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Effects of irrelevant spatial S-R compatibility depend on stimulus complexity

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Summary. Choice-reaction time is known to depend on the spatial correspondence of stimulus and response, even if the stimulus location is irrelevant to the task (Simon effect). An experiment investigated whether this effect depends on stimulus complexity – i.e., on whether properties of the stimulus render stimulus discrimination easy or difficult. It was hypothesized that high demands on discrimination slow down the processing of stimulus identity in relation to location, so that the facilitating or conflicting location code has more time to decay, thus losing impact on response selection. In fact, the results revealed an effect of irrelevant spatial S-R correspondence with easy, but not with difficult, stimulus discrimination. This finding resolves an apparent contradiction between the results of several previous experiments on the Simon effect.

Introduction

The time it takes to respond to a stimulus often depends on the spatial relationship between stimulus and response. First of all, this is the case when the stimulus position is the relevant attribute. It has been shown repeatedly that responses are faster when, for example, left-hand stimuli are reacted to with a left-hand response (i.e., pressing a left-hand key, moving a lever to the left, etc.) and right-hand stimuli with a right-hand response, than when stimulus-response mapping is crossed (e.g., Brebner, Shephard, & Cairney, 1972; Fitts & Seeger, 1953). Moreover, even if stimulus location is completely irrelevant to a task, spatial correspondence of stimulus and response can be shown to speed up spatially defined responses. When, for example, the verbal command to press a left-hand key is presented to only one ear at a time, the response is faster when command location and response location correspond than when they do not (e.g., Simon & Rudell, 1967). This effect of correspondence between irrelevant stimulus location and response location has become known as the *Simon effect*.

The Simon effect turned out to be very stable and has been replicated several times in a wide range of tasks employing different stimuli and stimulus modalities, responses and response modalities, as well as using various spatial parameters of stimuli and responses (for overviews, see contributions to Proctor & Reeve, 1990). There is, however, an interesting exception on which the present paper is focused: in two experiments of Umiltà and Liotti (1987: Experiments 3 and 4, no-delay conditions), the Simon effect disappeared for reasons that are not yet completely understood.

The arrangement of stimulus display and response keys in one of these experiments (Experiment 3, no-delay condition) is given in Figure 1. In each trial, the subject was presented with two frames either to the left or to the right of a central fixation cross. The stimulus was the outline of either a square or a rectangle, and it appeared simultaneously with the frames and inside one of them. The subject had to press a left- or a right-hand key according to the instructed mapping of stimulus form to response side. The result was that no Simon effect occurred; that is, there was no significant effect of spatial correspondence between stimulus and response. The same negative result was obtained in a further experiment (Experiment 4, no-delay condition), in which the two frames were always presented on opposite sides of the fixation cross.

This disappearing of the Simon effect is important for at least two reasons. First, it has been referred to by Stoffer (1991) and by Umiltà and Nicoletti (1992) as a main argument in favour of an attentional approach to the Simon effect.[1] So, the results of Umiltà and Liotti (1987) are more than a marginal curiosity and bear considerable theoretical importance. The question remains, however, whether they really support conclusions in favour of an attentional approach to the Simon effect. Second, while the results of Umiltà and Liotti were replicated successfully by Stoffer

[1] The other central argument rests on findings of Stoffer (1991) obtained with a single frame. These, however, have recently been challenged by Hommel (1993b).

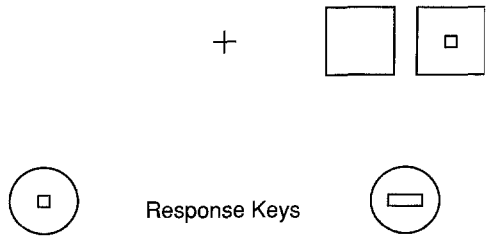

Fig. 1. Schematic diagram of a display condition that led to the disappearing of the Simon effect

(1991), they are incompatible with recent findings of Lamberts, Tavernier, and d'Ydewalle (1992), who used a design very similar to that of Umiltà and Liotti (1987) (see below) and did obtain a Simon effect. The question, of course, is how this empirical inconsistency can be explained.

