zooming operations at all. I shall respond to these arguments in two ways, theoretically and empirically.

Suppose that even attentional zooming required directional parametrization. If this were the case, none of the manipulations in Experiments 1–3 would have been able to prevent stimulus coding in left/right terms because each attentional movement would require left/right parametrization, at least if the location attended to is not identical with stimulus location. In fact, no manipulation could. Thus, the Simon effect would have to be expected each time there is a lateral spatial distance between stimulus and current attentional focus. Since this description matches all of the previous experiments, the occurrence of the Simon effect would not require rejecting such a reformulated attentional-movement hypothesis.

Theoretically, it is important to see that the very need for a reformulation would entail acceptance of my main conclusion from the first three experiments. This conclusion is that an attentional-movement hypothesis cannot be maintained *in its current formulation*, that is, in the shape outlined by Stoffer (1991), which has been also partly subscribed to by Umiltà and Nicoletti (1992). Without any doubt, it is possible to tailor every kind of theory to fit any data, as long as *ad hoc* assumptions are allowed. However, since until now there has been no independent empirical evidence on the question of zoom parametrization, any assumption on that issue is possible, but is at the same time without a sound base. Even if such evidence were available, a reformulation of the attentional hypothesis would be indispensable.

Furthermore, the claim of directional zoom parametrization would lead to severe theoretical problems even for a reformulated attentional-movement hypothesis. For example, given that attention is directed to the whole frame in a spatial-cueing experiment and given that the stimulus appears inside of this frame, to which point in space should an attentional-zooming-in parameter refer? To allow for a Simon effect to occur, it must refer to the geometrical center of the frame (or some point nearby), because only

[1] These arguments were kindly brought to my attention by Carlo Umiltà and an anonymous reviewer.

then would the proper left/right coding of stimuli result. Let us assume that there is a reformulated attentional hypothesis that would indeed predict left/right stimulus coding in relation to the center of a frame. The problem would then be to explain the absence of the Simon effect in Stoffer's (1991) experiment. And it was this experiment that was performed to lay the empirical ground for an attentional approach to the Simon effect!

Obviously, accepting a zoom-parametrization view would mean that the attentional-movement approach would not be able to explain the results of a study that was conducted exclusively to demonstrate its very plausibility. Of course, as I have argued elsewhere (Hommel, 1993a), one could find a way out of this argumentative dilemma with the help of further *ad hoc* assumptions. However, even if we concede that we may always be able to think of *ad hoc* assumptions to save the attentional approach, up to now it does not seem to have been of very much help in predicting empirical results.

There is a second objection against the previous experiments. While we have still assumed that stimuli were focused on by zooming operations, just as in Stoffer's study, this may not have been the case. As has already been mentioned in the introduction to Experiment 1, there is indeed reason to suppose that color discrimination is much easier than form discrimination, at least under the specific display arrangement of Stoffer (1991), so that zooming may have been necessary in the Stoffer study, but not in the present experiments (Hommel, 1993a). Assuming that zooming did not occur in our experiments, could it not be argued that our results are in fact trivial and nicely predicted by exactly this attentional approach we are attacking?

The answer is no – for the following reasons. Originally, the idea of attentional zooming was introduced by Stoffer (1991) as a means to explain why the Simon effect was absent in some experiments of Umiltà and Liotti (1987). Supposing that, in these experiments, zooming preceded stimulus analysis, and further supposing that zooming is generally not controlled by parametrization in left/right terms, the absence of the Simon effect would be understandable. Stoffer's own results lend some support to the view that this may be a coherent picture of what happened. However, it is important to see that while the presence of zooming may prevent the Simon effect, the reverse is not necessarily true: the absence of zooming does not imply the presence of the Simon effect, even from an attentional perspective.

Suppose that in Experiments 1–3 zooming had not been necessary. Spatial attention should have been drawn to the frame, since there is no difference between Stoffer's design and ours up to this point. When the stimulus appeared, zooming into the frame/stimulus structure would be absent, so that the spatial code of the stimulus should have been the same as that of the frame. But which spatial code has been assigned to the frame? According to Stoffer, no spatial code would have been assigned to the single central frame in Experiments 1 and 2, while the left or right frames in Experiment 3 should have been coded in relation to the center of the screen – that is, depending on their side. As the spatial code of the stimulus should be identical to the spatial code of the frame, the attentional-movement hypothesis would predict an absence of the Simon effect in Experiments 1 and 2, and a side-related Simon effect in Experiment 3. What we got is, of course, a completely different result pattern, namely, comparable Simon effects related to stimulus position in relation to the reference object in all three experiments. The conclusion is that even if our experiments had been completely unsuccessful in inducing attentional-zooming operations, not a single prediction of the attentional hypothesis would have come true. On the other hand, it is clear that the present results are fully consistent with any approach that denies a causal role of spatial attention in stimulus coding, as does the referential-coding view.

