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ORIGINAL ARTICLE

How different location modes influence responses in a Simon-like task

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Abstract Spatial information can be conveyed not only by stimulus position but by the meaning of a location word or direction of an arrow. We examined whether all the location-, arrow- and word-based Simon effects or some of them can be observed when a location word or an arrow is presented eccentrically and a left–right keypress is made to indicate its ink color. Results showed that only the location-based Simon effect was observed for location words, whereas an additional smaller arrow-based Simon effect, compared to the location-based Simon effect was observed, for arrows. These results showed spatial location, arrow direction, and location word stimulus dimensions affect response position codes in a spatial-to-verbal priority order, consistent with the possibility that they can activate mode-specific spatial representations.

Introduction

When people respond to an object or its features, the location occupied by the object can influence the response. This phenomenon is addressed in the *Simon task*, named for Simon (1990). In the typical visual version of this task, stimulus locations are task-irrelevant and nonspatial attributes (e.g., colors or shapes) convey the task-relevant information, to which left and right keypresses are paired. Responses are faster and/or more accurate when the nonspatial attributes and response positions correspond than when they do not, which is called the location-based Simon effect (see reviews of Lu & Proctor, 1995; Simon, 1990; Umiltà & Nicoletti, 1990).

The Simon effect also occurs with stimuli whose spatial information is not conveyed by their physical locations but through symbolic codes, such as location words or arrows (Khalid & Ansorge, 2013; Pellicano, Lugli, Baroni, & Nicoletti, 2009; Proctor, Yamaguchi, Zhang & Vu, 2009). Responding to a feature (e.g., color) of a centrally presented location word (e.g., *left* or *right*) and ignoring its meaning, yields better performance when response position and meaning of the word are compatible than when they are incompatible, which is referred to as a word-based Simon effect (Khalid & Ansorge, 2013; Lu & Proctor, 2001; Pellicano et al., 2009; Proctor, Marble, & Vu, 2000; Proctor et al., 2009). Similar results occur when location words are replaced by left- or right- pointing arrows (Masaki, Takasawa, & Yamazaki, 2000; Pellicano et al., 2009; Proctor et al., 2009) and with centered depictions of objects with salient left or right handles (Cho & Proctor, 2010; Lien, Gray, Jardin, & Proctor, 2014).

The location-based Simon effect has been attributed to responses activated by automatic processing of task-irrelevant stimulus location when the required response discrimination is left or right (Ansorge & Wühr, 2004), which interferes with responses activated by processing of a task-relevant attribute in accordance with the instructed stimulus–response (S-R) mapping (De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990; Zorzi & Umiltà, 1995). Similarly, the word- and arrow-based Simon effects occur because location word and arrow direction are processed automatically, interfering with the indication of their ink colors (Lu & Proctor, 2001; Proctor et al., 2000; Proctor et al., 2009).

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When the task-relevant attribute is location word or arrow direction, the location-based Simon task is often called a spatial Stroop task (Lu & Proctor, 1995). In this task, besides the location-based Simon effect as a function of S–R correspondence, there is an S–S congruency effect, with faster and less error-prone responses when stimulus location and the meaning of location word or direction of arrow are congruent than when they are incongruent. Moreover, there exists an S–R compatibility effect, manifesting as faster and less error-prone responses when response position and the meaning of the location word or direction of arrow are compatible than when they are incompatible (Funes, Lupiáñez, & Milliken, 2007; Lu & Proctor, 1995; Luo, Lupiáñez, Funes, & Fu, 2013).

Whether the different location modes activate mode-specific or shared spatial representations is a matter of debate and an issue of importance for understanding spatial processing (e.g., De Houwer, Beckers, Vandorpe, & Custers, 2005; Notebaert, De Moor, Gevers, & Hartsuiker, 2007; Proctor et al., 2009). Some studies have addressed this issue indirectly and found that these different types of spatial modes can activate shared spatial representations. For example, the Simon effect is eliminated when location-based Simon task trials are intermixed with ones in which participants respond to the words *left* and *right* with incompatibly mapped keypresses (Notebaert et al., 2007; Proctor et al., 2000; Vu, Ngo, Minakata, & Proctor, 2010).

