



How different direct association routes influence the indirect route in the same Simon-like task

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Abstract

The location-, word-, and arrow-based Simon effects are usually attributed to the result of a direct route (the spatially corresponding stimulus–response association, activated automatically) that interferes with an indirect route (the association of task-relevant information and response, activated in accordance with the instructed stimulus–response mapping). We examined whether and how distinct direct routes (stimulus–location–response position and location word–response position or arrow direction–response position associations) affect responding on the basis of the same indirect route (a stimulus color–response association) in a Simon-like task. For this task, left–right keypresses were made to indicate the ink colors of location words or left- or right-pointing arrows, presented eccentrically in left or right locations. The location-based Simon effect occurred at the levels of mean reaction time (RT) and RT distribution in the word Simon-like task, whereas the word-based Simon effect only occurred at the level of RT distribution. In the arrow Simon-like task, the location-based Simon effect did not occur at the level of mean RT, but did at the level of RT distribution, whereas the opposite pattern occurred for the arrow-based Simon effect. These results could imply that one direct route influences the effects of the other direct route on the responses, depending on the task context.

Introduction

When people respond to an object or a feature of it, the location occupied by the object can influence performance, as often demonstrated in the Simon task. In the prototypical version of this task, left and right keypresses are arbitrarily mapped to task-relevant non-spatial attributes (e.g., colors or shapes); responses are faster and more accurate when the task-irrelevant stimulus location and correct response positions correspond than when they do not, generating the location-based Simon effect (see reviews of Lu & Proctor, 1995; Simon, 1990; Umiltà & Nicoletti, 1990). The Simon effect also occurs with responses to colors of centrally presented location words or arrows that convey the spatial information (Khalid & Ansorge, 2013; Lu & Proctor, 2001; Pellicano, Lugli, Baroni, & Nicoletti, 2009; Proctor, Marble, & Vu,

2000; Proctor, Yamaguchi, Zhang, & Vu, 2009). These latter effects are called word- and arrow-based Simon effects, respectively. In the current study, we examined whether and how pairings of these various stimulus–location modes influence responses together in a Simon-like task, wherein location words [左(left) or 右(right)] or arrows (left- or right-pointing) were presented eccentrically, with left–right keypresses made to indicate the colors in which they were displayed.

The dual-route model

Explanations of the Simon effect are usually based on a dual-route concept, according to which response activation occurs via automatic and controlled, or direct and indirect, response-selection routes (e.g., De Jong, Liang, & Lauber, 1994; Ellinghaus, Karlbauer, Bausenhardt, & Ulrich, 2017; Ulrich, Schröter, Leuthold, & Birngruber, 2015). The direct route is that of the spatially corresponding stimulus–response (S–R) associations (stimulus location and response position), which have been established through a lifetime of experience in which locations of objects and responses to them usually coincide. These enduring S–R

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associations are presumed to reside in long-term memory (LTM; Barber & O'Leary, 1997; De Jong et al., 1994; Kornblum, Hasbroucq, & Osman, 1990; Zorzi & Umiltà, 1995). The indirect route is that of goal-oriented associations that depend on task-relevant information in accordance with the instructed S–R mapping, which is maintained actively in short-term memory (STM; Barber & O'Leary, 1997; De Jong et al., 1994; Kornblum et al., 1990; Zorzi & Umiltà, 1995). The location-based Simon effect is attributed to the activation of the direct route, which adds to that of the indirect route when response position corresponds to stimulus location but conflicts with it when they do not correspond (Ansorge & Wühr, 2004; Luo & Proctor, 2017; Proctor, Yamaguchi, Dutt, & Gonzalez, 2013).

Previous computational models that are instantiations of the dual-route accounts (Zhang, Zhang, & Kornblum, 1999; Zorzi & Umiltà, 1995) have been shown to simulate the basic pattern of the location-based Simon effect. The dual-route model also is used to explain the word- and arrow-based Simon effect, which are attributed to the direct route (the spatially corresponding S–R association, namely, location word or arrow direction and response position) being activated in an automatic processing way, which adds to the activation produced through the indirect route when response position corresponds to the meaning of location word or direction of arrow but conflicts when the two do not correspond (Lu & Proctor, 2001; Luo & Proctor, 2017, 2018).

