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Modes of Spatial Coding in the Simon Task

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Part of the data reported in the present study were used for a modelling purpose in Yamaguchi and Proctor (2012). The experimental data are available from the Open Science Framework project page (https://osf.io/unfkg/).

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Abstract

Many models of the Simon effect assume that categorical spatial representations underlie the phenomenon. The present study tested this assumption explicitly in two experiments, both of which involved eight possible spatial positions of imperative stimuli arranged horizontally on the screen. In Experiment 1, the eight stimulus locations were marked with eight square boxes that appeared at the same time during a trial. Results showed gradually increasing Simon effects from the central locations to the outer locations. In Experiment 2, the eight stimulus locations consisted of a combination of three frames of spatial reference (hemispace, hemifield, and position relative to the fixation), with each frame appearing in different timings. In contrast to Experiment 1, results showed an oscillating pattern of the Simon effect across the horizontal positions. These findings are discussed in terms of grouping factors involved in the Simon task. The locations seem to be coded as a single continuous dimension when all are visible at once as in Experiment 1, but they are represented as a combination of the lateral categories (‘left’ vs. ‘right’) with multiple frames of reference when the reference frames are presented successively as in Experiment 2.

Keywords: Stimulus-response compatibility; Simon effect; spatial representation; categorical perception; task representation.

Responses are faster and more accurate when the locations of stimuli and responses are spatially compatible than when they are incompatible (Proctor & Vu, 2006). This is also true when the compatibility between stimuli and responses involves a task-irrelevant stimulus-location feature (e.g., when responding to the colour of stimuli). The phenomenon is known as the *Simon effect* (Lu & Proctor, 1995; Simon, 1990). The Simon task has served as a major tool to investigate a range of psychological issues, such as automaticity, cognitive control, selective attention, and the nature of task representations (Hommel, 2011; Proctor, 2011). The present study investigated the spatial representation underlying the Simon effect for eight possible stimulus locations, addressing the question of whether the locations are represented categorically or continuously.

Perception is often categorical. For instance, difficulty discriminating spoken foreign language can be attributed in part to categorical perception of speech sounds, which prevents one from correctly recognising phonemes if these sounds are not used in their native language (e.g., Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). Also, deployment of visual attention is sometimes characterized better in terms of an object-based process rather than a spatial-based process (e.g., Duncan, 1984), suggesting that the basic unit of attention is discrete at a certain level of cognitive processing of visual environments. Indeed, most accounts of the Simon effect assume discrete spatial categories, such as ‘left’ and ‘right’, with respect to a reference point (e.g., Cho & Proctor, 2003; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kornblum, Hasbroucq, & Osman, 1990; Proctor & Cho, 2006; Yamaguchi & Proctor, 2011; Zorzi & Umiltà, 1995).

Given that the task typically involves only two stimulus locations (e.g., left vs. right) and two alternative responses, it seems reasonable to assume that the basic Simon task involves discrete categorical codes to represent the stimulus locations. However, according to most accounts of spatial cognition, binary codes are only one form of spatial representation, with another form being continuous (e.g., Kosslyn, 1994). Although the assumption of discrete spatial coding may have been a pragmatic choice and the discrete code assumption has served well in previous studies of the Simon task that typically involved only two stimulus locations, the assumption has rarely been examined explicitly for situations involving more than two stimulus locations.

An exception is a study of Lamberts, Tavernier, and d'Ydewalle (1992, Experiment 2). They presented boxes in two of eight horizontal locations, with one box containing a square or a circle to which their participants responded. If the eight possible stimulus locations were encoded continuously, the magnitude of the Simon effect should be a function of the spatial distance (or eccentricity) from a reference point (e.g., fixation point), so that the effect increases as the distance increases. If stimulus locations were encoded categorically as left or right with respect to a single left-right dimension, the magnitude of the Simon effect should be constant across the stimulus locations, regardless of how far away from the central position stimuli appeared. Lamberts et al.'s results supported neither of the two predictions. They showed that the Simon effect differed according to the stimulus locations, which contradicted models that assume a single categorical left-right coding of spatial locations. However, the Simon effect did not increase monotonically as a function of the distance from the reference point either, contradicting a model that assumes a continuous spatial representation. Instead, their data showed an oscillating pattern of the Simon effect across the horizontal positions (see Table 3 of Lamberts et al., 1992), the effect being largest at the outermost positions (46 ms), absent at the second from the outmost positions (1 ms), evident again at the third from the outermost positions

(14 ms), and, most unintuitively, reversed at the innermost positions (-28 ms).