In a first attempt to provide an explanation for the results of Umiltà and Liotti (1987), Stoffer (1991) suggested an attentional view. Following Neumann (1980), he assumed that stimulus analysis is necessarily preceded by an attentional operation that can be one of two kinds: (a) spatial attention can be *shifted* horizontally from one location to another, or (b) it can be *zoomed in* from a global to a local representational level or *zoomed out*, respectively, like the zoom lens of a camera. The critical assumption is that a given object is spatially coded (in terms of left or right) only if it is focused by the performance of a lateral shift of spatial attention, but not if its analysis is directly preceded by a zooming operation. Since the Simon effect can be understood as arising from a match or from a nonmatch of the spatial codes of stimulus and response (Wallace, 1971), a stimulus without a spatial code should not lead to a Simon effect. Thus, the disappearing of the Simon effect could be explained if the specific display conditions suggested that the stimulus proper is focused on mainly by zooming operations.

Stoffer argued that in the experiments of Umiltà and Liotti (1987) the arrangement does, in fact, suggest that their subjects performed zooming operations instead of lateral shifts to focus onto the stimulus. The visual structure, consisting of the two frames and the stimulus proper, is assumed to attract spatial attention to its outline. That is, a lateral shift would be performed, starting from the fixation cross and ending at the whole frame/stimulus structure. Then attention would be zoomed in, because the stimulus is only a part of the whole structure, represented at a more local level. Since it is a zooming operation that directly precedes stimulus analysis, the stimulus would not be coded as left or right, and hence no Simon effect would be expected.

Serious problems for such a view arose from a study of Lamberts et al. (1992: Experiment 2). They performed an experiment quite similar to that of Umiltà and Liotti (1987), yet with completely different results. In this study, the fixation cross was not presented at the centre of the screen, but on the left or right of the median plane some time before the stimulus onset, in order to precue the hemispace of the presentation. Apart from this variation, each trial ran as in the experiments of Umiltà and Liotti (1987) and of Stoffer (1991). Two frames appeared to the left or to the right of the fixation cross with the stimulus (square or circle) inside one of them. The result was that (additive) Simon-type effects were obtained for all of the three spatial relationships that had been varied. That is, responses were comparatively faster when their spatial position corresponded to the hemispace (side), the hemifield (relative to fixation), and/or to the relative stimulus position.

There is an obvious discrepancy between the findings of Umiltà and Liotti and of Stoffer and those of Lamberts et al. that begs for an explanation. The purpose of the present experiment is to investigate whether this discrepancy can be resolved by consideration of the complexity of the relevant stimulus in these studies.

In all the studies cited, the stimulus was presented within larger frames, so that the presence of frames as such cannot count as a critical factor. The same is true for the relevant dimension, which was always the form of the stimulus. However, the stimuli used were somewhat different. In the experiments of Umiltà and Liotti (1987) (and in Stoffer's 1991 replication), both stimuli were rectangular frames that only differed in width. As each stimulus was presented within a larger frame that looked just like the stimuli, relative width was no valid criterion to distinguish both between stimulus and background and among the stimulus alternatives. Thus, stimulus identification must have been rather difficult here as compared to the Lamberts et al. (1992) study, in which a square had to be discriminated from a circle. Indeed, responses were about 130–150 ms slower in the experiments of Umiltà and Liotti than in the Lamberts et al. study.

How could the time needed to identify the stimulus influence the Simon effect? There is evidence that the size of the Simon effect depends critically on the temporal overlap between spatial coding and coding of the relevant stimulus information (Hommel, 1993a; McCann & Johnston, 1992). Specifically, it was shown that the Simon effect can be reduced, and even eliminated, by the introduction of manipulations that slow down the processing of the relevant stimulus information selectively without affecting the timepoint of spatial coding. This implies that the activation of the spatial stimulus code (or of the response code activated by the location cue) decays over time, either spontaneously or as a result of inhibition. The more an experimental manipulation delays the processing of relevant information, the lower the activation of the continuously decaying spatial code, and, thus, the smaller its facilitating or interfering influence on response selection.