Apart from our theoretical handling of the objections to our conclusions, there is an empirical way of responding as well, namely the search for converging evidence. Of course, the best method to test the attentional approach would be to observe attentional movements directly. Unfortunately, we have no such direct measure of attentional movements. While it would be possible to tap this issue by introducing a secondary (e.g., detection) task, this would require a double-task design so different from the standard Simon task that it would be questionable to apply its results to the Simon effect. So, instead, we looked for additional and converging evidence in three further experiments, in which we attempted to manipulate spatial attention by using peripheral spatial distractors.

Experiment 4

In Experiments 1–3, a large frame appeared before the onset of the target stimulus. According to the attentional-movement hypothesis, the frame causes a reallocation of attention which brings the new object into the focus of attention. Since the frame is large enough to encompass both stimulus positions, a stimulus necessarily appears in some sense as a part of the frame. An attentional movement from an object to one of its parts is assumed to be a kind of zooming into a structure, but not a lateral shift. As the parametrization of attentional zooming is not in left/right terms, no *left/right* stimulus code is computed, so that no *left/right* code can interfere with response selection. As to the attentional-movement view, the situation should be quite similar if it was not a large frame that was preexposed in a trial but, instead, a small spatial cue appearing in one of the possible stimulus positions. The cue should attract attention just as the frame does, yet with a slightly different effect, since the target stimulus that appears later cannot be assumed to be represented as a part of the cue. Conversely, the small cue should be represented as a part of the large target stimulus. From this it follows that the attentional focus would first encompass the small cue and then, after the onset of the larger target stimulus, a zooming out instead of a zooming in would be required to encompass the target stimulus. Because zooming operations are not assumed to require directional parametrization, no *left/right* stimulus code should be computed, so that no *left/right* code can interfere with response selection.

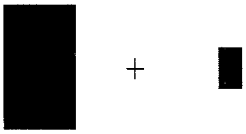

Fig. 3. Schematic diagram of the stimulus display in Experiment 4 with a righthand cue and a lefthand target stimulus. Cues and stimuli actually differed in color and did not temporally overlap

These predictions of the attentional-movement hypothesis were tested in Experiment 4. There were only two possible stimulus positions, one to the left and one to the right of a more or less continuously visible small central cross (see Figure 3). Instead of the large frame used in the preceding experiments, a small cue was presented either at the left-side or at the right-side stimulus position or in between. Since in some trials the cue and the target stimulus overlapped spatially, a blank interval was inserted between cue and stimulus to avoid any problems of forward masking. Just like the frame used in the preceding experiments, the cue was of no informational value as to relative stimulus position, that is, it was followed by left-side and right-side stimuli with equal probability.

From an attentional-movement perspective, a central cue should guarantee a standard Simon effect, serving the same function as a central fixation point as is used in standard Simon tasks. Conversely, a left-side cue should attract attention to the left-side stimulus position, so that a following left-side target stimulus would have to be focused on by zooming, which does not give rise to a *left* code while a right-appearing target stimulus would require a rightward shift, which does give rise to a *right* code. Analogously, a right-side cue would draw attention to the right-side position, so that a right-side target stimulus would get no *right* code while a left-side target stimulus would get a *left* code. In other words, a Simon effect is expected with central cues and with invalid cues (i. e., cues appearing at the alternative target position) but not with valid cues (i. e., cues appearing at the same position as the target), this leading to a 3-way interaction of cue location, stimulus location, and response location. According to the referential-coding hypothesis, there is no reason to assume that the Simon effect should occur only with a special kind of spatial cueing as long as a reference object is available to aid spatial coding. Since the more-or-less continuously visible central cross can serve this function, stimuli should always be coded as left or right and, thus, a Simon effect should occur in all cueing conditions.

Method

Subjects. Eight female and six male subjects aged 20–42 years took part for pay. All had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Stimuli. The center of the screen was marked throughout the whole experiment by a cross of 0.2° by 0.2°. The cue and the stimuli were solid rectangles, the former 0.3° × 0.6°, the latter 0.9° × 1.8° in size. The cue appeared either at screen center by shortly replacing the central cross, or 1.2° to the left or right of the median plane. The target stimulus appeared 1.2° to the left or to the right of screen center (center to center). The central cross was gray (3 cd/m^2), the cue was white (52 cd/m^2), and the target stimuli were blue (5 cd/m^2) and red (11 cd/m^2).