By contrast, some findings suggest that different location modes may activate mode-specific representations, given that the Simon effects based on them seem to be different in the temporal dynamics and in the aspects of anti-interference from the word diluter and hand-stimulus proximity. For example, using a Vincentizing procedure (Ratcliff, 1979), a group RT (response time) distribution is obtained by partitioning each participant's RT on the compatible and incompatible trials into percentile bins (e.g., 10), ranging from shortest to longest, and measuring the Simon effect (the difference) for each bin. The location-based Simon effect decreases as RT increase across the RT distribution when the imperative stimuli are displayed in a left or right location, whereas the word- and arrow-based Simon effects increase as RTs increase (Miles & Proctor, 2012; Pellicano et al., 2009; Proctor et al., 2009). The word-based Simon effect can be reduced by another word (called a diluter, because it reduces the effect), whereas that is not the case for the arrow-based Simon effect (Miles, Yamaguchi, & Proctor, 2009). Hand–stimulus proximity has no influence on semantic processing of location words but enhances the location-based Simon effect (Wang, Du, He, & Zhang, 2014). Moreover, physical locations, arrow directions, and location words have different effects on transfer of acquired spatial associations (Proctor et al., 2009). The location- and arrow-based Simon effects can be reduced or eliminated easily by prior practice with an incompatible mapping of physical locations or arrow directions to responses, but not of location words to responses. However, the word-based Simon effect is not reduced easily by prior practice with an incompatible mapping of physical locations, arrow directions, or location words to responses.

In the current study, we used a Simon-like task in which a location word or an arrow was presented eccentrically, with a left–right keypress made to indicate the stimulus's ink color. This task allowed us to examine whether the word-based and arrow-based Simon effects can be observed when a location-based Simon effect is also present, as they can be processed automatically. Three variables were manipulated, including stimulus meaning [location word (*left* vs. *right*) in Experiment 2 or arrow direction (left-pointing vs. right-pointing) in Experiment 3], stimulus location (left vs. right) and response position (left vs. right). No studies, to our knowledge, have directly addressed this issue. The Simon-like task is similar to the spatial Stroop task (Lu & Proctor, 1995), except that here participants are to indicate the ink color of stimuli, whereas in the spatial Stroop task participants usually are to identify the location words or the directions in which the arrows pointed.

We speculated that the current manipulations could yield results consistent with one of two possibilities. One possibility is that response position codes are affected by both stimulus location and stimulus meaning (location word or direction of arrow) in the same task context (which we refer to as the *joint-influence* hypothesis), which would result in both location-based and word-based Simon effects in Experiment 2 and both location-based and arrow-based Simon effects in Experiment 3. This hypothesis is supported indirectly by the prior findings obtained in the spatial Stroop task, in which the location-based Simon and S-R compatibility effects indicate that stimulus location and direction of arrow or meaning of location word can influence response position codes. However, in this task, arrow direction or location word is task-relevant.

Previous studies show that processing task-irrelevant and task-relevant arrows or location words may be different. For example, when location words *left* and *right* are presented on the left and right side, an irrelevant location word affects the time to name the relevant stimulus location, but irrelevant stimulus location exerts little influence on naming the location word (Virzi & Egeth, 1985). This asymmetric relation in the spatial Stroop task is reversed for keypress responses, with irrelevant stimulus location affecting the time to respond to the word but not vice versa (Logan, 1980). The disparity between processing task-irrelevant and task-relevant arrow directions or location words also is evident in the Simon and S-R compatibility tasks. Miles and Proctor (2012) investigated the relations between arrows, locations, and location words—using correlations of compatibility effects between each of these modes as well as compatibility effects at different segments of their RT distributions. Miles and Proctor found that when spatial information is task-irrelevant (in the Simon task), the compatibility effects elicited by arrows and words are more strongly related with each other than with those of locations. However, when spatial information is task-relevant in the S–R compatibility task, the compatibility effects elicited by arrows and locations are more related, and both are less related to the effect elicited by words. Therefore, the *joint-influence* hypothesis needs further test. If this hypothesis is confirmed, it may again suggest that the location word or arrow and stimulus location can activate shared spatial representations.

The second possibility is that response position codes are influenced by stimulus location but not or little by stimulus meaning (location word or direction of arrow) in the same task context, with physical location having priority and it may block or reduce all others (which we refer to as the *location-priority* hypothesis). If this hypothesis is correct, we should find a location-based Simon effect and little or no arrow- and location word-based Simon effect. The location priority is determined likely by mode similarity that exists between the stimulus code (e.g., verbal, spatial) and the response modality. Mode similarity of arrow direction with keypresses is higher than that of location words (for which the arrows have symbolic and visuospatial attributes and the location words have no visuospatial attributes and the keypress responses have visuospatial attributes), but both would be lower than that of stimulus locations (that have visuospatial attributes) with keypresses (Lu & Proctor, 2001; Wang & Proctor, 1996). Due to the differences in mode similarity, spatial location, arrow direction, and location word will affect response position codes in that priority orders. Consequently, the location-based Simon effect may be observed, whereas the word-based Simon effect and arrow-based Simon effect become small or disappear.