Such a decay-based explanation can easily be applied to the experiments under discussion. As has already been pointed out, the relevant stimulus properties may have permitted faster stimulus identification in the Lamberts et al. (1992) study than in the Umiltà and Liotti (1987) experiments. On the assumption that the timepoints of location coding were roughly comparable, there should have been more temporal overlap of code activation in the former than in the latter case. For this reason, the Simon effect may have disappeared in the Umiltà and Liotti experiments (as well as in the Stoffer replication) because of

the temporal delay in the processing of the relevant stimulus information (in relation to spatial coding) caused by unfavourable preconditions for stimulus discrimination/identification.[2] That is, stimulus complexity may be a critical factor in the Simon effect.

In our experiment, the effects of two sets of stimuli – a more complex and a less complex one – are compared in a task and under display conditions almost identical with those of the original experiments of Umiltà and Liotti (1987) and of Stoffer (1991; see Figure 1), in which no Simon effect was obtained when the stimulus was presented together with two frames. However, if the present argument is correct, a full-blown Simon effect should be demonstrated in the same task simply by exchanging the line stimuli used in the original studies by stimuli that are clearly defined by a single easily detectable and identifiable feature. Consequently, we replicated the original studies with a form condition in which the stimuli were identical to the original studies, and a colour condition in which the stimuli could easily be identified by their unique colour. The predictions are straightforward: no Simon effect, or at least a markedly reduced effect, should occur in the form condition compared to the effect in the colour condition.

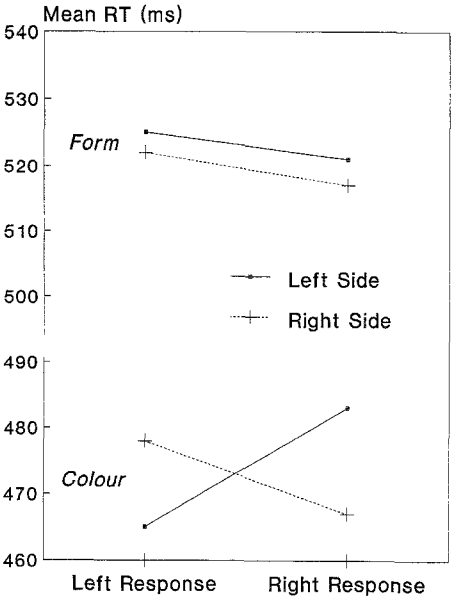

Fig. 2. Mean reaction times (in ms) as a function of stimulus type (colour or form), stimulus side (hemifield), and response location

Method

Subjects. Nine female and 10 male volunteers aged 17 to 35 years participated as paid subjects. They had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

Apparatus and stimuli. Stimulus presentation and data collection were controlled by a Hewlett Packard Vectra RS20 computer. Stimuli were presented on an Eizo 9080i monitor. Viewing distance was approximately 60 cm. Subjects responded by pressing the left- or right-hand shift key of the computer keyboard with the corresponding index finger.

The fixation point, a thin black 0.3° x 0.3° cross, was continuously visible at the centre of the screen. The frames were two thin 1.5° x 1.5° outlines appearing 3° and 5° to the left or right of the fixation point (centre to centre, respectively). The colour stimuli were 0.5° wide and 0.25° high solid rectangles. The form stimuli were a 0.25° x 0.25° square outline and a 0.75° x 0.25° rectangular outline. The stimulus always appeared within one of the two frames at 3° or 5° to the left or right of the fixation point. The background was grey (0.3 cd/m^2), the fixation point, the frames, and the form stimuli were white (3.6 cd/m^2), while the colour stimuli were green (2.3 cd/m^2) and red (3.0 cd/m^2).

Procedure. The experiment took place in a dimly lit room. In the colour condition, subjects were instructed to press the left-hand key in response to the red, and the right-hand key in response to the green, stimulus. In the form condition, the square was mapped onto the left-hand and the rectangle onto the right-hand response key. The sequence of events in each trial was a follows. After an inter-trial interval of 2,000 ms, the stimulus appeared, together with the two frames. The stimulus and the frames stayed on the screen until a response was given, but not longer than 1,000 ms. Responses with the wrong key were counted as errors and those with latencies exceeding 1,000 ms considered as missing. In both cases, the trial was recorded and then repeated at some random position in the remainder of the block. The subject was able to delay the next trial by keeping the key pressed down when he or she was feeling confused or inattentive.

