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Looking for the source of the Simon effect: Evidence of multiple codes

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The Simon effect (SE) usually is described as the performance advantage that results when a target and its associated response share the same spatial code, as opposed to when they do not, even when the target's spatial code is task-irrelevant. To some, this task-irrelevant code represents the location of the target with respect to the participant (Simon & Craft, 1970), whereas to others (Umiltà & Nicoletti, 1992) it represents the location of the target with respect to the locus of attention. By using a spatial cuing procedure, we simultaneously tested both of these hypotheses and found evidence that both types of codes produce independent SEs, therefore providing evidence that multiple spatial codes can simultaneously influence performance in a Simon task.

Imagine a speeded-response task under which the value of a visual target (e.g., its color or shape) determines the correct response, and the location of the target is completely irrelevant. Further assume that there are two possible responses, made with the right or left index finger, and that the two possible display locations are to the left and right of fixation. Under these conditions, myriad studies have found that people are faster and more accurate when the target appears on the same side as the correct response than when the locations of the target and response are in conflict. This difference in performance often is called the Simon effect (SE, after Simon & Rudell, 1967; see Hedge & Marsh, 1975), and a large literature concerns why this occurs (e.g., De Jong, Liang, & Lauber, 1994; Hasbroucq & Guiard, 1991; Hommel, 1993; Kornblum & Lee, 1995; Kornblum, Stevens, Whipple, & Requin, 1999; Rubichi, Nicoletti, Iani, & Umiltà, 1997; Stoffer, 1991).

The SE was originally explained in terms of a "natural tendency" for participants "to respond toward, rather than away from, the source of stimulation" (Simon, Small, Ziglar, & Craft, 1970, p. 311). More recent models are more cognitive and focus on a match or mismatch between internal codes (see Kornblum et al., 1999, for a review of recent models). Although these newer theories vary in detail, they all share one common

component. In particular, they all propose that a task-irrelevant spatial code that is derived during perceptual processing of the target affects the subsequent processing of the task-relevant spatial code that is needed to produce the lateralized response.

These recent models diverge with regard to the specific source of the task-irrelevant spatial code. Simon and his colleagues first argued that the source of the task-irrelevant spatial code was "a directional cue associated with the spatial location of the stimulus" (Simon et al., 1970, p. 16; also Simon & Craft, 1970). The spatial location of the target stimulus was implicitly defined with respect to the participant. For example, a target appearing to the right of the participant was described as appearing in the right side of the world. Because this left–right spatial distinction can be characterized in most experiments by the location of the target with respect to the participant's line of gaze at the beginning of a trial, this will be called the side-of-fixation theory of the SE.

Later theories proposed that it was not the location of the target relative to fixation that gives rise to the task-irrelevant spatial code but its relative position with respect to the participants' locus of attention. An example of such a theory is the integrated model of the SE (Umiltà & Nicoletti, 1992). Under this model, the focus of attention at the time of target onset determines the SE. In other words, a target appearing to the right of the focus of attention would give rise to a "right" irrelevant spatial code, regardless of where the eyes were fixated, where the absolute target is located on the screen, or where other objects (if any) are located in the display. In this article, this will be called the side-of-attention theory of the SE.

Recent research on the SE has produced evidence in support of both the side-of-fixation and the side-of-attention theories. For example, both Hommel (1993) and Zimba and Brito (1995) found SEs with respect to fixation, using conditions in which the participant was presumably paying attention to the target's location before target onset. Because the target stimuli in these studies appeared to the side of fixation, these results were taken as support for the side-of-fixation theory. Moreover, because the targets were not lateralized with respect to the locus of attention and yet an SE was still observed, the results were also presented as evidence against the side-of-attention theory.

In contrast, Nicoletti and Umiltà (1994) found SEs with respect to the locus of attention. They directed the participants to attend to an intermediate location on one side of the display, presented the target to either side of this point, and observed an SE. Because the target stimuli appeared to the side of attention, these results were taken as support of the side-of-attention theory. Moreover, because (on some trials) the target stimuli were not lateralized with respect to fixation and an SE was still

observed, the results were also presented as evidence against the side-of-fixation theory.

The apparent contradiction that has arisen from these two lines of research may be a result of researchers implicitly assuming that the SE results from the influence of only one type of irrelevant spatial code. If this assumption is abandoned, then the conflict just described can be resolved by hypothesizing that the "standard" SE (i.e., the pattern that is observed when the location of attention and the point of fixation are the same) is caused by the combination of the effects of at least two different spatial codes. For example, one could argue that there is one code that represents the location of the target with respect to fixation and another code that represents the location of the target with respect to the locus of attention.