If the *location-priority* hypothesis is confirmed, it may again suggest that the location word, arrow direction, and stimulus location can activate mode-specific spatial representations. Therefore, the current investigation may not only help to understand how different modes of spatial information affect response position codes in the same task context, but also may illuminate directly whether spatial location, arrow and location word can activate mode-specific or shared spatial representations (e.g., De Houwer et al., 2005; Notebaert et al., 2007; Vu et al., 2010).

Experiments 1A and 1B

As a baseline for Experiment 2, Experiment 1A examined, whether using the Chinese location words 左 (*left*) or 右 (*right*) in China with Chinese speakers could replicate the word-based Simon effect observed with English words (e.g., Miles & Proctor, 2012; Pellicano et al., 2009; Proctor et al., 2009). Although we anticipated obtaining similar results, this needed to be verified because prior studies have shown that languages are likely to influence the Simon effect (Notebaert et al., 2007; Vu et al., 2010), that spelled location words may be processed differently than location symbols (Proctor et al., 2000), and that logographic characteristics of stimuli affect the magnitude of the closely related spatial Stroop effect (for which the word and non-word stimulus dimensions involve vertical orientations and the responses are left and right keypresses; e.g., Luo & Proctor, 2013; Shimamura, 1987). Experiment 1B, as a baseline for Experiment 3, examined whether using the left- and right-pointing arrows could yield the arrow-based Simon effect (e.g., Miles & Proctor, 2012; Pellicano et al., 2009; Proctor et al., 2009).

Method

Participants

Twenty-two right-handed participants (eight males), age 19–26 years, took part in Experiment 1A, and 22 right-handed ones (nine males), age 18–24, took part in Experiment 1B. All participants in the current study had normal or corrected-to-normal vision and were naïve as to the purpose of the experiment.

Apparatus, stimuli, procedure, design

Stimuli were presented on a super VGA high-resolution color monitor with gray background. A personal computer, running E-Prime 1.1 software, controlled the presentation of stimuli, timing operations, and data collection. Participants placed their heads on a chinrest and viewed the monitor from a distance of 57 cm in a dimly lit room. The stimuli were Chinese single-character words 左 (left) and 右 (right) in Experiment 1A, and left- (←) and right-pointing (→) arrows in Experiment 1B on the center of the screen. The visual angle for each word or arrow was $0.85° \times 0.85°$.

Each participant performed eight practice trials followed by 128 test trials. Each trial began with onset of a white central fixation cross ($0.4° \times 0.4°$). After 1 s, a word or an arrow in red or green appeared for 150 ms. After that the gray screen became blank, during which the trial terminated if the participant responded or after 1.5 s if no response had been made. After the response, a 1-s intertrial interval occurred, during which the screen remained blank. Responses were made by pressing a left key (V) for the red ink color or right key (M) for the green ink color on the computer keyboard with the left or right index finger. The mapping of colors to left or right responses was counterbalanced across participants. The response keys and computer screen were aligned such that the fixation point and the midway point between the two response keys were on the participant's sagittal midline. Participants were instructed to maintain fixation and to respond to the targets as quickly and accurately as possible. Experiments 1A and 1B had a 2 (word: *left*, *right* or arrow: left-pointing, right-pointing) × 2 (response position: left, right) design, with 32 observations per experimental condition.

Results

The practice trials were excluded from the RT and percent errors (PE) analysis in Experiments 1 to 3. Test trials wherein participants responded incorrectly to the target (2.1 % in Experiment 1A and 2.7 % in Experiment 1B) and RTs longer than 1,500 ms or response made preceding the disappearance of target (0.4 % in Experiment 1A and 1.4 % in Experiment 1B) were excluded from the RT analyses. Mean correct RTs and PE in Experiments 1–3 are presented in Table 1. Using the Vincentizing procedure (Ratcliff, 1979), RTs were rank ordered from shortest to longest in each condition for each participant in Experiments 1–3, divided into three equally sized bins (early, middle, and late responses) and averaged in each bin. The Simon effects for each spatial mode were then calculated for each bin by collapsing each spatial mode stimulus and response position variables in Experiments 1–3, as shown in Fig. 1. An analysis of variance (ANOVA) was performed on RT, with bin (early, middle, and late responses), location word (*left* and *right*) or arrow direction (left-pointing and right-pointing) and response position (left and right) as within-subject variables. Considering the way in which the RT data were grouped, the bin main effect was significant in all analyses, so it was not reported and discussed here or in the following experiments. The same analysis was performed on PE without the variable bin.