Procedure. Following an intertrial interval of 2,000 ms, the cue was presented for 200 ms either at the center or at one of the two stimulus positions. Then, after a blank interval of 200 ms, one of the target stimuli appeared to the left or to the right of the central cross for 150 ms. Further procedure was as in Experiments 1–3. The experiment was run in single sessions of about 20 min. A session was composed of 2 warming-up blocks and 30 experimental blocks. Each block consisted of 12 randomly mixed trials whose type resulted from the factorial combination of cue location (left, central, right), target color (red or blue), and target location (left or right).

Results

Missing trials (<0.5%) and anticipations (<0.5%) were excluded from the analysis. Mean RTs and error rates were calculated for each combination of cue location (left, center, or right), stimulus location (left or right), and response location (left or right).

An omnibus $3 \times 2 \times 2$ repeated measurement ANOVA of mean RTs revealed two effects. One of them was a highly significant interaction of stimulus location and response location, $F(1,13) = 70.25$, $p < .001$, showing that left responses were faster to left than to right stimuli (400 vs. 428 ms), while right responses were faster to right than to left stimuli (402 vs. 432 ms). However, this Simon effect was modified by cue location, as is indicated by a significant 3-way interaction, $F(2,26) = 3.43$, $p < .05$. The latter result pattern was further explored in an additional $2 \times 2 \times 2$ ANOVA, excluding the conditions with central cueing. In this analysis, only one source of variability proved to be significant, namely the interaction of stimulus location and response location, $F(1,13) = 62.20$, $p < .001$, again showing that left responses were faster to left as compared to right stimuli (399 vs. 426 ms), whereas right responses were faster to right than to left stimuli (406 vs. 431 ms). The remaining effects, including the 3-way interaction, were far from significance ($.23 < p < .96$). This confirms that the 3-way interaction in the omnibus analysis did not arise from any differential influences of valid and invalid cues, but from a larger Simon effect with central (34 ms) than with peripheral cues (26 ms).

In the omnibus ANOVA of the error rates, there were two significant effects. First, a highly significant interaction of stimulus location and response location, $F(1,13) = 23.09$, $p < .001$, showed that errors were less frequent when left responses were made to left stimuli, or right responses to right stimuli (1.6%, 1.6%, respectively), than vice versa (3.6%, 4.4%, respectively). Second, a significant interaction of cue location and stimulus location, $F(2,26) = 4.42$, $p < .05$, indicated that error rates increased with the distance between cue and stimulus. For left stimuli, errors were least frequent with left cues, intermediate with central, and most frequent with right cues (2.1%, 2.9%, and 3.9%, respectively), whereas for right stimuli the pattern was reversed (2.3%, 2.6%, and 2.9%, for right, central, and left cues, respectively). The remaining effects did not even approach significance ($.21 < p < .73$).

Discussion

The results allow for two main conclusions. First, there is evidence that the particular kind of spatial cueing can slightly modify the extent of the Simon effect. The present data do not permit an unequivocal interpretation of the result that the Simon effect is larger with central than with peripheral cueing, but it is clear that cueing does have an effect. This conclusion is further supported by the effect of cue validity on error rates. Second, the effects of spatial cueing on the Simon effect are in no way those predicted by the attentional-movement hypothesis. Most importantly, there is no empirical support for the assumption that correctly cued stimuli (presumably approached by zooming) do not give rise to a Simon effect, while incorrectly cued stimuli (presumably approached by lateral shifts) do. The present data do not even indicate a reduction of the effect. From this it follows that while the Simon effect may generally be somewhat reduced by peripheral, as compared to central, spatial cues, it definitely does not depend on the location of the peripheral cue.

Experiment 5

In this experiment, an attempt was made to counter two different and unrelated objections that might be raised against Experiment 4. First, one could argue that spatial attention might have been initially drawn to the spatial cue, but then shifted back to the screen center. That is, too much time could have elapsed between cue presentation and target onset to lock attention continuously to the location of the cue. If this were the case, then, each stimulus would have been approached by a lateral shift of attention, just as in a standard Simon task. Consequently, in the present experiment, cues appeared very shortly (100 ms) before the target stimulus proper. There is abundant evidence that an abrupt onset presented 150 ms or less before the reaction stimulus is fairly successful in capturing spatial attention in a stimulus-driven and largely goal-independent fashion (e.g., Lambert et al., 1987; Müller & Rabbitt, 1989; Posner & Cohen, 1984; Yantis & Jonides, 1984). Thus one of the main goals of the present experiment was to enhance experimental control over the location of the attentional focus just before the target stimulus is presented.