The idea that there might be more than one source of the SE has been raised before. For example, De Jong, Liang, and Lauber (1994) proposed a dual-process model of the SE, consisting of two independent mechanisms, whose separate effects are added to yield the observed SE. Other authors have acknowledged this possibility but have not formalized it (e.g., Lamberts, Tavernier, & d'Ydewalle, 1992; Rubichi et al., 1997). What is new about the present proposal is that it posits two different and separate irrelevant codes, as opposed to two different and separate cognitive mechanisms.

The purpose of the present study was to seek evidence of the simultaneous influence on performance of two different task-irrelevant spatial codes. To do so, an experimental procedure was designed that combined the methods used by Hommel (1993) and by Nicoletti and Umiltà (1994) because these methods have been used to produce evidence in favor of two different types of SE. In brief, in the present experiment, both target location with respect to fixation and target location with respect to attention were manipulated simultaneously and independently, allowing separate assessments of the two different SEs.

EXPERIMENT

METHOD

To manipulate the target location with respect to fixation, we asked participants to fixate on the center of the display and then presented the target to one side or the other. To manipulate the target location with respect to attention, we used a spatial cuing procedure (Posner, Snyder, & Davidson, 1980) to direct attention to a location other than fixation. To verify that the cues were successful in directing attention, we calculated the cuing effect, which is the response time (RT) advantage of valid cue trials (i.e., trials in which the target appeared at the cued location) over invalid cue trials (see Posner & Cohen, 1984). To test for two different

types of SE, we calculated differences in RT as a function of whether the target appeared on the same side of fixation (as the correct response) and as a function of whether the target appeared on the same side of attention.

Participants

Thirty-two adults, who reported normal or corrected-to-normal visual acuity, participated in the experiment. From a power analysis based on an effect size of 15 ms and a standard deviation of 19 ms, estimated from a previous experiment,¹ we concluded that 16 participants would be necessary to have 80% power. This number was then doubled to ensure sufficient power to detect two different SEs.

Equipment

All stimuli were presented on a 21-inch color monitor controlled by a Pentium-based computer. Responses were gathered with a standard keyboard.

Stimuli

Displays consisted of a fixation cross ($0.2^\circ \times 0.2^\circ$ of visual angle) that was present throughout the trial. A rectangular gray flash was used as the cue ($0.6^\circ \times 0.8^\circ$) on every trial. The targets were a green circle (diameter of 0.8°) and a green diamond (diagonal of 0.8°). There were six possible target locations (three to each side of fixation), arranged horizontally and equally spaced within each side of the display (Figure 1). The distance between two adjacent locations on the

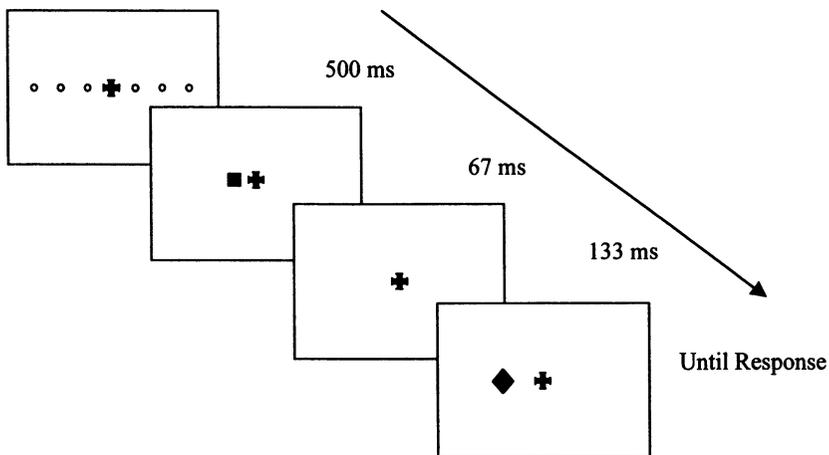


Figure 1. Schematic of the sequence of events. The circles in the first display show the different target positions in the experiment and were not presented to the participants. The second display shows the cue, and the fourth display shows the target on an invalid trial. Because the target appears to the left of the fixation cross, this should have created a “left” spatial code with respect to fixation; because the target appears to the left of the cue, this should have created a “left” spatial code with respect to the locus of attention at target onset

same side of fixation was 1.4° . The distance between fixation and the first target location away from it in each direction was also 1.4° . No placeholders were used to indicate these locations throughout the trial. The background of the display was black.