Shared representations underlying various location modes

There is agreement that spatial locations activate visual–spatial codes and that location words are symbolic and activate semantic–spatial codes (i.e., codes of spatial meaning; Hommel, Pratt, Colzato, & Godijn, 2001; Notebaert, De Moor, Gevers, & Hartsuiker, 2007). Arrows are usually regarded as symbolic (e.g., Freitas, Bahar, Yang, & Banai, 2007; Tipples, 2002; Weeks & Proctor, 1990), although they also have visual–spatial properties (e.g., for a left-pointing arrow, the arrowhead is located to the left of the shaft). Therefore, arrows may activate both visual– and semantic–spatial codes.

Although the spatial codes activated by various spatial modes are different, they may indicate the same concepts (e.g., left or right) and have shared representations, as implied by some studies (e.g., De Houwer, Beckers, Vandorpe, & Custers, 2005; Notebaert et al., 2007; Proctor et al., 2009). Both location words and arrows yield S–R mapping effects when the location information conveyed by them is relevant (Wang & Proctor, 1996) and Simon effects when that information is irrelevant (Proctor & Vu, 2002).

Moreover, the location-based Simon effect is eliminated or reversed when trials of the location-based Simon task are intermixed with ones in which participants respond to the words left and right or left- and right-pointing arrows with incompatibly mapped keypresses (Notebaert et al., 2007; Proctor et al., 2000; Vu, Ngo, Minakata, & Proctor, 2010).

Different RT distributions underlying various Simon effects

There is a distinct pattern at a more fine-grained RT distributional level: The size of the various Simon effect types usually differs between fast and slow responses, although a similar effect size may be obtained in these Simon tasks at the mean RT level. The RT distributions of correspondence effects can be revealed through delta functions (often also called delta plots), which were introduced by De Jong et al. (1994). Delta functions depict the difference in corresponding and noncorresponding conditions on the *y*-axis with the increase of quantile bins of the RT distribution on the *x*-axis. Increasing Simon effects are shown by positive-going delta functions, whereas decreasing correspondence effects are shown by negative-going delta functions (see Proctor, Miles, & Baroni, 2011, for a review). For word- and arrow-based Simon tasks, the Simon effects usually grow with increasing RT (e.g., Lu & Proctor, 2001; Proctor et al., 2000; Proctor et al., 2009), whereas for horizontal visual location-based Simon tasks, the effect usually declines and sometimes even reverses (e.g., De Jong et al., 1994; Wiegand & Wascher, 2005; see Proctor et al., 2011, for a review).

Increasing and decreasing delta plots of Simon effects obtained in various tasks are assumed by some authors to be the result of two distinct mechanisms (Pratte, Rouder, Morey, & Feng, 2010; Wascher, Schatz, Kuder, & Verleger, 2001; Wiegand & Wascher, 2005, 2007). Negative-going or inverse U-shaped delta plots in location-based visual Simon tasks with horizontal S–R arrangements reflect visuomotor activation mediated by a direct pathway. In contrast, positive-going delta plots for auditory Simon tasks or visual Simon tasks using vertical S–R arrangements result from mismatching S–R codes at the level of response selection (Wascher et al., 2001; Wiegand & Wascher, 2005, 2007).

Different from Wascher's theory of separate mechanisms (Pratte et al., 2010; Wascher et al., 2001; Wiegand & Wascher, 2005, 2007), the decreasing delta plots in the location-based Simon task have also been explained with a dual-route model (e.g., De Jong et al., 1994; Ellinghaus et al., 2017; Proctor & Vu, 2006; Ulrich et al., 2015). According to the model, the decreasing delta plots for the location-based Simon effect is because the activation of the direct route is short-term and quickly dissipates (Hommel, 1994; Ulrich et al., 2015), which gradually reduces interference with the

responses. The dual-route model has been used as well to explain conflict effects with increasing delta plots obtained in the other tasks, such as Stroop, flanker, and arrow- or word-based Simon tasks (e.g., Luo & Proctor, 2017; Ulrich et al., 2015), wherein the direct route is presumed to be a long-term, automatic and accumulating process and increasing gradually interference with the responses. Ulrich et al. (2015) developed a diffusion model for conflict tasks (DMC) that simulates the dual-route model. They found that location-based Simon effect with a decreasing delta plot and flanker effect with an increasing delta plot can be fit by the same model; the shape of the delta functions largely depends on the relative speeds of the automatic activation and the controlled processes. If automatic activation occurs relatively early (late), the slope of the delta functions has a negative (positive) tendency. The DMC model argues for a single underlying mechanism as the most parsimonious explanation to the RT distributions of the various Simon effects.