Secondly, the assumption of a necessary zooming-out operation between cue and stimulus presentation could have been false. Note that there was a blank interval between cue and stimulus in Experiment 4. For this reason, the original extent of the cue could have been somehow forgotten, so that cue and stimulus were not perceived to be of different extent and, therefore, were not represented at different representational levels. A related possibility is that zooming is only performed to switch between representations of really simultaneously available objects. Furthermore, as has already been mentioned, zooming may generally not be necessary with easily discriminable color stimuli. To encounter these possibilities, the design of the present experiment was not based on the assumption of any hierarchical relationship between cues and stimuli. The

Fig. 4. Schematic diagram of the stimulus display in Experiment 5 with a right-hand cue (asterisk) and the two reference objects (rectangles). For presentation of the target stimulus, one of the reference objects changed its color

cues were not presented at locations where stimuli could appear, but either to the left or to the right of both stimulus positions (see Figure 4). To permit optimal spatial discrimination of cue locations from stimulus positions, the latter were marked throughout the whole experiment by means of two adjacent rectangles, the color of one of these being changed in order to present the stimulus. Again, a control condition with central cueing was added.

Provided that the cue captures attention before the target-stimulus onset, the attentional-movement hypothesis should predict the following: a left-side cue should draw attention to the extreme left, so that focusing of both left-side stimuli and right-side stimuli would require a rightward shift of attention. Analogously, a right-side cue should draw attention to the right of both stimulus positions, so that either target stimulus would have to be approached with a leftward attentional shift. As it is the direction of the attentional shift that should matter in the Simon task and since, in this experiment, shift direction does not depend on the location of the target stimulus, response speed should depend on cue location, but not on stimulus location. Since left-side cues lead to rightward shifts towards both left-side and right-side stimuli, right-hand responses should always be faster than left-hand responses, irrespective of stimulus location. Analogously, right-side cues always lead to leftward shifts, so that left-hand responses should be faster than right-hand responses. In other words, the attentional-movement hypothesis predicts an interaction of cue location and response location, but no dependence of response speed on the spatial correspondence of stimulus and response. From a referential-coding view nothing changes, so that similar results to those in the preceding experiments are predicted. As long as referential coding is possible, a Simon effect should occur. Since the continuously available stimulus-position markers can serve as a reference, there is no reason to expect an elimination of the Simon effect.

Method

Subjects. Nine female and five male subjects aged 19–29 years took part for pay. All had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

*Stimuli.*The two possible stimulus positions to the left and right of the screen center were marked throughout the whole experiment by means of two solid 0.3° × 0.6° adjacent rectangles with a distance of 0.3° to each other. The cue was an asterisk, 0.2° in diameter, appearing either in between the stimulus positions, or 1.2° to the left or right of the center of the screen. That is, a left-side cue appeared 0.9° to the left of the left-side stimulus and a right-side cue appeared 0.9° to the right of the right-side stimulus. The stimulus position markers were gray (5 cd/m²), the cue was white (114 cd/m²), and the target stimuli were blue (13 cd/m²) and red (30 cd/m²).

Procedure. The only changes in comparison with Experiment 4 were as follows: the intertrial interval was 2,400 ms; the precue was presented for 50 ms either to the left or to the right of the two stimulus position markers or just between them; after a blank interval of 50 ms, one of the target stimuli appeared on the screen, replacing either the left-side or the right-side position marker, while the remaining adjacent position marker remained visible.

Results

Missing trials (<0.5%) and anticipations (<0.5%) were excluded from analysis, and the remaining data were treated as in Experiment 4. In the $3 \times 2 \times 2$ omnibus ANOVA of the RT data, only two significant effects were obtained. First, there was a highly significant interaction of stimulus location and response location, $F(1,13) = 36.58$, $p < .001$, resulting from the fact that left responses were faster to left than to right stimuli (447 vs. 471 ms), while right responses were faster to right than to left stimuli (453 vs. 485 ms). As was evidenced by the absence of a significant 3-way interaction ($p > .38$), this Simon effect of 28 ms overall was not modified by cue location. Second, a significant interaction of cue location and stimulus location, $F(2,26) = 4.80$, $p < .05$, indicated that responses were faster with cue-stimulus correspondence. This pattern was not so clear with left stimuli, which were responded to most quickly following a central (461 ms) and most slowly after a right cue (472 ms), with the left cue lying in between (465 ms). As to right stimuli, however, there was an obvious ordering, with fastest responses following right cues (457 ms), intermediate after central (463 ms), and slowest following left cues (467 ms). Overall, there was a cueing effect (invalid-valid) of 8 ms.

A $3 \times 2 \times 2$ ANOVA of the error rates produced two significant effects. First, a main effect of response location, $F(1,13) = 6.89$, $p < .05$, showed that left responses were more often correct than right responses (1.9 vs. 3.5% errors). Second, a significant interaction of stimulus location and response location, $F(1,13) = 5.49$, $p < .05$, indicated fewer errors when left responses were made to left than to right stimuli (1.4 vs. 2.5%), and when right responses were made to right than to left stimuli (2.0 vs. 4.9%). This Simon effect was clearly not modified by cue location ($p > .6$).