Task

The task was to respond as quickly and accurately as possible to the value of the target's shape (the cutoff level for accuracy was 95%). Half of the participants responded with the "Z" key for the circle and with the key "/" for the diamond, with their left and right forefingers, respectively. The other half of the participants used the reversed mapping. The keyboard was centered with respect to the display.

Design

A nested, within-subjects design was used. The independent variables were cue validity (valid, invalid), side of fixation (right, left), side of cue (right, left), and side of response (right, left). Side of fixation is the target's location with respect to fixation. Side of cue is the target's location with respect to the cue. (Note that side of cue takes on the values of right and left only on invalid cue trials.) Side of response is the appropriate response key.

Overall, the target was equally likely to appear at any of the six locations in the display. The target appeared at the cued location on 33% of the trials. The cue appeared only at the center location on each side of the display (the second and fifth location in Figure 1). On invalid cue trials, the target was equally likely to appear at either of the two uncued locations on the cued side; the target never appeared on the uncued side of the display.

Participants completed 10 blocks of 48 trials each. The first two blocks of the session were discarded as practice. This resulted in 32 observations per cell (side of cue by side of fixation by side of response) on invalid trials and 32 observations per cell (side of fixation by side of response) on valid trials.

Procedure

Each participant completed a single 1-hour session that began with a set of written instructions that described the task. After the instructions, participants completed a 30-trial block with no speed stress, followed by two full blocks of practice and eight blocks from which data were collected.

Trial events are illustrated in Figure 1. Each trial began with the presentation of the fixation cross, which stayed on the display throughout the trial. After 500 ms, the cue flashed for 67 ms, followed by a 133-ms interval at the end of which the target was presented. The target remained on the screen until a response was made. After the response, the screen went blank and remained so for a 1,500-ms intertrial interval, at which point the fixation cross for the next trial appeared. Trials on which the wrong button was pressed or on which responses were longer than 1,500 ms or shorter than 150 ms were flagged as errors. Each error was followed by a 100-ms 500-Hz tone. The mean RT and percentage of trials correct for a given block were displayed on the monitor after each block. If the accuracy for a given block was lower than 95%, the following message accompa-

nied the end-of-block feedback: "You are making too many errors. Please slow down and increase accuracy."

RESULTS

In brief, the attention manipulation was effective, and evidence was also found to support the separate existence of two different SEs: one determined by a side-of-fixation spatial code and another determined by a side-of-cue spatial code. Errors were committed on only 2% of the trials; these data were not further analyzed.

Attention manipulation

Mean RTs were submitted to a two-way within-subject ANOVA, with cue validity and side of fixation as the independent variables. A significant cuing effect of 12 ms was found when valid trials were compared with invalid trials, $F(1, 31) = 34.07$, $p < .001$. Mean RT was 428 ms for valid and 440 ms for invalid trials. Side of fixation had no significant main effect on performance, $F(1, 31) = 0.10$, $p = .75$. The two-way interaction was also not significant, $F(1, 31) = 0.16$, $p = .69$. In summary, the cues were successful in drawing attention to a specific display location and were equally efficient on the left and right sides of the display.

Simon effects

To assess the two different SEs, we looked only at invalid cue trials because it was only on these trials that the two effects can be clearly distinguished. The data were submitted to a three-way analysis of variance (side of fixation, side of cue, and side of response). The only significant main effect was side of response, $F(1, 31) = 17.90$, $p < .001$, demonstrating that right-hand responses were significantly faster than left-hand responses by 18 ms (431 ms for right and 449 ms for left), which is not surprising, given that most of the participants were right handed.

The two-way side-of-fixation by side-of-response interaction was significant, $F(1, 31) = 18.70$, $p < .001$, indicating a fixation-based SE of 11 ms (Figure 2). The side-of-cue by side-of-response interaction was also significant, $F(1, 31) = 24.20$, $p < .001$, indicating an attention-based SE of 12 ms (Figure 2). The side-of-fixation by side-of-cue interaction was not significant, $F(1, 31) = 4.04$, $p = 0.053$. In addition, the three-way interaction was not significant, $F(1, 31) = 0.15$, $p = 0.7$, which implies that the two different SEs were statistically additive.