The different RT distributions of correspondence effects are also revealed through ex-Gaussian parameters (μ , σ , and τ) that are obtained by fitting a mathematical ex-Gaussian function to empirical RT distributions (Andrews & Heathcote, 2001; Balota & Spieler, 1999; Heathcote, Popiel, & Mewhort, 1991; Luo & Proctor, 2018; White, Risko, & Besner, 2016). The ex-Gaussian distribution has been reported to provide a good fit for RT data and to evaluate cognitive models (De Jong et al., 1994; Heathcote et al., 1991). It also offers a parsimonious way of characterizing the influence of factors on RT distributions, with the ex-Gaussian parameters providing more information about changes in the RT distribution than are reflected in analyses of mean RTs and delta plot functions (Andrews & Heathcote, 2001; Balota & Spieler, 1999; Heathcote et al., 1991; White et al., 2016).

The parameters μ and σ reflect, respectively, the mean and standard deviation of the Gaussian component of the RT distribution. Changes in σ and μ represent separately the difference of standard deviation and a shift of the RT distribution across different conditions, with μ indicating that a variable has an influence early in the RT distribution, as shown for the location-based Simon task in Fig. 2. τ reflects the mean and standard deviation of the exponential component, and a change in τ represents the change in the tail of the RT distribution across different conditions, indicating that a variable has its effect primarily on longer RTs, as shown for the arrow-based Simon task in Fig. 2. Moreover, as sample mean equals μ plus τ , ex-Gaussian analysis can specify whether the difference at the mean RT level mainly arose from the faster or slower responses or both.

There is a distinct pattern at the RT distribution level for various Simon effects in these ex-Gaussian parameters, although the effects have similar patterns at the mean RT level. The location-based Simon effect occurs on mean RT

and μ but not on τ , and a reverse effect occurs on σ (i.e., the standard deviation was larger for corresponding than noncorresponding trials), indicating that the location-based Simon effect on mean RT mainly arises from fast responses. The size of the location-based effect as a function of RT is a negative-going delta plot (Luo & Proctor, 2018), given that positive or negative value of σ is associated with the monotonicity of the delta plot (Zhang & Kornblum, 1997). In contrast, positive arrow- and word-based Simon effects occur on all these measures (including σ), indicating that the arrow- or word-based Simon effects on mean RT arise from both fast and slow responses. The size of the arrow- and word-based Simon effects increases as RT increases, yielding a positive-going delta plot (Luo & Proctor, 2018). Those results together suggest that spatial information conveyed by the various location modes is different in the time-course of activation.

Present study

Stimulus locations and location words may activate separately visual- and semantic-spatial codes, arrows may activate both, and the various location modes may have shared representations and influence responses with different RT distributions. Consequently, an issue is whether the spatial information conveyed by the various stimulus modes affects responses together. Luo and Proctor (2017) addressed the issue with a Simon-like task in which location words [左 (left) or 右 (right)] or arrows (left- or right-pointing) were presented eccentrically (5°) for 150 ms, with left-right key-presses made to indicate their ink colors. According to the dual-route model (De Jong et al., 1994; Kornblum et al., 1990; Zorzi & Umiltà, 1995), this task includes two direct routes (the association of stimulus location with response position and of location word or arrow direction with response position), and one indirect route, the association of color and response position. This task hence can examine whether the word- or arrow-based and location-based Simon effects can be observed, as various location modes have been found to be processed automatically. Results showed that the word-based Simon effect on mean RT and the positive-going delta plot were not obtained, but the location-based Simon effect on mean RT and the negative-going delta plot were evident, as well as a small arrow-based Simon effect on mean RT.

That outcome seems inconsistent with the dual-route model, as only one direct route (the association of stimulus location and response position) influenced the responses, resulting in the location-based Simon effect. In contrast, the other direct route (the association of word meaning or arrow direction and response position) had little or no effect on responses, resulting in no word-based Simon effect and little

arrow-based Simon effect. This difference between word- and arrow-based effects is likely 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 mode similarity results are consistent with dimensional weighting (Memelink & Hommel, 2013; Yamaguchi & Proctor, 2012), assuming that only one spatial dimension at any given time can cause much impact. However, lack of word-based Simon effect and small arrow-based Simon effect could also be because the location word or arrows were presented eccentrically (5°) for 150 ms. That brief duration may not be sufficient for saccadic eye movements to the stimuli, which may be necessary to identify the meanings of the word and arrow forms adequately, given that mean saccadic latencies range from 150 to 200 ms (Carpenter, 1988).