The authors proposed that this Simon effect pattern could be produced when the eight spatial positions consisted of three binary dimensions, each consisting of ‘left’ and ‘right’ categorical codes. They referred to the three dimensions as *hemispace*, which divided the entire screen into halves, *hemifield*, which divided each hemispace into halves, and *relative position*, which referred to the left or right of the two possible locations in a hemifield. Lamberts et al.’s (1992) method encouraged differentiating these three reference frames by presenting a fixation mark in either half of the display at the beginning of a trial, emphasizing the hemispaces, and then two stimulus holders on either side of the fixation mark, emphasizing the hemifields, in which one of the holders containing the imperative stimulus, emphasizing the relative positions. The oscillating pattern of the Simon effect could be accounted for by a combination of categorical spatial coding in the three frames of spatial reference. Using the same display configuration, Roswarski and Proctor (1996, Experiment 1; also see Ciardo, Luigi, Nicoletti, Rubichi, & Iani, 2016) replicated Lamberts et al.’s (1992) method and found evidence consistent with the binary coding of stimulus locations based on the three reference frames. Moreover, while Lamberts et al. used stimulus shape as the task-relevant attribute, Roswarski and Proctor found that the results were similar when the relevant stimulus dimension was colour (red/green). However, whether coding of stimulus locations according to multiple binary dimensions is a general mode of spatial representation in the Simon task is still subject to scrutiny.

Studies in other areas have provided evidence that categorical coding with respect to multiple dimensions occurs when the situation induces participants to represent the task in that manner (e.g., Kleinsorge, Heuer, & Schmidtke, 2004; see Xiong & Proctor, 2018, for a review). For example, in a study by Dreisbach and Haider (2008), participants responded to eight German words. Four words were names of moving objects and were assigned to one response key, and the remaining four words were names of non-moving objects and were assigned to the other response key. Half of each set of four words were animals and were coloured in one colour (e.g., red), and the other half were names of non-animals and were coloured in another colour (green). Also, half of the animal and non-animal words started with a vowel, and the other half started with a consonant. The study demonstrated that changes of word colour from one trial to the next slowed responding (i.e., a switch cost) only when participants were told to perform different tasks (animal/non-animal judgment or vowel/consonant judgment) according to the word colour, despite the fact that each word was assigned to the same keypress response and, thus, participants responded to all words by pressing the same keys in both tasks. However, changes of word colour did not slow responding when they were instructed to make responses to the same stimuli with respect to a single set of rules (moving/non-moving distinction). That is, participants represented the eight words as consisting of two orthogonal categories or of one category, depending on how they were instructed on the task.

In the present study, we tested whether different modes of spatial coding could be induced in the Simon task. We hypothesized that the specific display used in the studies of Lamberts et al. (1992) and Roswarski and Proctor (1996), with its distinct subgroups of locations, induced discrete groupings of stimulus locations and resulted in their participants adopting categorical, binary spatial coding. If so, it should be possible to induce participants to adopt continuous spatial coding when the stimulus locations vary in a single continuous dimension. We conducted two experiments that involved eight stimulus locations but differed mainly as to whether display contained factors inducing grouping of the stimulus locations. In both experiments, participants pressed left and right response keys according to a non-spatial attribute of stimuli (circle/square in Experiment 1 and green/red in Experiment 2). Although both experiments involved eight stimulus locations that were arrayed horizontally on the screen, the experiments differed in several factors intended to increase the likelihood of continuous or categorical spatial coding (see Figure 1). This was done by making multiple spatial frames of reference less salient in Experiment 1 and more salient in Experiment 2.