Experiment 1A: RT

The mean bin RTs separately from bin 1 to 3 were 223, 307, and 451 ms. The main effects of location word and response position were not significant ($ps > 0.148$), nor were the two-way interactions between each of them and bin ($Fs < 1$). Location word interacted with response position, $F(1, 21) = 23.47$, $p < 0.001$, $MSE = 2300$, $\eta_p^2 = 0.528$, which reflects a Simon effect of 29 ms (faster responding when the meaning of location word and response position corresponded than when they did not). Moreover, the interaction between bin, location word, and response position was significant, $F(2, 42) = 16.80$, $p < 0.001$, $MSE = 1114$, $\eta_p^2 = 0.444$. Further analysis showed that the word-based Simon effect increased linearly from bin 1 to bin 3, $F(1, 21) = 17.08$, $p < 0.001$, $MSE = 2002$, $\eta_p^2 = 0.448$, and also showed a quadratic component, $F(1, 21) = 11.10$, $p = 0.003$, $MSE = 218$, $\eta_p^2 = 0.346$ (see Fig. 1), and the effect was not significant for bin 1, $t(21) = 1.40$, $p = 0.177$, but was for bins 2 and 3, $t(21) = 3.52$, $p = 0.002$; $t(21) = 4.76$, $p < 0.001$.

PE

The main effects of location word and response position were not significant, $Fs < 1$, but the interaction between location word and response position was significant, $F(1, 21) = 12.02$, $p = 0.002$, $MSE = 0.001$, $\eta_p^2 = 0.364$. The interaction reflects a Simon effect of 2.1 %, with fewer response errors when the location word meaning and response position corresponded (1.5 %) than when they did not (3.5 %).

Experiment 1B: RT

The mean RTs from bin 1 to 3 were 224, 294, and 415 ms. The main effects of arrow direction and response position were not significant ($ps > 0.191$), nor were the two-way interactions between each of those variables and bin ($ps > 0.207$). Arrow direction interacted with response position, $F(1, 21) = 25.65$, $p < 0.001$, $MSE = 5559$, $\eta_p^2 = 0.550$, which reflects a Simon effect of 44 ms (faster responding when the arrow direction and response position corresponded than when they did not). Moreover, the interaction between bin, arrow direction and response position was significant, $F(2, 42) = 9.26$, $p < 0.001$, $MSE = 981$, $\eta_p^2 = 0.306$. Further analysis showed that the arrow-based Simon effect increased linearly from bin 1 to 3, $F(1, 21) = 9.60$, $p = 0.005$, $MSE = 1855$, $\eta_p^2 = 0.314$ (see Fig. 1), and the effect for each bin was significant: $t(21) = 4.50$, $p < 0.001$; $t(21) = 4.98$, $p < 0.001$; $t(21) = 4.36$, $p < 0.001$, for bins 1–3, respectively.

PE

The main effects of arrow direction and response position approached the 0.05 level, $F(1, 21) = 3.83$, $p = 0.064$, $MSE = 0.001$, $\eta_p^2 = 0.154$; $F(1, 21) = 3.64$, $p = 0.070$, $MSE = 0.010$, $\eta_p^2 = 0.148$. The interaction between them was significant, $F(1, 21) = 25.12$, $p < 0.001$, $MSE = 0.002$, $\eta_p^2 = 0.545$, which reflects a Simon effect of 4.4 %,

Table 1 Mean response time (RT, in ms), mean percentage of error (PE), and standard deviation (in parentheses) as a function of location word, stimulus location and response position

Location word and arrow direction			Left or left-pointing		Right or right-pointing	
			LR	RR	LR	RR
Exp. 1A (Word)	RT		320 (140)	344 (168)	341 (171)	307 (127)
	PE		1.6 (0.12)	3.5 (0.18)	3.6 (0.19)	1.3 (0.11)
Exp. 1B (Arrow)	RT		296 (144)	338 (180)	328 (145)	284 (131)
	PE		0.7 (0.08)	9.0 (0.29)	3.6 (0.19)	3.1 (0.17)
Exp. 2 (Word)	RT	Left location	302 (140)	308 (120)	306 (147)	308 (139)
		Right location	318 (128)	301 (164)	327 (148)	294 (149)
	PE	Left location	2.2 (0.14)	5.3 (0.22)	4.0 (0.20)	2.9 (0.17)
		Right location	3.7 (0.19)	3.2 (0.17)	3.3 (0.18)	3.3 (0.18)
Exp. 3 (Arrow)	RT	Left location	304 (131)	315 (124)	307 (121)	305 (104)
		Right location	328 (126)	293 (132)	327 (117)	277 (112)
	PE	Left location	3.6 (0.19)	4.2 (0.20)	3.3 (0.18)	3.9 (0.19)
		Right location	3.7 (0.19)	2.7 (0.16)	4.0 (0.20)	3.6 (0.20)