In a separate analysis, it was tested whether an SE had also occurred on valid cue trials (i.e., when the target appeared at the presumed locus of attention). This test compared the RTs on valid cue trials for corresponding and noncorresponding spatial codes (i.e., when side of fixation

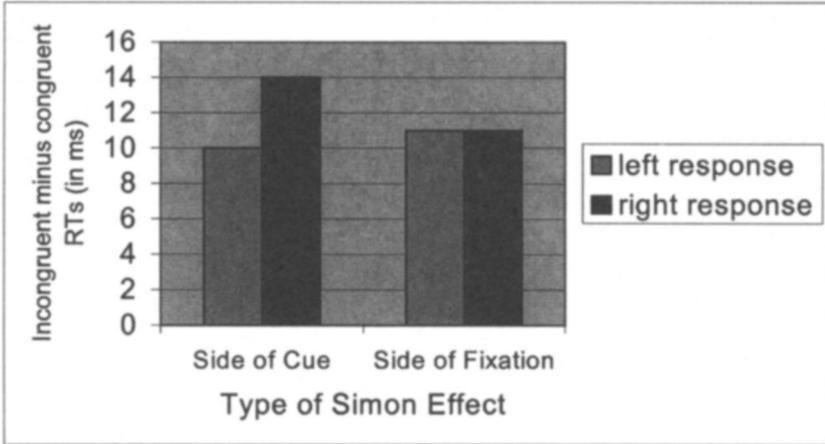


Figure 2. Incongruent minus congruent response times as a function of the type of Simon effect for left and right responses. Congruency was determined by the match (congruent condition) or mismatch (incongruent condition) of the irrelevant spatial code and the response spatial code

and side of response had the same or opposite values, respectively). The results confirmed the existence of a significant 16-ms SE on valid cue trials, $F(1, 31) = 20.07, p < .001$. Table 1 contains a summary of these data.

DISCUSSION

This study provides simultaneous evidence of two different types of SEs: one that is fixation based and another that is attention based. Thus, these results provide evidence in favor of both the side-of-fixation theory and

Table 1. Mean reaction times (ms) as a function of the irrelevant spatial code of the target and the side of the response for invalid and valid trials

Type or irrelevant spatial code	Value	Side of response	
		Left	Right
Invalid trials			
Side of cue	Left	444	438
	Right	454	424
Side of fixation	Left	444	437
	Right	455	426
Valid trials			
Side of fixation	Left	431	428
	Right	446	411

the side-of-attention theory but also indicate that neither theory alone is sufficient. Going further, insofar as the two SEs that have been observed were both additive and similar in magnitude (11 and 12 ms, respectively), the two types of code appear to have independent and interchangeable effects on performance.

Is it just one code?

Although our results seem to indicate that two different irrelevant spatial codes can have separate and simultaneous effects on performance, it is important to consider whether any single-code accounts might be able to explain these data as well. The most direct way to do this is to ask whether there is any reason for the side-of-fixation and side-of-attention codes to have the same value, such that a single model could explain both effects.

As an example, assume a model that attempts to explain all of the present results in terms of a side-of-fixation spatial code. In this case, the fixation-based SE is easily explained; the question is how to explain the attention-based SE (without resorting to a second spatial code). One way to do this is to posit that participants moved their eyes to the cued location on some proportion of the trials. This could cause the side-of-fixation code (which is the only code that is ever produced under this particular model) to act as if it were a side-of-cue code because now fixation is at the presumed location of attention.

Conversely, a model that attempts to explain all of the results in terms of side of attention could be reconciled with the fixation-based SE if it were posited that attention is not always summoned by the cue. On the trials in which attention did not move, this would cause the side-of-attention code (which is the only code produced under this model) to act as a side-of-fixation code because now attention remains at fixation.

In summary, if it is assumed that some aspect of the instructions or procedure fails on some nonnegligible proportion of the trials (such that the eyes are moved to the location of the cue or attention remains at fixation), then a single-code model appears to be consistent with the entire pattern of results. Thus, the next question becomes, Are there any counterarguments to these alternative interpretations for the present results?

There are two reasons to doubt that eye movements can account for the pattern of results shown here. First, the stimulus onset asynchrony in the experiment was fairly short (200 ms), which should have precluded eye movements on most trials (Viviani, 1990). Second, to account for two different SEs that are almost identical in magnitude, not only does one have to assume that eye movements occurred, but one also would have to assume that participants moved their eyes to the cue on exactly

half of the trials. This added constraint makes a single account in terms of side-of-fixation codes (only) much less probable.