Discussion

Again, we have found no evidence for the dependence of the Simon effect on certain attentional movements presumably performed to approach the target stimuli. Neither of the two possible objections to Experiment 4 can be reasonably made against Experiment 5. Here, the cue-target interval should have been short enough to render rather unlikely a post-cue return of the attentional focus to screen center, so that the target stimuli should have been approached either from the extreme left or from the extreme right, no matter what their own relative position was. This supposition gains additional support from the finding of a cueing effect in response times. Although this effect is rather small, it shows that the cues have not been ignored altogether. Furthermore, in this experiment the attentional predictions did not rely on, and did not require, any assumptions concerning the level of cue or target representation. Nevertheless, the predictions of the attentional-movement hypothesis did not hold, in contrast to those from the referential-coding approach.

Experiment 6

In the last two experiments reported above (Experiments 4 and 5), the cue was always more or less uninformative (although it could be used as a means to reduce temporal uncertainty). Since there was little benefit to be drawn from attending the cues, the question arises whether our assumption that they attracted attention really holds. It is true that cueing effects were obtained in Experiments 4 and 5, but these were rather small, and were confined to either error rates or RTs, so that one may doubt whether they are replicable at all. Could it be that the cues had been ignored most of the time?

Such a misgiving is clearly not supported by available empirical evidence. On the contrary, it has been demonstrated several times that peripheral-visual onsets attract spatial attention even if these distracting stimuli are without any informational value and the subjects are explicitly instructed to ignore them (Lambert & Hockey, 1991; Maylor, 1985; Maylor & Hockey, 1987; Posner & Cohen, 1984). Furthermore, peripheral onsets attract attention even when another location or stimulus is cued by an additional valid cue, when the uninformative onset precedes the valid information (Theeuwes, 1991) or when the validity of the latter is rather low (Müller & Rabbitt, 1989). This kind of automatic capture can only be avoided when highly valid spatial information is presented ahead of the distracting onset (Theeuwes, 1991; Yantis & Jonides, 1990), or – after considerable practice – when the onset cue itself is made informative (Warner, Juola, & Koshino, 1990).

Since our subjects were quite uncertain about stimulus position, we have no reason to assume that they could have avoided attending the onset cue. Nevertheless, our conclusions would gain persuasive power if we had some more positive indication that the cues were not simply ignored – at least most of the time – than that provided by the two preceding experiments. Unfortunately, there are limits to this sort of attempt. First, it would be of no use to make the cues valid predictors of stimulus position. If one were to do that, the spatial code of the stimulus could be formed before stimulus presentation. Since there is evidence that spatial codes decay over time (Hommel, 1993c; Simon et al., 1976), the Simon effect would disappear as long as there is a sufficient cue–stimulus asynchrony. Second, introducing a too complex cue-related secondary task could have the same effect: analyzing the relevant information of the reaction stimulus and the following response selection could be delayed, so that the spatial code has time to decay (McCann & Johnston, 1992). While these phenomena are interesting, they would clearly not be helpful in the present case.

As a result of these considerations, it was attempted to make the cues slightly relevant to the task in the following way: the design of Experiment 5 was supplemented by catch trials, when the cue was simply omitted; in these trials, the subject had to refrain from responding – that is, the subject was not allowed to ignore the cue completely, even though the cue was neither relevant to the Simon task proper nor informative with respect to stimulus position.

Two additional modifications were introduced to improve the experimental control over the hypothetical lateral movements of spatial attention. First, the cue–stimulus interval was further reduced in order to minimize the possibility that attention moves back to screen center or to the position markers before stimulus presentation. Second, the stimulus-position markers were deleted before cue onset, so that there was no visible target for an attentional movement before stimulus presentation except the cue itself. Besides blocking the way back, marker deletion may facilitate the disengagement of attention from the markers, this having been postulated as a necessary precondition of an attentional shift to a new stimulus (Fischer, 1986; Fischer & Breitmeyer, 1987).

Because all of these modifications left intact the rationale of the design adopted from Experiment 5, the predictions of both the attentional-movement hypothesis and the referential-coding hypothesis were as in Experiment 5.