The experiment was run in single sessions lasting about 25 min. Subjects began with either the colour or the form task, in balanced order. Each task consisted of 2 warming-up blocks and 20 experimental blocks. Each block was composed of eight randomly mixed trials, whose type resulted from the factorial combination of stimulus type (red or green/square or rectangle), side of stimulus (and frame) presentation (left or right), and relative stimulus position (left or right; i. e., stimulus within left-hand or right-hand frame).

Results

Missing trials (<0.5%) were excluded from the analysis. For each subject, median RTs of valid trials and error rates were calculated for each of the 16 combinations of stimulus type, stimulus side, relative stimulus position, and response location. The results are given in Table 1. Median RTs were subjected to a 2x2x2x2 analysis of variance (ANOVA) for repeated measures, which produced three significant effects.

First, the highly significant main effect of stimulus Type, $F(1,18) = 32.59$, $p < .001$, indicated that the response to colour was faster than that to form (473 vs. 521 ms). Second, there was a highly significant interaction of Stimulus Side and Relative Stimulus Position, $F(1,18) = 18.37$, $p < .001$, showing that responses were faster to stimuli closer to fixation than to those at more eccentric positions (493 vs. 502 ms).

Third, and most importantly, there was a significant three-way interaction of Stimulus Type, Stimulus Side, and Response Location, $F(1,18) = 6.83$, $p < .05$. Figure 2 shows that side and response location interacted in the colour

[2] Here and in the following, no attempt is made to distinguish between effects of a) discriminability of the stimulus from its context (i. e., figure-ground segregation), and b) discriminability between the stimulus and its alternative (i. e., stimulus similarity). While these factors are confounded in the present experiment (and subsumed under the umbrella term "stimulus complexity"), both can be shown to have an (similarly directed) impact of their own (Hommel, 1993a, Experiment 3 and 4; Hommel, 1993c, Experiment 1).

Table 1. Mean reaction times (in ms) and error percentages (in parentheses) as a function of stimulus type (colour or form), side of stimulus presentation, relative stimulus position, and response location

	Side	
	Left	Right
	Colour	
Left relative position		
Left response	470 (3.8)	477 (2.4)
Right response	484 (3.3)	462 (4.7)
Right relative position		
Left response	459 (2.9)	479 (2.2)
Right response	483 (5.1)	472 (3.6)
	Form	
Left relative position		
Left response	529 (3.1)	514 (2.5)
Right response	528 (3.8)	512 (5.0)
Right relative position		
Left response	522 (2.5)	530 (3.1)
Right response	514 (3.0)	522 (5.0)

condition, while no such interaction was observable in the form condition. This was confirmed by separate ANOVAs, which yielded a significant interaction of Side and Response Location with colour stimuli, $F(1,18) = 5.52$, $p < .05$, but not with form stimuli ($p > .9$). With the exception of a marginally significant interaction of Stimulus Side and Response Location ($p < .09$), all remaining main or interaction effects clearly failed to reach the significance criterion ($.14 < p < .9$).

Discussion

The experiment produced four results. First, the main effect of stimulus type shows that when presented within a line drawing, a line figure is more difficult to identify than a stimulus that is specified by a unique colour. This finding is not particularly surprising, given the bundle of evidence showing that visual search is more difficult when the defining features of the target are shared by distractors (e.g., Pashler, 1987; Quinlan & Humphreys, 1987; Treisman & Gelade, 1980). But, on the other hand, this very effect indicates that the preconditions for the temporal-overlap hypothesis sketched above are in fact given. Thus, while it is plausible to assume that, in temporal terms, at least the coding of presentation side is not influenced markedly by stimulus type, the processing of the relevant information clearly is. Since the temporal lag of the relevant information to location information is longer in the form condition, the location code should have been comparatively more decayed upon the arrival of the relevant information, so that its contribution to a response conflict would be reduced.