For Experiment 1, eight square frames appeared at once, and the imperative stimulus appeared in one of these squares on each trial. We expected that this display would encourage continuous spatial coding as there was no salient visual information other than the eight stimulus locations. For comparison to Lamberts et al.'s (1992) original experiment, we used the circle/square distinction as the relevant task dimension. If continuous spatial coding is used in this display, the Simon effect would increase as the distance from a reference point (i.e., the central cross) increases. If categorical left-right spatial coding is used, the Simon effect should depend only on the side of the display in which the stimulus appears but not on how far it is from the screen centre. If participants adopt multiple frames of reference voluntarily to code the eight locations, the Simon effect should display an oscillating pattern as in Lamberts et al.'s results.

For Experiment 2, two rectangular frames first appeared on the left and right sides of the screen, and each of the rectangular frames contained a centred cross. In this display, a division of the display into two halves (hemispace) was salient. With a brief delay, two horizontal bars occurred on the left or right side of the centre cross in one of the rectangle frames, making division of the hemispace into two halves (hemifields) salient. Finally, the imperative stimulus appeared above one of the bars, which emphasized the relative position of the stimulus within the hemifield. We expected that this display would encourage categorical spatial coding of stimulus locations with respect to the three frames of reference and result in a non-monotonic pattern of the Simon effect that oscillates across the stimulus locations as in the studies of Lamberts et al. (1994) and Roswarski and Proctor (1996).

General Method

Participants

Forty undergraduate students at Purdue University participated for experimental credits toward their introductory psychology courses. All reported having normal or corrected-to-normal visual acuity. Twenty participants (11 females; mean age = 19.70, *SD* = 2.08) partook in Experiment 1, and the remaining twenty (11 females; mean age = 19.45, *SD* = 1.43) in Experiment 2. Participants' handedness was not examined, but because approximately 90% of the population is right handed (McManus, 2009), the majority of participants can be assumed to be right handed.

Apparatus and Stimuli

The apparatus consisted of a 19-in. colour monitor and a personal computer, controlled by an E-Prime program (Psychology Software Tools, Pittsburgh, PA). Responses were made by pressing the left ("z") and right ("/") keys on a QWERTY keyboard. A chin rest was placed at a distance of 65 cm from the computer monitor.

In Experiment 1, the imperative stimuli were filled circle (2.2-cm diameter) and square (2.0-cm sides) that appeared in white against a black background. There were four stimulus locations on each side of the screen centre, marked by square boxes (3.2-cm sides) drawn in white. In Experiment 2, the stimuli were green and red filled squares (0.7-cm sides). There were also two rectangular frames drawn on the left and right halves of screen. The height and width of the frames were 12.4 cm and 8.2 cm, respectively, and a cross was at the centre of each frame. The frames and the crosses were drawn in white against black background. Two white horizontal lines (1.1 cm) appeared on the left or right side of the cross in either of the two frames; the separation between the two lines was 0.4 cm, and the distance from the cross and the edge of the line at the near end was 0.8 cm. The coloured shapes occurred 0.2 cm above either line. These displays are illustrated in Figure 1 (top panels).

Procedure

The experiment was conducted individually in a dimly lit cubicle. Participants were seated directly in front of the computer monitor and asked to maintain their chin in the chin rest throughout the experiment. They first read task instructions displayed on the computer monitor and started a block of 16 practice trials by pressing the space bar, followed by five blocks of 80 test trials each. An experimental session lasted for less than half an hour.

In Experiment 1, each trial started with a blank screen for 1000 ms. A crosshair then occurred at the centre of the screen for 500 ms, and was replaced with a row of eight white boxes. One of the eight boxes contained the imperative stimulus, and the stimulus appeared in the eight boxes equally often in a random order. The stimulus and the box array stayed on the screen for 3000 ms or until a response was made. For half the participants, circles and squares were assigned to the left and right keys, respectively, and the mappings were reversed for the other half. If an incorrect response was made, or if no response was registered before the 3000-ms deadline, an error tone (400 Hz) was presented for 500 ms. If the correct response was made, no feedback was given. The next trial started with the 1000-ms blank screen. Response time (RT) was the interval between stimulus onset and a keypress.