Method

Subjects. Nine female and five male subjects aged 20–37 years took part for pay. All had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Stimuli. These were exactly as in Experiment 5. Procedure. The only modifications as compared to Experiment 5 were as follows. After an intertrial interval of 2,300 ms, the two position markers were deleted and the screen remained blank for 200 ms. The precue was then presented for 50 ms either at screen center or to the left or right of the two possible stimulus positions. Simultaneously with cue deletion, one of the target stimuli appeared on the screen together with a position marker. In catch trials, cue presentation was omitted and subjects were instructed not to respond to the reaction stimulus in that case. If they did, auditory error feedback was given, but unlike trials producing false or missing responses, the given trial was not repeated. Again, subjects worked through 2 warming-up blocks and 30 experimental blocks of 12 intermixed trials. Now, however, 36 additional catch trials were randomly inserted, consisting of 3 repetitions of each of the 12 (3 cue locations $\times 2$ stimulus colors $\times 2$ stimulus positions) conditions.

Results

Missing trials (<1%) and anticipations (<0.5%) were excluded from analysis. On average, catch trials were correctly recognized in 80% of the cases, ranging from 66.7% to 94.4%. The remaining data were treated as in Experiment 5.

In the omnibus ANOVA of the RT data, three significant effects were found. First, a highly significant main effect of response location, $F(1,13) = 14.85$, $p < .005$, showed that left responses were faster than right responses (484 vs. 507 ms). Second, there was a highly significant interaction of stimulus location and response location, $F(1,13) = 31.36$, $p < .001$. Left responses were faster to left than to right stimuli (477 vs. 491 ms), and right responses were faster to right than to left stimuli (499 vs. 515 ms). As was indicated by the lack of a 3-way interaction ($p > .48$), this Simon effect of overall 15 ms was not modified by cue location. Third, a significant interaction of cue location and stimulus location was obtained, $F(2,26) = 3.70$, $p < .05$. Responses to left stimuli were faster if preceded by left than by central or right cues (489, 495, and 504 ms, respectively), while responses to right stimuli did not seem to depend on whether the cue was right, central, or left (494, 496, and 495 ms, respectively). Overall, this cueing effect amounted to 8 ms.

In the error analysis, three significant effects were obtained. First, a significant main effect of cue location, $F(2,26) = 4.20$, $p < .05$, showed that the error rates followed a right-to-left ordering, with right cues leading to the lowest, central cues to intermediate, and left cues to the highest rates (1.5%, 2.2%, and 2.8%, respectively). Second, a significant main effect of response location, $F(1,13) = 8.54$, $p < .05$, indicated that more errors were related to the right than to the left response (2.8% vs. 1.5%). Third, there was a significant interaction of stimulus location and response location, $F(1,13) = 7.64$, $p < .05$, produced by fewer errors of the left hand in response to left than to right stimuli (0.9% vs. 2.1%), and fewer errors of the right hand in response to right than to left stimuli (2.0% vs. 3.6%). The 3-way interaction of cue location, stimulus location, and response location was far from significance ($p > .27$).

Discussion

This experiment was performed to replicate the general findings of Experiment 5 and, at the same time, to obtain additional evidence for our assumption that spatial attention is indeed attracted by a more or less uninformative onset precue. The first goal was clearly achieved. This is confirmed by the presence of a Simon effect in response times and error rates as well as by the absence of any interaction of this effect with cue location. Obviously, the attentional predictions failed again.

The results also reveal that the experiment was also successful in its second goal. Most of the catch trials were responded to correctly, although the extremely short cue–stimulus interval must have made the task very difficult. On the plausible assumption that a correct catch-trial response can be made only when the cue is somehow attended to, this result provides strong evidence that the subjects did not ignore the cue. Further, there was an interaction of cue and stimulus location. Though its size is not impressive, it is just as pronounced as in Experiment 5, and, thus, replicable.

A cueing effect in experiments like the present one is in no way a matter of course. Here, the distance between cue and cued stimulus was much greater than the distance between cued and uncued (or not equally cued) stimulus locations. Thus, it cannot be the very location of the stimulus that has been cued, but rather a larger area into which the cued stimuli happened to fall. There are several interpretations of this result; but they are not equally plausible.

First, the cue may attract spatial attention that then has to be redirected onto the appearing stimulus. Supposing that this reallocation takes more time the larger the distance between cue and stimulus (see, e. g., Tsal, 1983), stimulus analysis could have started earlier when cue and stimulus were on the same, rather than on different, sides. However, this would suggest that in Experiments 5 and 6, central cueing should have produced the fastest responses, because this was the condition with the smallest cue–stimulus distance. Such a prediction is not consistent with our results.

Second, the cue-stimulus intervals in Experiments 5 and 6 may have been long enough to attract attention to the side of the cue, but too short for an exact adjustment of the attentional focus to cue location (e. g., Castiello & Umiltà, 1990). Thus, stimulus processing would be facilitated only when the stimulus is located on the very side the cue draws attention to and only as long as the focus is not fully restricted to cue extension. This explanation, too, does not perfectly fit the data because it also implies that the greatest benefits are from centrally presented cues.