The second result is somewhat trivial. As is indicated in the stimulus side by relative-position interaction, stimulus eccentricity affects response time. This is to be expected with visual stimuli, since retinal acuity decreases towards the periphery. Comparable effects were obtained in the studies of Umiltà and Liotti (1987), Stoffer (1991), and Lamberts et al. (1992).

The third result is that the Simon effect clearly depends on the kind of stimulus employed. As Figure 2 shows, no Simon effect occurs with form stimuli as used in the studies of Umiltà and Liotti (1987) and of Stoffer (1991). That is, the results of these studies are replicated here. However, in the colour condition, a full-blown Simon effect is obtained. The data then support our preliminary consideration, that the apparent contradiction between the results of Lamberts et al. (1992) and those of Umiltà and Liotti (1987) may be resolved if one takes into account the relevant stimulus properties. In fact, the Simon effect shows up when the stimuli permit rapid identification, but not when identification is difficult.

The fourth result that the stimulus side (i.e., the hemifield), but not its relative position, produced a Simon effect, is related to the question as to which spatial reference system(s) play(s) a role in the Simon task. The present result does not correspond to the findings of Lamberts et al. (1992), who obtained Simon effects related to hemispace, hemifield, and relative position. However, the display conditions were somewhat different in their experiment. Both stimuli and frames were much larger, so that relative stimulus position should have been much easier to discriminate (and probably faster to code). Therefore, our failure to find an effect related to relative position should not be interpreted in such a way that this effect is impossible to produce with simultaneous presentation of stimulus and frames, but rather that our display conditions did not allow it to occur. This presumption is supported by the finding that Simon effects related to relative position show up in tasks quite similar to the present one when the stimulus is accompanied by a distinctive reference object to enhance the salience of the relative position (Hommel, 1993b). Moreover, under less complex viewing conditions (i.e., either without any distractors or with sufficiently pre-exposed frames), the relevance for the Simon effect of relative position apart from side is established well enough (Nicoletti & Umiltà, 1989; Umiltà & Liotti, 1987; Umiltà & Nicoletti, 1985). These findings suggest the cautious conclusion that a side-related Simon effect may or may not be accompanied by an effect related to relative position, depending on the specific display conditions employed.

Conclusions

The present experiment was carried out to obtain an answer to two questions. The second question was how to account for the contradiction between the findings of Umiltà and Liotti (1987) and of Lamberts et al. (1992). It was claimed that this contradiction can be resolved by considering whether the relevant stimulus properties permit rapid or rather slow stimulus identification; and the present data indeed provide good support for this assumption. With form targets that are hard to discriminate, the Simon effect was absent, just as in the studies of Umiltà and Liotti (1987) and of Stoffer (1991). With colour targets that are easy to discriminate, however, the Simon effect occurred,

as in the Lamberts et al. (1992) study, even though here the display conditions were exactly the same as in the experiments of Umiltà and Liotti and of Stoffer.

As was outlined in the Introduction, the results are clearly predicted from a temporal-overlap hypothesis, already put forward in more detail elsewhere (Hommel, 1993a). The main effect of the type of stimulus signals that the preconditions for this hypothesis are fulfilled – that is, the processing of the relevant stimulus information is slowed down while the coding of location should not be hampered by the stimulus manipulation. During the comparatively prolonged processing of stimulus form, the spatial code decays (spontaneously or by inhibition). Because less conflict (or facilitation) is to be expected from a weaker code, more decay means less conflict (or facilitation). In other words: the more slowly the relevant information is processed, the smaller the Simon effect.

The fact that an elimination of the Simon effect in the form condition, and not in the colour condition, is quite predictable without any reference to attentional operations, brings us back to our first question. We asked whether the results of Umiltà and Liotti (1987) and of Stoffer (1991) really support and require an attentional approach to the Simon effect, as Stoffer (1991) postulated. Since up to now the empirical base of an attentional approach to the Simon effect is limited to the results of these studies, an answer to this question is theoretically important. So how can we account for the present results from an attentional view?