In Experiment 2, each trial started with a display containing two rectangular frames on the left and right of display. With a 1,000-ms delay, two horizontal lines appeared on the left or right side of the cross at the centre of either frame. After further delay of 300 ms, the imperative stimulus occurred on either of the two lines, and participants responded to the colour of the stimulus by pressing a key. The colour-key mappings were counterbalanced across participants. The procedure followed Experiment 1 in other respects.

Results

Trials for which RT was < 200 ms or > 2000 ms were discarded (0.60% of all trials in Experiment 1, and 0.48% in Experiment 2). Mean RT for correct responses and percentage errors (PE) were computed for each participant and are summarized in Figure 1 (middle panels) and Table 1, respectively. RT and PE showed similar patterns of the Simon effects across the eight stimulus locations in both experiments, and our analyses focused on RT. The Simon effect was computed with respect to the screen centre (i.e., hemispace). For the stimulus locations in the left hemispace, the Simon effect was RT for the right response (incompatible) minus RT for the left response (compatible), and for the stimulus locations in the right hemispace, it was RT for the left response (incompatible) minus RT for the right response (compatible). The Simon effect is summarised in Figure 1 (bottom panels).

In both experiments, RT for correct responses were analysed in terms of linear mixed effect models. The baseline (null) model only involved a random intercept based on individual participants. In the next model, the hemispace (left vs. right), response side (left vs. right), and their interaction, were added to the baseline model as fixed effects, which in essence assumed categorical coding based on the hemispace. The full model included hemispace (left vs. right), response side (left vs. right), stimulus eccentricity (1-4 from the innermost to outermost positions), and all of their interactions[1]. The models were fitted and compared by using the "nlme" R-package.

Experiment 1

The linear mixed effect model analysis indicated that adding the hemispace and response side to the baseline model improved the model fit significantly, $\chi^2(3) = 92.71$, $p < .001$, and adding stimulus eccentricity further improved the fit, $\chi^2(4) = 71.87$, $p < .001$. All effects included in the two models are summarised in Table 2. The first model shows that hemispace, response side, and their interaction were all reliable predictors of RT. The interaction term indicates the Simon effect based on the hemispace. The second model further indicated that hemispace, response side, and their interaction, were no longer reliable predictors by themselves. Instead, stimulus eccentricity predicted RT reliably, and so did its interactions with response side, hemispace, and both of these factors. As shown in Figure 1 (middle left panel), RT was generally longer as the stimulus eccentricity increased. Most importantly, the Simon effect depended on the stimulus eccentricity as well (see bottom left panel).

In the left hemispace, the Simon effect was -8, 18, 26, and 52 ms, from the innermost to the outermost positions. The Simon effects were not significant statistically in the two inner positions (*p*s = .482 and .113), but they were significant in the two outer positions (*p*s = .014 and < .001). Multiple comparisons with the Bonferroni correction indicated that the Simon effect

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[1] We also tested a version of the full model with random slopes for the three predictors. Although this model did provide a better fit to the data in the two experiments, the resulting parameter values were very similar. We also tested the full model with random slopes for all interaction terms, but this model did not perform better than the full model with random slopes for the three predictors (*p*s > .9). Therefore, we only report the full model without random slopes here.

was significantly smaller for the innermost position than for the outermost position ($p = .001$[2]) although it did not differ significantly from the second and third positions (*p*s = .215 and .261). In the right hemispace, the Simon effect was 39, 51, 36, and 48 ms, from the innermost to the outermost positions; all effects were statistically significant (*p*s = .014 for the innermost and < .001 for the remaining positions). There were no significant differences among these locations (*p*s > .950). Therefore, the increasing Simon effect with the stimulus eccentricity reflected the results in the left hemispace, but the Simon effect was relatively constant across the four positions in the right hemispace.