In the current study, we used the same Simon-like task as in Luo and Proctor (2017), but the stimuli were presented until responses were recorded, so that the stimuli are likely to be processed sufficiently. In addition to the Vincentile analysis on RT used in Luo and Proctor (2017), we here also used the analysis on PE and an ex-Gaussian analysis on RT (Heathcote et al., 1991; Plourde & Besner, 1997; Spieler, Balota, & Faust, 1996) to measure RT distribution characteristics for the various Simon effects. If lack of word-based Simon effect and small arrow-based Simon effect in Luo and Proctor's (2017) study is a consequence of insufficient processing of the eccentric location words or arrows because they were displayed for only 150 ms, then the current response-terminated manipulation should yield location-, word- and arrow-based Simon effects on mean RT and across the RT distribution. The different RT distributions for the three effects also would be evident for the ex-Gaussian analysis. There should be positive arrow- and word-based Simon effects on μ , σ , and τ , and a location-based Simon effect on μ but not on τ , and a reverse effect on σ , as observed in Luo and Proctor's (2018) study. These results would provide support for the dual-route model, as location, word and arrow can be processed automatically and influence the responses.

Moreover, these results (the location-, word- and arrow-based Simon effects on mean RT and across the RT distribution obtained by the current response-terminated manipulation) may test the dimensional weighting hypothesis (Memelink & Hommel, 2013; Yamaguchi & Proctor, 2012), assuming that only one spatial dimension can cause much impact at any given time, given that spatial information conveyed by the various location modes is different in the time-course of activation. Specifically, this hypothesis predicts that in Experiment 2 both direct routes (the association of

stimulus location and response position and of word meaning and response position) will influence responses, given that the location-based Simon effect often occurs in the faster responses but the word-based Simon effect occurs in the slower responses. In Experiment 3, stimulus location may activate visual-spatial codes that are immediately coded after stimulus onset (Bundesen, 1991; Tipper, Weaver, & Houghton, 1994), and arrows may activate both visual- and semantic-spatial codes. According to the dimensional weighting hypothesis (Memelink & Hommel, 2013; Yamaguchi & Proctor, 2012), these disparities of time-course of activation may enable the direct route (the association of stimulus location and response position) to reduce or eliminate the effect of the other direct route (the association of arrow direction and response position) on performance for the faster responses. This reduction would result in a reduced or eliminated arrow-based Simon effect for those responses.

According to Wascher's theory of separate mechanisms (Pratte et al., 2010; Wascher et al., 2001; Wiegand & Wascher, 2005, 2007), in Experiments 2 and 3, the stimulus location and location word or arrow direction will influence separately the responses and they will not influence each other, generating the location- and word- or arrow-based Simon effects. This prediction is made because separate mechanisms are responsible for the location-based Simon effect and the word- or arrow-based Simon effects.

Experiments 1A, 1B, and 1C

In Experiment 1, different from Luo and Proctor (2017, 2018), who presented the stimuli for 150 ms, the stimuli were displayed until a response was made. Ellinghaus et al. (2017) found that duration of stimulus presentation in the location-based Simon task did not influence the shape of the delta plot. We examined whether location-, word-, and arrow-based Simon effects (with different delta plots) would be obtained for mean RT and the ex-Gaussian parameters, to provide a baseline for the following experiments.

Method

Participants

Twenty right-handed participants (8 males; age 18–24 years) took part in Experiment 1A, 20 right-handed ones (10 males; age 19–26 years) in Experiment 1B, and another 20 right-handed ones (9 males; age 18 to 25 years) in Experiment 1C. All were undergraduates or graduates from universities near the Institute of Psychology, Chinese Academy of Science,

Beijing, China. They had normal or corrected-to-normal vision and were naïve to the purpose of the study.

Apparatus, stimuli, procedure, and design

Stimuli were presented on a super VGA high-resolution color monitor with grey 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 58 cm in a dimly lit room. The stimuli in Experiment 1A were red and green squares ($0.85^\circ \times 0.85^\circ$), whose centers were 4.8° to the left or right of the center of screen. Centrally presented stimuli ($0.85^\circ \times 0.85^\circ$) in red and green were location words [左 (left) and 右 (right)] in Experiments 1B, and left-pointing and right-pointing arrows (\rightarrow and \leftarrow , $0.85^\circ \times 0.85^\circ$, with $0.51^\circ \times 0.85^\circ$ for arrowhead and $0.34^\circ \times 0.15^\circ$ for arrow bar) in Experiment 1C.