It goes without saying that the approach of Stoffer (1991) does not provide a correct prediction of our findings. Upon stimulus presentation, the hypothetical attentional focus is assumed to shift to the compound of frame and stimulus; then, in order to focus onto the stimulus proper, attention should zoom into this structure. Because zooming should lead to a spatially neutral coding of the stimulus, no Simon effect is expected. This expectation was met in our form condition, but not in the colour condition. Since the kind of stimulus does not play any role in the attentional framework, there is obviously something missing.

However, it would be possible to extend the attentional approach and argue that a zooming operation of spatial attention is necessary only if the stimulus is difficult to discriminate, either from the background or from an alternative stimulus. While a difficult discrimination may require shifting plus zooming, shifting alone will probably suffice when the discrimination is easy, so that a lateral attentional shift would immediately precede stimulus analysis with easy, but not with difficult, discriminations. As the Simon effect is thought to depend critically on lateral shifts of spatial attention, the present interaction of stimulus definition and correspondence would be accounted for. That is, although the attentional approach to the Simon effect in its present state is not capable of handling the present findings, one could think of revised versions that are.

Still, there are several reasons for preferring a temporal overlap account to an attentional one. First, the proposed attentional reformulation is clearly ad hoc. It remains to be seen whether independent evidence in support of the additional assumption can be found.

Second, even a modified attentional approach would lack criteria that help to decide when, with which kind of stimuli, and under which conditions attentional zooming is required or not. Without such criteria, the approach is immune to further empirical tests. In contrast, the temporal-overlap account provides clear and simple criteria that allow an independent testing of its preconditions, as, for example, simple reaction-time tasks for estimating relative processing speeds for different stimulus attributes.

Third, there is an obvious imbalance between the high number of assumptions put into the attentional approach and its rather low utility in predicting empirical results, such as the present findings or others (e.g., Hommel, 1993a; McCann & Johnston, 1992). These data are reliably predicted from a temporal-overlap approach, despite its greater parsimony.

Fourth, there is not one result that really requires an attentional approach. While the absence of the Simon effect in the studies of Umiltà and Liotti (1987), Stoffer (1991), and in the present form condition can be accounted for by both the attentional and the temporal-overlap approaches, the results of Hommel (1993a) and McCann and Johnston (1992) can be explained by the overlap approach only. Even the results that Stoffer (1991: Experiment 1, single-frame condition) presented in support of his attentional approach, can easily be accounted for by a conventional coding approach (Hommel, 1993b).

Fifth, there is a hidden assumption of decay even in the attentional approach. In accounting for the results of Umiltà and Liotti (1987), Stoffer (1991) assumes that the attentional focus is first laterally shifted onto the frame-stimulus structure, this leading to non-neutral spatial coding of the whole structure. Only then is attention zoomed into the structure, with the result that the stimulus proper gets a spatially neutral code. This explains why the stimulus neither facilitates nor interferes with the response. But what about the spatial code of the frame-stimulus structure? Although Stoffer does not state this as a problem, it has to be assumed that this latter code must have decayed because, otherwise, a frame-related Simon effect should have occurred. Of course, it would be possible to add this as an explicit assumption to a revised attentional approach. But the other alternative, namely, to maintain the decay-related assumptions and drop the attentional overhead seems clearly more obvious.

In sum, it has been shown that the Simon effect depends on the relevant properties of the stimulus and that it can be eliminated by the difficulty of stimulus identification being raised. This finding resolves the apparent contradiction between the results of studies in which the Simon effect disappears and the very similar one in which it does not. While the results of the present experiment may be brought into line with a modified attentional approach to the Simon effect if the adding of ad-hoc assumptions is allowed, it seems obvious that the absence of the Simon effect in the experiments of Umiltà and Liotti (1987) and Stoffer (1991) cannot be used as a powerful argument in favour of such an approach. Instead, a more parsimonious temporal-overlap hypothesis is suggested. It relates these results and the impact of stimulus properties on the Simon effect in general to the temporal relations between the processing of the

relevant stimulus information and the processing of information about stimulus location. Thus, the cognitive coding of environmental events is assumed to depend on information conveyed by the stimulus, but not on certain operations of spatial attention.

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