Experiment 2

Unlike Experiment 1, adding the hemispace and response side to the baseline model did not improve the model fit, $\chi^2(3) = 1.91$, $p = .592$, but adding stimulus eccentricity in the full model significantly improved it, $\chi^2(4) = 32.04$, $p < .001$, which indicated that all predictors in the model were reliable (see Table 3). There was a clear oscillating pattern of the Simon effect in both hemispaces (see Figure 1, right bottom panel). In the left and right hemispaces, respectively, the Simon effects were -28 and -23 ms for the innermost positions (*ps* < .001 and = .019), 18 and 21 ms for the second inner positions (*p*s = .050 and .011), 1 and -7 ms for the third inner positions (*p*s = .910 and .558), and 20 and 22 ms (*p*s = .099 and .073) for the outermost positions. The Simon effects for the innermost positions were statistically smaller than the Simon effects in the second inner positions (*p*s = .008 and .005), not different from the Simon effects for the third inner positions (*p*s = .113 and .938), but again significantly smaller than the effects for the outermost positions (*p*s = .001 and .027). These outcomes differ from those of

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[2] *P*-values for multiple comparisons were Bonferroni adjusted by multiplying it by the number of the comparisons (= 4).

Experiment 1 but are similar to the results of Lamberts et al.'s (1992) Experiment 2, which were explained in terms of three spatial frames of reference, hemispace, hemifield, and relative position.

As in Lamberts et al.'s study, we also submitted RT to a 2 (Hemispace: left vs. right) x 2 (Hemifield: left vs. right) x 2 (Relative Position: left vs. right) x 2 (Response Side: left vs. right) analysis of variance (ANOVA; see Table 4). The results showed no significant main effects, but the interactions between Hemifield and Response Side and between Relative Position and Response Side were significant. In the left hemifield, the left responses (*M* = 484 ms) were faster than the right hemifield (*M* = 489 ms), whereas in the right hemifield, the right response (*M* = 484 ms) were faster than the left hemifield (*M* = 490 ms). Thus, there was a 6-ms Simon effect with respect to the hemifield. On the left relative position, the left responses (*M* = 479 ms) were faster than the right responses (*M* = 495 ms), whereas on the right relative position, the right responses (*M* = 478 ms) were faster than the left responses (*M* = 495 ms). Thus, there was a 17-ms Simon effect with respect to the relative position. Nevertheless, the interaction between Hemispace and Response Side was not significant, indicating no evidence for the Simon effect with respect to the hemispace.

In addition, there were also the interactions between Hemispace and Relative Position and between Hemifield and Relative Position. In the left hemispace, responses were faster on the right relative position (*M* = 484 ms) than on the left relative position (*M* = 493 ms), and in the right hemispace, responses were faster on the left relative position (*M* = 481 ms) than on the right relative position (*M* = 489 ms). In the left hemifield, responses were faster on the left relative position (*M* = 485 ms) than on the right relative position (*M* = 488 ms), but in the right hemifield, responses were faster on the right relative position (*M* = 485 ms) than on the left relative position

(M = 489 ms). These outcomes simply suggested that, overall, responses were faster if the stimulus location was closer to the screen centre, although the Simon effects did not vary linearly across the horizontal positions.

General Discussion

The present study tested two variations of the Simon task in which different types of display were used to manipulate how participants represent eight stimulus locations arranged horizontally on the screen. Experiment 1 presented eight horizontally arranged squares as the markers of the stimulus locations. This arrangement was similar to Lamberts et al.'s (1992) experiment, in which the authors found that the eight positions were represented as the combinations of three binary spatial references, hemispace, hemifield, and relative position. However, the method differed from that of Lamberts et al. in that all eight squares were presented at the same time, whereas Lamberts et al.'s display presented a fixation mark in a hemispace that was followed by two squares in a hemifield, emphasizing the three reference frames. Experiment 2 also involved eight stimulus locations, but the display differed from Experiment 1 and Lamberts et al.'s in that only two horizontal lines were presented to indicate two adjacent stimulus locations on each trial. However, Experiment 2 was similar to Lamberts et al.'s display in that it emphasized the three reference frames by presenting different parts of the display in different timings. Consequently, we expected that the eight stimulus locations would be coded continuously with respect to a single spatial reference in Experiment 1 but categorically in terms of the three reference frames in Experiment 2.