Similarly, there are two reasons to doubt that attention remained at fixation. First, the stimulus onset asynchrony in the experiment was typical of previous spatial cuing studies that used exogenous cues to direct attention (e.g., Posner, Snyder, & Davidson, 1980), and, consistent with this, a significant spatial cuing effect was found. Second, to explain two effects that are almost identical in size, one has to assume not only that attention did not move on some trials but also that participants failed to move attention on exactly half of the trials, which likewise makes a single account in terms of side-of-attention codes improbable.

More directly, both of these single-code models would predict a strong negative correlation between the magnitudes of the fixation-based and attention-based SEs because only one such effect can occur at a time. Although it is not possible to measure the magnitudes of these effects on a trial-by-trial basis, on the added assumption that some participants would be better at obeying the instructions and procedure than others, the correlation across participants becomes relevant and can be tested easily. The value of this correlation was an insignificant -0.19 , $p = .291$, which argues against both of the single-code models.

In addition to the evidence presented here concerning the existence of multiple codes, Simon et al. (1970) also found evidence that separate SEs could be produced by two different spatial codes. In particular, they found separate effects for what they labeled the “physical” source of the stimulation and the “perceived” source of stimulation. (These two sources were dissociated by manipulating the phase shift between the two ears on binaural trials in an auditory version of the Simon task.) Also as in the present work, Simon and colleagues found that each source was responsible for approximately half of the overall SE.

Finally, it is also important to note that understanding our findings as evidence of two sources for the SE can help reconcile the previous studies that seemed to be in conflict. One example of an apparent contradiction is given by Hommel (1993), who found evidence of a fixation-based SE, and Nicoletti and Umiltà (1994), who found evidence of an attention-based SE. However, if one assumes that more than one spatial code is involved in creating an SE, then the results from these two studies are no longer in conflict.

One or two mechanisms?

Until this point, the two irrelevant spatial codes that are hypothesized to cause the SE have both been discussed in terms of relative location. The side-of-fixation theory concerns the location of the target relative to fixation; the side-of-attention theory concerns the location of the target

relative to attention. In this view, it seems most parsimonious to posit two perceptual mechanisms, one that codes space in terms of the eyes and another that codes space in terms of attention. Each mechanism produces a separate relative location code, and the two codes both contribute to the overall SE.

However, a different conception can explain the existence of two different codes using a single mechanism. This model is an extension of the theory proposed by Rubichi et al. (1997): the last attention shift theory. According to the original version of this theory, the single code that is responsible for the SE is one that was used to program and execute the last attention shift before response selection. If this theory were modified to allow that more than one of the recently used codes may influence response selection, then this single mechanism could produce both codes needed to explain the present results.

To see how this new model would work, note that in the present experiment, there were always two shifts of attention on invalid trials. The first shift of attention is to the cue, and because the cue and the target were always on the same side of the midline, the code used to program and execute this shift will always be the same as the side-of-fixation code referred to previously. The second shift is from the cue to the target, and this would use a code that matches the side-of-attention code. Therefore, if both of these attention shifts yield a spatial code and both codes are assumed to influence response selection, then this revised version of the last attention shift theory could also account for our results. As before, two different codes are assumed to cause the two different SEs, but, in contrast to before, a single theoretical mechanism produces both of the codes.

Summary

Whereas previous research sought evidence to favor one specific single-code account of the SE over others, the present data strongly argue for multiple codes. In particular, the present results provide evidence in favor of both a fixation-based and an attention-based model of the SE. Put differently, both side-of-fixation and side-of-attention theories were simultaneously supported. Therefore, we conclude that the mechanisms that yield the SE must be susceptible to the simultaneous influence of several irrelevant spatial codes. The exact nature of these codes has yet to be determined, with both relative position and attention shift submodels being currently viable.

Notes

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1. A previous experiment performed in our lab had the cue appear in all three locations at each side of the display. The cue was 75% valid, and all five invalid locations were equally likely. The results from that experiment did not differ from those of the experiment reported here: Evidence was found in support of two independent SEs of equal size, a side-of-fixation based SE (14 ms) and a side-of-attention based SE (15 ms). Fifty participants were tested in this experiment.

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