In all experiments, each participant performed two blocks of trials, with a 30-s interval between them. Each block included 8 practice trials followed by 128 test trials. Each trial began with onset of a white central fixation cross ($0.4^\circ \times 0.4^\circ$). After 1 s, a stimulus appeared until the participant responded or for 1.5 s if no response had been made. The stimulus was a square presented eccentrically in Experiment 1A, a location word presented centrally in Experiment 1B, and an arrow presented centrally in Experiment 1C. After trial completion, 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. This study had one variable, location-based Simon in Experiment 1A, word-based Simon in Experiment 1B and arrow-based Simon in Experiment 1C (corresponding, noncorresponding), with 128 observations per experimental condition.

Data analysis

The practice trials were excluded from RT and percent error (PE) analysis, as was the case for test trials with no responses (0.02, 0.02 and 0.04% for Experiments 1A, 1B, and 1C, respectively).

The PE data were then analyzed as follows. First, using a Vincentizing procedure (Ratcliff, 1979), RTs for all responses (including error and correct responses) were rank ordered from shortest to longest in each experimental

condition for each participant, divided into five equally sized bins. Second, mean PE of each bin for each experimental condition for each participant was calculated. Finally, a repeated-measure analysis of variance (ANOVA) was performed on PE, with bin, location-based Simon in Experiment 1A, word-based Simon in Experiment 1B or arrow-based Simon in Experiment 1C, as within-subject variables.

In the RT data analysis, we excluded test trials wherein participants responded incorrectly to the target (2.1, 2.2 and 1.9% for Experiments 1A, 1B and 1C) and test trials (2.4, 2.4, 3.7%, for Experiments 1A, 1B and 1C) wherein RTs beyond three standard deviations of mean in each condition for each participant. Using a Vincentizing procedure, the remaining correct RTs were rank ordered from shortest to longest in each experimental condition for each participant, divided into five equally sized bins, and averaged in each bin. A repeated-measures ANOVA was performed on RT, with bin, location-based Simon in Experiment 1A, word-based Simon in Experiment 1B or arrow-based Simon in Experiment 1C, as within-subject variables. Considering the way in which the RT data were grouped, the bin main effect on RT was significant in all analyses, so it is not reported and discussed.

Finally, the same correct RT data were fit to the ex-Gaussian function for each participant in each condition in each experiment using the timefit function in the retimes package (Massidda, 2013). The timefit function uses maximum likelihood estimation to generate the three parameters (μ , σ , τ). Separate repeated-measures ANOVAs were performed on these parameters, with location-based Simon in Experiment 1A, word-based Simon in Experiment 1B or arrow-based Simon in Experiment 1C, as within-subject variables. Mean correct RTs and PEs are presented in Table 1.

Table 1 Mean percentage of error (PE), mean reaction time (RT, in ms), μ , σ , τ , with standard deviations in parentheses, for compatible and incompatible trials in the location-based Simon (in Experiment 1A), word-based Simon (in Experiment 1B) and arrow-based Simon (in Experiment 1C) tasks

	PE	RT	μ	σ	τ
Exp. 1A					
Corr	2.4 (0.02)	453 (85)	388 (70)	70 (24)	66 (19)
Noncorr	3.6 (0.03)	478 (85)	420 (64)	62 (26)	57 (27)
Exp. 1B					
Corr	1.6 (0.04)	421 (72)	368 (53)	59 (19)	53 (26)
Noncorr	3.8 (0.04)	440 (103)	372 (69)	68 (36)	68 (39)
Exp. 1C					
Corr	0.7 (0.02)	399 (74)	363 (64)	47 (20)	37 (21)
Noncorr	3.2 (0.05)	428 (94)	379 (92)	62 (37)	49 (44)