In Experiment 1, the Simon effect showed an overall increasing function of stimulus eccentricity. This trend appeared to depend more on increasing RT for incompatible responses rather than decreasing RT for compatible responses (see Figure 1, middle left panel). However, one should exercise caution interpreting these observations to reflect separate contributions of facilitation and interference (e.g., Cohen, Dunbar, & McClelland, 1990). In this particular task setting, there was an increasing trend of RT with stimulus eccentricity, which could reflect a number of factors, such as the duration of shifting focal attention to the target location from the central fixation or greater variability in processing time for more peripheral visual areas; in both cases, RT would increase as the stimulus eccentricity increases (Yamaguchi & Proctor, 2012). This increasing trend of RT was consistent with increasing incompatibility with stimulus eccentricity, which would amplify the effect of eccentricity for incompatible responses, but the trend was inconsistent with increasing compatibility, which would counteract the benefit of eccentricity for compatible responses.[3]

Moreover, although the overall results of Experiment 1 indicated an increasing trend of the Simon effect as the stimulus eccentricity increased, the results also showed somewhat different patterns of the Simon effect in the two hemispaces. The Simon effect in the left hemispace showed a monotonically increasing function, whereas the Simon effect in the right hemispace showed a non-monotonic, which might be slightly oscillating. These observations may imply that both continuous and categorical spatial coding influenced the Simon effect simultaneously. Alternatively, it is possible that, because the majority of participants can be assumed to be right-handed (McManus, 2009), they could react to stimuli on the right-hand side faster and yielded stronger interference with the left-hand responses in the right hemispace than in the left hemispace. This would increase the Simon effect in the right hemispace and reduces the effect in the left hemispace. The discrepancy between the two hemispaces may also reflect

[3] We also ruled out the possibility that response speed alone accounted for the smaller Simon effects for inner positions (i.e., the Simon effect increased as overall RT was longer) because the Simon effect tended to decrease as overall RT increased (also see Proctor et al., 2009) at each eccentricity in Experiment 1.

attentional biases. As seen in Figure 1 (middle left panel), RTs for the left and right responses were equivalent in the first position of the left hemispace, which yielded the Simon effect near zero or even negative. This result may imply that this position served as the attentional centre of the spatial continuum. Suppose that the centre of attention was at the left side of the innermost position of the left hemispace, the distance to the outermost position of the left hemispace was about the same as the distance to the second inner position of the right hemispace (12.8 cm), and these two positions yielded similar magnitudes of the Simon effect (52 ms vs. 51 ms). That is, the same spatial coding might have been used in both hemispaces, but the Simon effect might have reached an asymptote early in the right hemispace, producing a relatively flat pattern across the four positions of the right hemispace whereas the asymptote was reached only at the fourth position of the left hemispace.

Categorical spatial coding was more apparent in Experiment 2. As in Lamberts et al.'s (1992) study, the Simon effect showed an oscillating pattern across the horizontal positions, and the patterns were similar in the two hemispaces. The analysis based on the three reference frames yielded effects of hemifield and relative position, but unlike Lamberts et al.'s results, the Simon effect did not emerge based on the hemispace. The lack of the effect of hemispace might be due to the large frame that divided the display into halves (see Figure 1). This might have allowed participants to focus only on the content within the frame and ignore the relative positions of the frames within the entire display.