Third, a given cue may activate the whole contralateral cortical hemisphere, so that stimuli are processed faster if they fall only in the same visual half-field as the cue (e. g., Hughes & Zimba, 1985). However, this assumption seems to be rather unlikely in the face of findings that cueing benefits are not evenly distributed over a whole visual hemifield, but gradually drop off around the cued location (Castiello & Umiltà, 1990; Klein & McCormick, 1989; Shepherd & Müller, 1989).

Fourth, spatial attention may be shifted to a new stimulus by means of an oculomotor program that requires specification of a direction and a distance parameter (e. g., Rizzolatti, Riggio, Dascola, & Umiltà, 1987). Since the programs to move the eyes to a cue and to a stimulus located at the same side should share a common direction parameter, attentional reallocation would be faster than when both direction and distance are to be reprogrammed, which would be necessary with different-sided cues.[2] The predictions of this approach match our findings: facilitation when cue and stimulus are on the same side, inhibition when they are on different sides, with the central cueing condition lying in between.

In sum, there is considerable evidence that attention was attracted to the cue in Experiment 6 and, most likely, in Experiment 5 too. Given this conclusion, the predictions of the attentional-movement hypothesis were incorrect, since no evidence for a dependence of the Simon effect on the location of an attended pre-stimulus cue was found. In contrast, the referential-coding hypothesis allows for a correct prediction of our findings.

Conclusions

Six experiments were carried out to test between predictions from an attentional-movement hypothesis and a referential-coding hypothesis. In Experiments 1–3, display conditions were chosen such as to prevent lateral shifts of attention and at the same time to enhance spatial codability. In contrast to predictions from the attentional-movement hypothesis, pronounced Simon effects were obtained. In Experiments 4 and 5, peripheral cues were presented to attract spatial attention in order to control the direction in which the attentional focus had to be moved onto the stimulus. In Experiment 6, the task relevance of the cue ensured that subjects paid attention to it. While several effects indicated that the cue did in fact attract attention, none of the predictions of the attentional-movement hypothesis could be confirmed. In contrast, the data are fully consistent with the referential-coding hypothesis as outlined in the Introduction. In sum, the results suggest that the occurrence of the Simon effect is not bound to a certain attentional movement performed to bring the target stimulus into the attentional focus, but rather depends on spatial correspondence between responses and stimuli, provided that these are codable as left or right in reference to some reference object.[3]

While the referential-coding hypothesis has been introduced as a working hypothesis, its underlying idea can be traced back to the coding approach of Wallace (1971, 1972); since then, it has been developed and extended by Kornblum, Hasbroucq, and Osman (1990), Prinz (1990), and Umiltà and Nicoletti (1990). Wallace assumed that both stimulus and response are represented in the cognitive system, like stimuli. Since these stimuli have perceivable attributes, they are cognitively represented by codes of these attributes. One of the stimulus attributes is its position in space, but Wallace concedes that other attributes are coded as well. In the Simon task, a certain attribute (e. g., color) has to be associated with one of those stimuli by which the possible responses are represented (a response

[2] The oculomotor-programming approach may seem to be similar to the attentional-movement approach under discussion, but it does not lead to the same predictions. The former implies that the direction parameters of both programs, the cue-related and the stimulus-related, are specified by use of the same reference, as e. g., the current position of the eye or a common reference point. Otherwise, the program induced by an eccentric precue would share neither the direction nor the distance parameter with the program prepared to move to a stimulus much nearer to the original fixation point. The attentional-movement approach as outlined by Stoffer (1991), on the contrary, states that direction parameters always refer to the location that has been specified previously. That is, the stimulus should always be coded with reference to the preceding cue. This is, of course, the assumption that motivated the conduct of Experiments 4–6. As it seems, the former, but not the latter, kind of programming approach is suited to account for the present cueing effects.

[3] It is not possible to conclude from the present data that enhanced spatial codability resulted exclusively from the introduction of additional reference objects. As has already been discussed, there is evidence that the choice of single-feature targets instead of conjunctively defined target stimuli could have played a critical role (Hommel, 1993 a). But the present arguments do not rely on any assumption as to by what means spatial codability is ensured, but only that, if it actually is, Simon effects do not depend on any particular movement of spatial attention.

code). The activation of such a response code is thought to cause the motor action proper. Wallace supposed that the access to a given response code is facilitated by the similarity between stimulus and response code – that is, if some or all of the stimulus attributes match the attributes of the (perceived) response. Thus, the Simon effect is understood to arise from the similarity of the stimulus and the response as a perceived event. Because, for example, left-side stimuli and left-hand responses share a spatial attribute, left-hand responses can be accessed faster by left-side stimuli than by right-side stimuli. If the left-hand response is indeed the correct one, facilitation would follow, but, on the other hand, there would be interference if the right-hand response were correct.[4]