Corr corresponding, *Noncorr* noncorresponding

Results

Vincentile analysis on PE

Experiment 1A The main effect of location-based Simon was not significant, $F(1, 19)=1.95$, $p=.178$, $MSE=0.004$, $\eta_p^2=0.093$, but the main effect of bin was, $F(4, 76)=5.64$, $p<.001$, $MSE=0.002$, $\eta_p^2=0.229$. The interaction between location-based Simon and bin was also significant, $F(4, 76)=10.85$, $p<.001$, $MSE=0.003$, $\eta_p^2=0.363$. Trends analysis showed that the Simon effect on PE had both linearly decreasing and quadratic components from bin 1 to bin 5, $F(1, 19)=15.51$, $p<.001$, $MSE=0.008$, $\eta_p^2=0.449$; $F(1, 19)=14.49$, $p<.001$, $MSE=0.005$, $\eta_p^2=0.433$, respectively, indicating a negative-going delta plot (see Fig. 1). The location-based Simon effect for bin 1 (10.5%) was significant ($p<.001$), but it was not for the other bins (-0.8 , -0.6 , -2.0 , -1.0% , for bins 2–5, respectively, $ps>0.171$).

Experiment 1B The main effect of bin was not significant ($F<1$), but that of word-based Simon was, $F(1, 19)=7.86$, $p=.011$, $MSE=0.003$, $\eta_p^2=0.293$: Fewer response errors were made in the corresponding condition (1.6%) than in the noncorresponding condition (3.8%). The interaction between the two factors was nonsignificant, $F<1$.

Experiment 1C The main effect of bin was not significant, $F(4, 76)=1.73$, $p=.152$, $MSE=0.001$, $\eta_p^2=0.083$, but that of arrow-based Simon was, $F(1, 19)=15.09$, $p=.001$, $MSE=0.002$, $\eta_p^2=0.443$: Error rate was lower in the corresponding condition (0.7%) than in the noncorresponding condition (3.2%). The interaction between bin and arrow-based Simon was nonsignificant, $F(4, 76)=1.05$, $p=.386$, $MSE=0.001$, $\eta_p^2=0.053$.

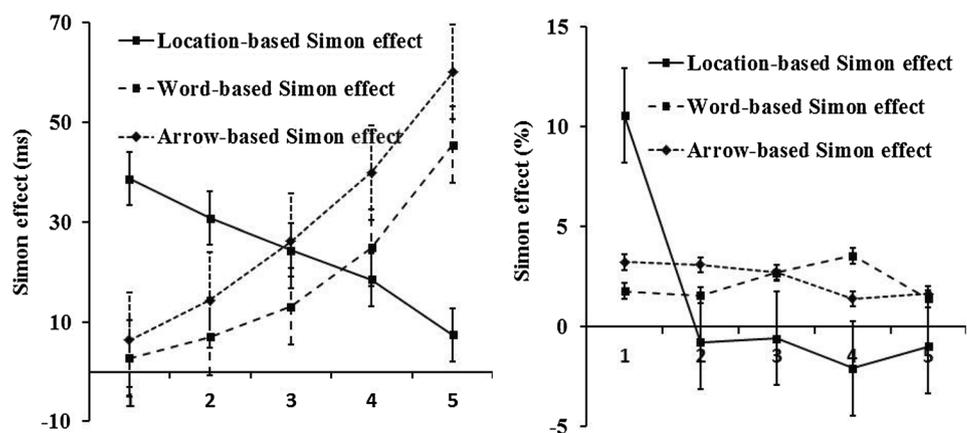
Vincentile analysis on RT

Experiment 1A The main effect of location-based Simon was significant, $F(1, 19)=17.71$, $p<.001$, $MSE=1,611$, $\eta_p^2=0.482$, reflecting a Simon effect of 25 ms, as was the interaction between bin and location-based Simon, $F(4, 76)=3.45$, $p=.012$, $MSE=411$, $\eta_p^2=0.154$. Trends analysis showed that the location-based Simon effect decreased linearly from bin 1 to bin 5, $F(1, 19)=4.44$, $p=.049$, $MSE=2,525$, $\eta_p^2=0.189$, indicating a negative-going delta plot (see Fig. 1). The Simon effect was significant for bins 1–4 (39, 31, 24, 18 ms, $ps<0.027$) but not for bin 5 (7 ms, $p=.601$).