Overall, the present results demonstrated different patterns of the Simon effect in the two experiments, supporting the conclusion that different modes of spatial coding operate in the Simon task. Most models of the Simon task assumed categorical coding of stimulus and response locations, and this assumption is not consequential if the task setting is as simple as to involve two possible stimulus and response locations. However, in more complex task settings as in the present study, categorical coding may occur with respect to different frames of reference. Ciardo et al. (2016) examined a joint Simon task in which colour stimuli could occur in any of four locations demarcated by vertical lines. Their results provided evidence that stimulus position was coded only relative to the reference of the centre of the screen (hemispace) when each participant was assigned a single response to make to a single colour. In contrast, when each participant was assigned two different responses to make to two of four possible stimulus colours, stimulus position was coded relative to both hemispace and relative position within a hemispace (as in the present Experiment 2). The findings also provide evidence that different modes of spatial coding can be used for the same visual environment in different task contexts.

Categorical spatial coding may be a limited approach to account for the underlying cognitive processes when more than two stimulus locations are possible, as implied by the present Experiment 1. To date, the only model of the Simon task that assumes continuous spatial representations appears to be the vector model (Yamaguchi & Proctor, 2012), which assumes a geometrical representation of stimuli and responses in a common psychological space. This has also been shown to account for task settings in which categorical coding appears appropriate (e.g., Yamaguchi & Proctor, 2011). Whether this approach could account for the Simon effect with symbolic stimuli (e.g., spatial words and arrows; Proctor, Yamaguchi, Zhang, & Vu, 2009; Yamaguchi, Chen, & Proctor, 2015) would be an interesting issue to address in future investigations.

Disclosure of Interest

The authors report no conflict of interest.

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Table 1. Percentages of error trials as a function of stimulus eccentricity (1 = innermost, 4 = outermost) and hemispace (left vs. right).

Compatibility	Left hemispace								Right hemispace							
	4		3		2		1		1		2		3		4	
Experiment 1																
Compatible	1.41	(.53)	1.44	(.55)	1.41	(.53)	2.04	(1.18)	1.20	(.51)	1.60	(.74)	.60	(.33)	.81	(.37)
Incompatible	6.83	(1.65)	5.34	(1.61)	3.23	(.81)	3.06	(1.15)	2.40	(1.25)	4.04	(.83)	5.65	(1.10)	5.65	(1.32)
Simon effect	5.42	(1.68)	3.90	(1.51)	1.82	(1.11)	1.02	(.88)	1.20	(1.16)	2.44	(1.18)	5.05	(1.64)	4.84	(1.39)
Experiment 2																
Compatible	1.22	(.52)	2.20	(.68)	.81	(.37)	5.51	(1.03)	2.67	(1.01)	1.20	(.42)	3.32	(1.07)	1.20	(.42)
Incompatible	2.15	(1.02)	1.42	(.54)	2.63	(.60)	2.06	(.58)	1.82	(.68)	4.64	(1.40)	2.03	(.86)	5.14	(1.41)
Simon effect	-.94	(.86)	-.78	(.68)	1.82	(.61)	-3.46	(.80)	-.85	(.91)	3.44	(1.42)	-1.29	(.85)	3.94	(1.44)

Note: Values in parentheses are the standard error of means.

Table 2. The parameter estimates of the linear mixed effect models for Experiment 1

Factors	*Estimate*	*95% CI*	*df*	*SE*	*t*	*p*
Fixed Effects						
Response Side (RS)	**86.93**	**(64.76, 109.11)**	**7709**	**11.31**	**7.68**	**< .001**
Hemispace (HS)	**94.55**	**(72.40, 116.69)**	**7709**	**11.30**	**8.37**	**< .001**
RS x HS	**-65.13**	**(-79.14, -51.12)**	**7709**	**7.15**	**-9.11**	**< .001**
Random Effect						
Participants (intercept)	112.01	(82.03, 152.95)				
Fixed Effects						
RS	-9.35	(-63.27, 44.56)	7705	27.52	-.34	.734
HS	28.95	(-24.93, 82.84)	7705	27.50	1.05	.293
SE	**-41.60**	**(-72.73, -10.46)**	**7705**	**15.89**	**-2.62**	**.009**
RS x HS	-15.88	(-49.96, -18.20)	7705	17.39	-.91	.361
RS x SE	**38.91**	**(19.17, 58.66)**	**7705**	**10.08**	**3.86**	**< .001**
HS x SE	**26.52**	**(6.80, 46.25)**	**7705**	**10.07**	**2.63**	**.008**
RS x HS x SE	**-19.93**	**(-32.41, -7.46)**	**7705**	**6.37**	**-3.13**	**.002**
Random Effect						
Participants (intercept)	111.89	(81.94, 152.79)				