LR left response, *RR* right response

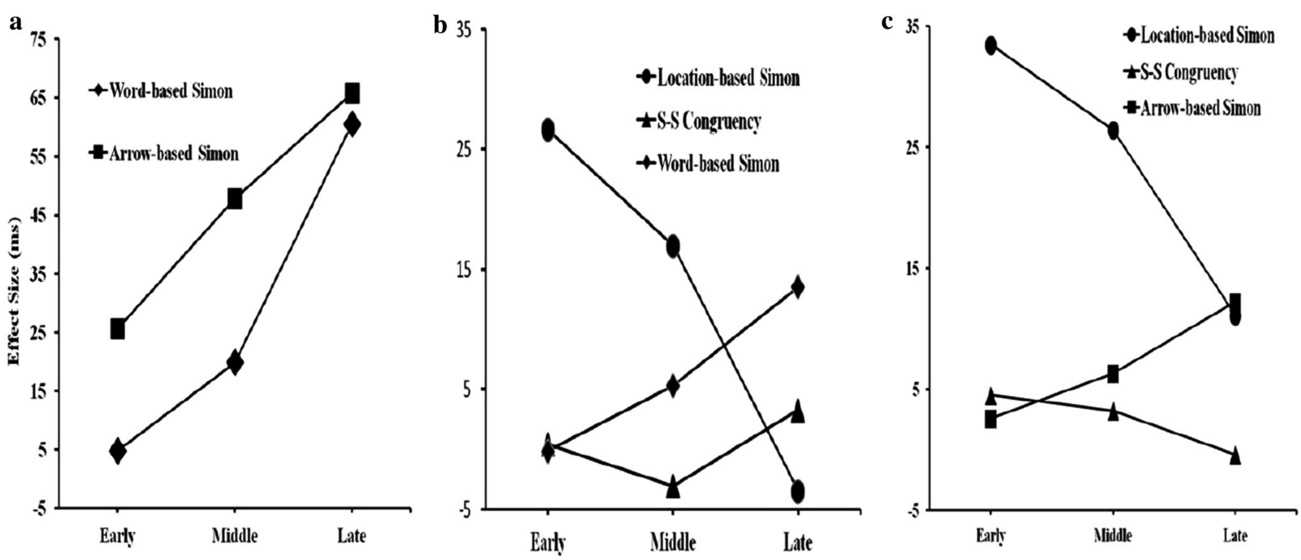

Fig. 1 Mean effect size for each of the Simon and S–S congruency effects for early, middle, and late responses. **a** For word-based and arrow-based Simon effects (Experiment 1), **b** for location-based Simon, S–S congruency, and word-based Simon effects, and **c** for location-based Simon, S–S congruency, and arrow-based Simon effects

with fewer response errors when the arrow direction and response position corresponded (1.9 %) than when they did not (6.3 %).

Discussion

The responses were faster, with fewer errors, when response position and the meaning of the location word or arrow direction were compatible than when they were incompatible, indicating a word-based Simon effect and an arrow-based Simon effect. Moreover, these effects in RT were larger when responses became slower. These results replicate previous findings obtained with arrows and English words *left* and *right* (e.g., Miles & Proctor, 2012; Pellicano et al., 2009; Proctor et al., 2009), suggesting that the location word and arrow direction are processed without intention to respond to their meaning.

Experiment 2

A Chinese word 左 (*left*) or 右 (*right*) written in red or green was presented eccentrically, and participants made left and right responses to indicate their colors. According the *joint-influence* hypothesis, both a location-based Simon effect created by stimulus location and response position and a word-based Simon effect created by location word and response position should be evident. According to the *location-priority* hypothesis, there should be a location-based Simon effect and little or no word-based Simon effect, as mode similarity of stimulus locations with key-presses is higher than that of location words with key-presses. The disparity of mode similarity may allow stimulus location to affect the response codes firstly, or more strongly.

Method

Participants

Twenty-two right-handed participants (nine males), age 19–25 years, took part in this experiment.

Apparatus, stimuli, procedure, design

They were the same as in Experiment 1, with following exceptions. The location word was presented 5° to the left and to the right of fixation, and each participant performed 256 test trials. This experiment had a 2 (word: *left*, *right*) × 2 (location: left, right) × 2 (response position: left, right) design, with 32 observations per experimental condition.

Results

Test trials wherein participants responded incorrectly to the target (3.2 %) and RTs were longer than 1500 ms or response made preceding the disappearance of target (0.2 %) were excluded from the RT analyses. A repeated-measures ANOVA was performed on RT, with bin, location word, stimulus location and response position as within-subject variables. The same analysis was performed on PE without the variable bin.