The present referential-coding hypothesis is consistent with Wallace's general assumptions regarding the question of which spatial criteria are applied in the process of coding stimuli and responses as left or right. Wallace (1972) did not propose that stimuli would be coded with reference to a fixed and task-independent reference system, but maintained instead, as we did, that coding refers to some chosen reference point. The spatial codes are further assumed to be somehow degraded, so that, for example, only two values are used for spatial stimulus coding if these always appear in one of two locations. In other words, spatial coding of stimuli is assumed to depend on a chosen reference and on uncertainty regarding stimulus location.

This latter formulation implies that stimuli may give rise to multiple spatial codes if there is spatial uncertainty regarding multiple frames of reference. This prediction nicely fits recent results of Lamberts et al. (1992). In their study, three different correspondence relations were varied independently, so that the response could correspond spatially to stimulus side (hemispace), hemifield, and/or relative position (within hemifield). The results show the additive effects of all these spatial relationships. Obviously, this finding stands in sharp contrast to any one-and-only-reference approach as embodied by the attentional-movement framework and its predecessors (Simon, 1969; Simon et al., 1976).

The coding approach is further well suited to handle the apparent contradiction between the present finding that the Simon effect does not vary with cue location (Experiments 4–6) and demonstrations that spatial cueing can be very effective in reducing, or even eliminating, the Simon effect. For example, Verfaellie et al. (1988) showed that the Simon effect is reduced by validly precueing stimulus position. Furthermore, relative and absolute stimulus position selectively loses its influence when precued in time (present Experiment 3; Stoffer, 1991; Umiltà & Liotti, 1987). These results are clearly predicted by the coding approach, because stimuli should be coded in terms of only those spatial relationships as to which uncertainty exists. Since uncertainty can only be reduced by information, informative (but not uninformative) cues should affect stimulus coding. In Experiments 4–6, no spatial information relevant to the stimulus was provided by the cue, so that stimulus coding should not be affected. In the studies that demonstrate effective cueing, on the other hand, information was conveyed by the cue that subjects could use to reduce or eliminate uncertainty as to stimulus location. Given that uncertainty equals zero, no left/right coding should occur. An attentional-movement approach is hardly able to provide a reasonable account for the dependence of the Simon effect on cue utility – a result of its silence as to the issue of information.

While a coding approach is well supported by the data, some theoretical problems remain. One of the most pertinent problems is that something more and something more precise should be said about stimulus coding than that it depends on referential coding, the availability of coding aids, and the like. What is needed is a coding theory that allows for precise predictions of the likelihood and (at least relative) size of the Simon effect, even in complicated cases. These would include, for example, multiple frames of reference (Lamberts et al., 1992), head tilt (Schroeder-Heister, Heister, & Ehrenstein, 1988), or variations of instruction (Gopher, Karis, & Koeing, 1985; Hommel, 1993b).

As has been argued above, a possible solution might be based on the more general notion that the Simon effect depends on both a reference and spatial uncertainty. However, a flexible uncertainty-related coding assumption is only one of at least four possible coding rules. A second hypothesis is that each discriminable spatial relation is coded automatically, independently of the task or the subject's intention or uncertainty (Kornblum et al., 1990). As a third possibility, one could think of a version lying in between the first and the second, namely that – while all relations are coded – these codes may be differently weighted, depending on task and/or intention, on the relation's salience (Proctor, Reeve, & Van Zandt, 1992), or on some other contextual factor. Finally, a fourth hypothesis might be that there is a fixed coding hierarchy (Heister, Schroeder-Heister, & Ehrenstein, 1990), so that weights are assigned to the codes of spatial relations according to the relation's rank in that hierarchy. Furthermore, one could think of combinations of at least some of these coding rules. For example, there may be – by default – a certain weighting or rank order of codes, which however, is open to intention-related and/or context-sensitive adjustments and the like. Thus, there are a great many factors that may play a role in the spatial coding of stimuli. But spatial attention still does not seem to be a particularly promising candidate.

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[4] While facilitation can be easily explained by this reasoning, interference cannot. If only the *accessibility* to the correct response mattered, then noncorresponding stimuli should no more facilitate or interfere with the correct response than neutral stimuli do. An explanation of interference presupposes that response codes are not only more accessible, but in fact *activated* by similar stimulus codes (Kornblum et al., 1990; Prinz, 1990). The presentation of noncorresponding stimuli would thus result in preactivation of the wrong response code, by spatial similarity. If the wrong response had to be inhibited by a presumably time-consuming process, the slowing down of responses could be explained.

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