Note: Response Side (left = 1, right = 2), Hemispace (left = 1, right = 2), Stimulus Eccentricity (1 = innermost, 4 = outermost); *bold indicates statistical significance at alpha = .05.*

Table 3. The parameter estimates of the linear mixed effect models for Experiment 2

Factors	*Estimate*	*95% CI*	*df*	*SE*	*t*	*p*
Fixed Effects						
Response Side (RS)	8.31	(-10.12, 26.74)	7743	9.40	.88	.377
Hemispace (HS)	6.25	(-12.21, 24.71)	7743	9.42	.66	.507
RS x HS	-5.98	(-17.64, 5.68)	7743	5.95	-1.01	.315
Random Effect						
Participants (intercept)	53.32	(38.92, 73.04)				
Fixed Effects						
Response Side (RS)	**-83.42**	**(-128.64, -38.20)**	**7739**	**23.08**	**-3.61**	**< .001**
Hemispace (HS)	**-84.56**	**(-129.82, -39.31)**	**7739**	**23.10**	**-3.66**	**< .001**
Stimulus Eccentricity (SE)	**-51.35**	**(-77.46, -25.24)**	**7739**	**13.33**	**-3.85**	**< .001**
RS x HS	**53.61**	**(25.05, 82.18)**	**7739**	**14.58**	**3.68**	**< .001**
RS x SE	**36.70**	**(20.22, 53.19)**	**7739**	**8.41**	**4.36**	**< .001**
HS x SE	**36.34**	**(19.86, 52.89)**	**7739**	**8.43**	**4.32**	**< .001**
RS x HS x SE	**-23.86**	**(-34.29, -13.44)**	**7739**	**5.32**	**-4.49**	**< .001**
Random Effect						
Participants (intercept)	53.31	(38.91, 73.04)				

Note: Response Side (left = 1, right = 2), Hemispace (left = 1, right = 2), Stimulus Eccentricity (1 = innermost, 4 = outermost); *bold indicates statistical significance at alpha = .05.*

Table 4. ANOVA table for RT in Experiment 2.

Factor	*df*	*MSE*	*F*	*p*	η_p^2
Hemispace (HS)	1,19	310.71	2.27	.148	.107
Hemifield (HF)	1,19	679.23	< 1	.843	.002
Relative Position (RP)	1,19	661.55	< 1	.894	.001
Response Side (RS)	1,19	2348.15	< 1	.941	< .001
HS x HF	1,19	965.75	4.06	.058	.176
HS x RP	**1,19**	**483.86**	**12.21**	**.002**	**.391**
HF x RP	**1,19**	**215.91**	**5.10**	**.036**	**.212**
HS x HF x RP	1,19	676.86	1.00	.329	.050
HS x RS	1,19	668.95	.99	.332	.050
HF x RS	**1,19**	**429.04**	**6.76**	**.018**	**.262**
HS x HF x RS	1,19	647.40	.43	.521	.022
RP x RS	**1,19**	**841.64**	**26.87**	**< .001**	**.586**
HS x RP x RS	1,19	450.23	< 1	.678	.009
HF x RP x RS	1,19	797.27	.20	.657	.011
HS x HF x RP x RS	1,19	1036.33	2.29	.147	.108

Note: Bold indicates statistical significance at alpha = .05.

Figure 1. The trial sequences (top panels), response times (RT; middle panels), and the Simon effect (bottom panels), with respect to the hemispace in Experiment 1 (left panels) and Experiment 2 (right panels). The displays are shown only for an illustrative purpose, not in the actual scale.