Experiment 1B The main effect of word-based Simon was significant, $F(1, 19)=5.01$, $p=.037$, $MSE=3,473$, $\eta_p^2=0.209$, reflecting a Simon effect of 19 ms. The interaction between bin and arrow-based Simon was also significant, $F(4, 76)=5.67$, $p<.001$, $MSE=522$, $\eta_p^2=0.230$. Trends analysis showed that word-based Simon effect increased linearly from bin 1 to bin 5, $F(1, 19)=5.67$, $p<.001$, $MSE=1,043$, $\eta_p^2=0.230$, indicating a positive-going delta plot (see Fig. 1). The word-based Simon effect was not significant for bins 1 and 2 (3, 7 ms; $ps>0.125$), approached significance for bin 3 (13 ms; $p=.084$), and was significant for bins 4 and 5 (25 and 46 ms; $ps<0.046$).

Experiment 1C The main effect of arrow-based Simon was significant, $F(1, 19)=60.79$, $p<.001$, $MSE=711$, $\eta_p^2=0.762$, reflecting a Simon effect of 29 ms, as was the interaction between bin and arrow-based Simon, $F(4, 76)=34.22$, $p<.001$, $MSE=133$, $\eta_p^2=0.643$. Trends analysis showed that the arrow-based Simon effect increased linearly from bin 1 to bin 5, $F(1, 19)=46.44$, $p<.001$,

Fig. 1 Mean Simon effects for reaction time (left panel) and percent error (right panel) as a function of bin and location-based Simon effect (Experiment 1A), word-based Simon effect (Experiment 1B) and arrow-based Simon effect (1C)



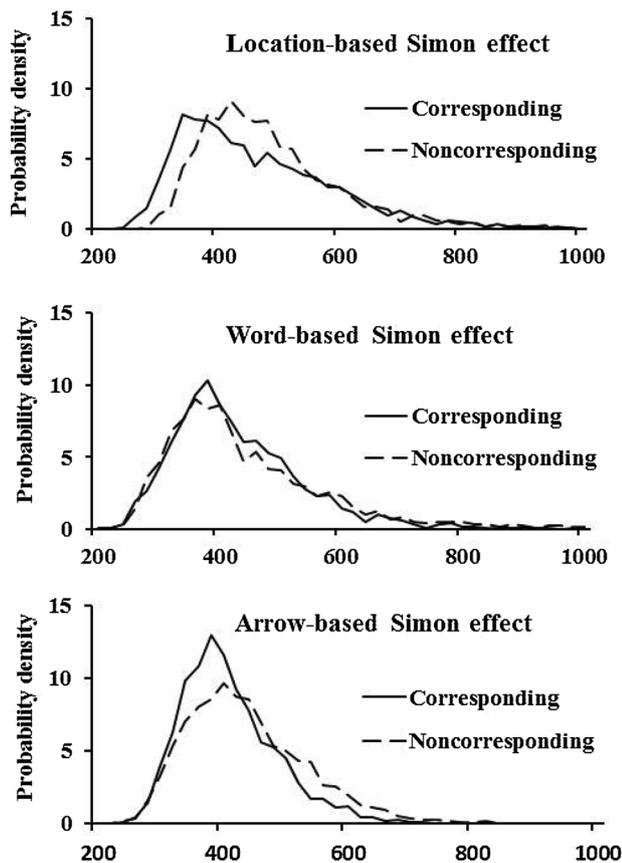


Fig. 2 Probability density (%) functions separately for corresponding and noncorresponding trials in the location-based Simon task of Experiment 1A (top panel), the word-based Simon task of Experiment 1B (middle panel), and the arrow-based Simon task of Experiment 1C (bottom panel)

MSE = 762, $\eta_p^2 = 0.710$, indicating a positive-going delta plot (see Fig. 1). The arrow-based Simon effect was significant for bins 1–5 (6, 14, 26, 40, 60 ms, p s < 0.012).

Ex-Gaussian analysis on RT

Experiment 1A The main effect of location-based Simon was significant on μ (33 ms), $t(19) = 6.98$, $p < .001$. It approached but did not attain significance on σ , $t(19) = -1.93$, $p = .068$, and τ , $t(19) = 2.05$, $p = .054$, with the effects being negative (–7 and –9 ms, respectively).

Experiment 1B The main effect of word-based Simon was not significant on μ (4 ms), $t(19) = 0.85$, $p = .408$, but it approached significance on σ (9 ms), $t(19) = 1.75$, $p = .097$, and was significant on τ (15 ms), $t(19) = 3.17$, $p = .005$.

Experiment 1C The main effect of arrow-based Simon was significant on μ (17 ms), $t(19) = 4.62$, $p < .001$, σ (15 ms), $t(19) = 6.58$, $p < .001$, and τ (13 ms), $t(19) = 3.37$, $p = .003$.