RT

The mean bin RTs separately from bin 1 to 3 were 213, 288, and 420 ms. The main effects of location word, stimulus location and response position were not significant ($ps > 0.127$), nor were the two-way interactions between each of these variables and bin ($ps > 0.276$). The interaction of stimulus location and response position was significant, $F(1, 21) = 7.25$, $p = 0.014$, $MSE = 3153$, $\eta_p^2 = 0.257$, reflecting a location-based Simon effect of 13 ms, with faster response when stimulus location and response position corresponded than when they did not. Moreover, the interaction between the two variables and bin was significant, $F(2, 42) = 9.96$, $p < 0.001$, $MSE = 1096$, $\eta_p^2 = 0.322$. Further analysis showed that the location-based Simon effect decreased linearly from bin 1 to bin 3, $F(1, 21) = 10.52$, $p = 0.004$, $MSE = 474$, $\eta_p^2 = 0.334$ (see Fig. 1).

By contrast, the interaction between location word and response position was not significant, $F(1, 21) = 1.31$, $p = 0.265$, $MSE = 4124$, $\eta_p^2 = 0.059$, nor was the three-way interaction between them and bin, $F(2, 42) = 1.66$, $p = 0.203$, $MSE = 1275$, $\eta_p^2 = 0.073$, which showed that the word-based Simon effect was not observed and was not modulated by bin. Further analyses of the individual bins also showed that the word-based Simon effect for each bin was not significant, $t(21) = 0.05$, $p = 0.962$; $t(21) = 1.06$, $p = 0.301$; $t(21) = 1.23$, $p = 0.234$, for bins 1–3, respectively. Similarly, the interaction between stimulus location and location word was not significant, $F < 1$, nor was the interaction between them and bin, $F(2, 42) = 1.70$, $p = 0.205$, $MSE = 443$, $\eta_p^2 = 0.075$, which showed that a S–S congruency effect was not observed and was not modulated by bin.

The interaction between location word, stimulus location, and response position was not significant, $F < 1$, but the four-way interaction between these variables and bin was significant, $F(2, 42) = 5.12$, $p = 0.010$, $MSE = 643$, $\eta_p^2 = 0.196$. Further analysis showed that the interactions between bin, stimulus location, and response position for left-presented word and for right-presented word were both not significant, $F < 1$; $F(2, 42) = 2.64$, $p = 0.119$, $MSE = 901$, $\eta_p^2 = 0.112$.

PE

The interaction between location word and response position was not significant, $F(1, 21) = 1.74$, $p = 0.202$, $MSE = 0.002$, $\eta_p^2 = 0.076$. The main effects and other interactions were also not reliable, $Fs < 1$.

Discussion

The location-based Simon effect was obtained: responses were faster when response position and stimulus location were compatible than when they were incompatible and this effect became smaller from bin 1 to 3. By contrast, no word-based Simon effect and S–S congruency effect were obtained, and there was no modulation by bin. This result could be due to mean RTs in Experiment 2 being shorter than in Experiment 1A. However, this possibility is unlikely, given that the word-based Simon effect occurred at bin 2 (mean RT = 307 ms) in Experiment 1 but not at bin 3 (mean RT = 420 ms) in Experiment 2. These results, therefore, imply that activation of the response code was not influenced by location word but by stimulus location, consistent with the prediction of the *location-priority* hypothesis.

Experiment 3

A left- or right-pointing arrow depicted in red or green was presented eccentrically, and participants made left and right responses to indicate their colors, respectively. This experiment examined whether a location-based Simon effect and an arrow-based Simon effect could be observed. According to the *joint-influence* hypothesis, both location-based and an arrow-based Simon effects should occur. According to the *location-priority* hypothesis, there should be a location-based Simon effect and little or no arrow-based Simon effect, as mode similarity of stimulus locations with keypresses is higher than that of arrows. The disparity of mode similarity may allow the stimulus location to affect the response position codes firstly, or more strongly.

Method

Participants

Twenty-two right-handed participants (eight males), age 19–25 years, took part in this experiment.

Apparatus, stimuli, procedure, design

They were the same as in Experiment 2, except for the location words *left* and *right* being replaced by left- and right-pointing arrows as used in Experiment 1B.

Results

Test trials wherein participants responded incorrectly to the target (3.3 %) and RTs were longer than 1,500 ms or response made preceding the disappearance of target (0.4 %) were excluded from the RT analyses. A repeated-measures ANOVA was performed on RT, with bin (1 to 3), arrow direction (*left* vs. *right*), stimulus location (left vs. right) and response position (left vs. right) as within-subject variables. The same analysis was performed on PE without the variable bin.

RT

The mean bin RTs separately from bin 1 to 3 were 222, 288, and 408 ms. The main effect of response position was significant, $F(1,\ 21) = 26.97$, $p < 0.001$, $\mathrm{MSE} = 1770$, $\eta_p^2 = 0.562$, with faster right responses than left responses, but the main effect of stimulus location and arrow direction were not significant ($ps > 0.188$). The two-way interactions between each of these variables and bin were not significant (ps > 0.228).

The interaction of stimulus location and response position was significant, $F(1,\ 21) = 52.73$, $p < 0.001$, $\mathrm{MSE} = 1436$, $\eta_p^2 = 0.715$, reflecting a location-based Simon effect of 21 ms (faster responding when stimulus location and response position corresponded than when they did not). Moreover, the three-way interaction between the two variables and bin was significant, $F(2, 42) = 9.64$, $p < 0.001$, $\mathrm{MSE} = 583$, $\eta_p^2 = 0.315$. Further analysis showed that the location-based Simon effect decreased from bin 1 to bin 3 linearly, as show in the significant linear trend, $F(1,\ 21) = 14.21$, $p = 0.001$, $\mathrm{MSE} = 194$, $\eta_p^2 = 0.404$ (see Fig. 1).

The interaction between arrow direction and response position was significant, $F(1,\ 21) = 4.50$, $p = 0.046$, $\mathrm{MSE} = 1527$, $\eta_p^2 = 0.176$, reflecting an arrow-based Simon effect of 7 ms, which was smaller than the location-based Simon effect, $t(21) = 3.87$, $p < 0.001$, and the arrow-based Simon effect in Experiment 1B, $t(42) = 4.00$, $p < 0.001$. However, the interaction between bin, arrow direction, and response position was not significant, $F(2, 42) = 1.70$, $p = 0.207$, $\mathrm{MSE} = 1298$, $\eta_p^2 = 0.075$. As shown in Fig. 1, the arrow-based Simon effect increased linearly from bin 1 to 3, although the trend analysis showed it was not significant, $F(1,\ 21) = 2.01$, $p = 0.171$, $\mathrm{MSE} = 507$, $\eta_p^2 = 0.087$. Further analysis showed that the arrow-based Simon effect was not significant for bins 1 and 2 but was for bin 3, $t(21) = 1.29, p = 0.210$; $t(21) = 1.68$, $p = 0.108$; $t(21) = 2.29$, $p = 0.033$.

The interaction between arrow direction and stimulus location and the three-way interaction between them and bin were not significant, $Fs < 1$, nor were the three-way interaction between arrow direction, stimulus location and response position and the four-way interaction between these variables and bin, $Fs < 1$.

PE

The main effects and interactions were not reliable, $Fs < 1$.

Discussion

A location-based Simon effect was obtained, and this effect became smaller from bin 1 to bin 3. Moreover, an arrow-based Simon effect was observed with faster responses when response position and arrow direction were compatible than when they were incompatible. This arrow-based Simon effect was smaller than the location-based Simon effect and the arrow-based Simon effect in Experiment 1B, in which the arrows were presented at a central location. The smaller arrow-based Simon effect could be due to mean RT in Experiment 3 being shorter than that in Experiment 1A. However, again, evidence is against this possibility: the arrow-based Simon effect occurred at all bins (mean RT for each bin = 224, 294, and 415 ms, respectively) in Experiment 1, whereas it occurred only at bin 3 (mean RT = 408 ms) in Experiment 3. Moreover, no S–S congruency effect was obtained. These results suggest that stimulus location may have a priority in activating response position codes, although the direction of arrow can also affect response position codes.

General discussion

The current study examined how different modes of spatial information influence response position codes when a location word or an arrow is presented eccentrically and a left–right keypress is made to indicate its ink color. In Experiments 1A and 1B, the word-based Simon effect with English words *left* and *right* (e.g., Miles & Proctor, 2012; Pellicano et al., 2009; Proctor et al., 2009) and arrow-based Simon effect were replicated with Chinese location words 左 and 右, and arrows that were centrically presented. This result indicates that responses to colors are affected by whether the meaning of location words or arrow direction is compatible with response position, suggesting that the task-irrelevant location word or arrow direction is processed.

In Experiments 2 and 3, the location-based Simon effect was observed, indicating that stimulus location affects the response position codes. However, the word-based Simon effect was not apparent in Experiment 2, and a smaller arrow-based Simon was found in Experiment 3. These results suggest that the spatial representations of location words do not affect the response position codes and that those of arrows likely have only a small effect on the response codes. Moreover, in Experiments 2 and 3, S–S congruency effects for stimulus location with location word meaning and arrow direction, respectively, were not observed. The absence of a S–S congruency effect in Experiments 2 and 3 seems inconsistent with the previous finding in the spatial Stroop task (Logan, 1980; Virzi & Egeth, 1985), in which responding to direction of arrow or the location word with keypress can be affected by the stimulus location coding. This disparity in our findings and theirs may be due to the different response tasks. Lameira, Pereira, Fraga-Filho, and Gawryszewski (2015) reported a S–S congruency effect for stimulus location and arrow direction when participants responded to the direction of a left or right-presented arrow. Therefore, the occurrence of location-based Simon effect, paired with the absence of word-based Simon effect and the S–S congruency effect and the small arrow-based Simon effect, suggest that the code of stimulus location may occur earlier when compared to arrow or location word when the responses are keypresses.

The obtained pattern of results is inconsistent with the *joint-influence* hypothesis that predicts both the location-based, word-based and arrow-based effects will be observed. However, these results seem consistent with the *location-priority* hypothesis, which predicts that the effect of stimulus location should be largest and the effect of arrow direction intermediate to that of stimulus location and location word. This is because mode similarity of arrow direction with keypresses is higher than that of location words (for which the stimulus dimension is verbal and the response is nonverbal; Lu & Proctor, 2001; Wang & Proctor, 1996), but both would be lower than that of physical locations with keypresses.

The largest mode similarity of stimulus location with keypresses might make stimulus location affect the response position coding earlier in processing compared to location word and arrow, resulting in the location-based Simon effect being obtained in Experiments 2 and 3. Likewise, the mode similarity of arrow with keypresses is closer to that of location word with keypresses might make the arrow-based Simon effect being obtained in Experiment 3. The mode similarity is consistent with dimensional weighting (Memelink & Hommel, 2013; Yamaguchi & Proctor, 2012), assuming that only one spatial dimension at any given time can cause an impact. The current results are also in agreement with the previous finding that the different stimulus modes show different onsets of the Simon effect across the RT distributions. For arrows, the location-based Simon effect was already significant at the shortest RT intervals, providing evidence that they are distinctively more effective directional indicators than words (Pellicano et al., 2009). These disparities may be because spatial words are more difficult to interpret compared to arrow stimuli, probably due to computational complexity and attentional requirements underlying the comprehension of the stimulus (Gibson & Kingstone, 2006).

Previous findings imply that different location modes can activate mode-specific representations, given that the Simon effects based on them are different in the temporal dynamics and in the aspects of anti-interference from the diluter and hand-stimulus proximity (Miles & Proctor, 2012; Miles et al., 2009; Pellicano et al., 2009; Proctor et al., 2009; Wang et al., 2014), and physical locations, arrow directions, and location words have different effects on transfer of acquired spatial associations (Proctor et al., 2009). The location-based Simon effect occurring in Experiments 2 and 3, and the absence of word-based Simon effect in Experiment 2 and a small arrow-based Simon effect in Experiment 3 again are consistent with the viewpoint that different location modes can activate mode-specific representations.

One concern with the absence of the word-based Simon effect and the S–S congruency effect, and the small arrow-based Simon effect, might be that meaning of the location word was not accessed and the direction of arrow was not processed sufficiently, as they were eccentrically presented, which may reduce the processing efficiency, compared to the centrally presented location words and arrows. This possibility seems unlikely, given that in the spatial and color-word Stroop tasks, the eccentrically presented location words are processed, as the spatial and color-word Stroop effects are obtained regardless of whether the responses are to name the locations occupied by them or to indicate the colors of the color-words (MacLeod, 1991; Peng & Wang, 2011; Virzi & Egeth, 1985). Moreover, the location-based Simon effect also varies with eccentricity, with a positive relationship between eccentricity and the effect size (Hommel, 1993). Therefore, eccentricity may not be the determining factor that affects the location word or arrow-based Simon effect, whereas further research is needed to examine this issue directly.

Another possible concern with the results, the location-based Simon effect occurring in Experiments 2 and 3, paired with a small arrow-based Simon effect in Experiment 3 and no word-based Simon effect in Experiment 2, is that stimulus location coding may not need focused attention, whereas arrow and location word processing need focused attention. This possibility can be ruled out, though, as previous studies found that S–S congruency effects in the spatial Stroop task with keypress responses to the arrow directions are affected by focused attention, with smaller effects for locations on which attention is focused attention than for locations on which it is not (Funes, Lupiáñez, & Milliken, 2007; Luo, Lupiáñez, Fu, & Weng, 2010; Luo, Lupiáñez, Funes, & Fu, 2010, 2011). However, it is still unclear whether the arrow-based and location word Simon effects depend on focused attention, and further studies are need to test this possibility.

In conclusion, indicating the color of a location word presented eccentrically resulted in a location-based Simon effect and lack of word-based Simon effect and S–S congruency effect, whereas indicating the color of a pointing arrow presented eccentrically resulted in a location-based Simon effect, a small arrow-based Simon effect, and no S–S congruency effect. These results suggest that different modes of spatial information may influence response position coding in a spatial-to-verbal priority order, and arrows and location words may activate mode-specific spatial representations.

Compliance with ethical standards

Written consent was obtained from all participants prior to participation. The protocol was approved by the institutional review board (IRB) at the institute of psychology, Chinese Academy of Sciences.

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Conflict of interest The authors have declared that no competing interests exist.

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