Discussion

An overall location-based Simon effect on PE was not obtained, but a negative-going delta plot was evident. In contrast, the location-based Simon effect was evident on RT, and a decreasing delta plot was obtained. This latter result suggests that the Simon effect decreased gradually with the slowing of responses, replicating the findings of previous studies (De Jong et al., 1994; Proctor et al., 2013; Ulrich et al., 2015). These results, taken together with those of Luo and Proctor (2017) with stimuli presented for 150 ms, which showed a similar pattern, suggest that duration of stimulus presentation in the location-based Simon task does not influence the shape of the delta plot, paralleling the findings of Ellinghaus et al. (2017). Moreover, there was a positive location-based Simon effect on μ , but a negative location-based Simon effect trend on τ , replicating the results obtained in previous studies (De Jong et al., 1994; Luo & Proctor, 2018). The finding of a Simon effect on mean RT and μ , but a possible reversed effect on τ , suggests that the location-based Simon effect on mean RT mainly arises from a shift of the RT distribution in the corresponding and noncorresponding conditions, as shown in Fig. 2.

The word-based Simon effect on PE was obtained, but it did not change with bin. In contrast, the word-based Simon effect and an increasing delta plot were found on RT, replicating the findings obtained for keypress responses in prior studies (Experiment 2 in Khalid & Ansorge, 2013; Pellicano et al., 2009; Proctor et al., 2009, 2011). Moreover, the occurrence of the word-based Simon effect on τ but not μ indicates that the effect on mean RT arose mainly from the tail of the RT distribution in the noncorresponding condition, compared to that in the corresponding condition. This finding suggests that the word-based Simon effect mainly occurred in the slow responses, as shown in Fig. 2.

The arrow-based Simon effect on PE was obtained, but it did not change with bin. In contrast, the arrow-based Simon effect was obtained on mean RT, and the effect became larger at longer RTs in the Vincentile analyses, replicating findings of previous studies (Pellicano et al., 2009; Proctor et al., 2009; Proctor et al., 2011). The arrow-based Simon effects were evident on all three ex-Gaussian parameters, indicating that the effect on RT arose from a shift of the RT distribution and from the tail of the RT distribution in the incompatible condition, compared to that in the compatible condition. Thus, the arrow-based Simon effect occurred in both the fast and slow responses, as shown in Fig. 2. These results suggest that it had a spatial component similar to

the location-based Simon effect and a symbolic component similar to the word-based Simon effect (Miles & Proctor, 2012). Overall, these results of the various Simon effects in Experiment 1 showed that the effects were similar at the mean RT level but different at the RT distribution level.

Experiment 2: location-word Simon-like task

In this experiment, a Chinese word 左 (*left*) or 右 (*right*) written in red or green was presented eccentrically on the left or right side of the display, and participants made left and right responses to indicate their colors. The aim was to examine whether the location-based Simon effect and word-based Simon effect could occur in the same task and whether each was similar to the comparable effect in Experiments 1A and 1B at the mean RT and RT distribution levels.

Method

Participants

Twenty right-handed participants (9 females), age 18–29 years, from the same subject pool as in Experiment 1, took part in this experiment.

Apparatus, stimuli, procedure, design, and data analysis

Apparatus and stimuli were identical to those in Experiment 1B, except that the centers of the location words were 4.8° to the left or right of the screen center. The procedure and design were identical to Experiment 1A, except that the squares were replaced by location words, and the design became 2 (word-based Simon: corresponding, noncorresponding) × 2 (location-based Simon: corresponding, noncorresponding) design, with 64 observations per experimental condition. Data analysis was identical to that in

Experiment 1, except that a new variable word-based Simon was added to the analysis.

Results

Test trials with incorrect responses (3.1%) and RTs longer than 1.5 s (0.5%) were excluded from the RT analyses. Moreover, test trials (3.4%) wherein RTs were not within the 3 standard deviations of the mean in each condition for each participant were excluded from the RT analyses, including the Vincentile and ex-Gaussian analyses (see Table 2 for mean PE and RT).

Vincentile analysis on PE

The main effect of word-based Simon was significant, $F(1, 19) = 11.55$, $p = .003$, $MSE = 0.003$, $\eta_p^2 = 0.378$, with fewer response errors in the corresponding condition (2.7%) than in the noncorresponding condition (4.6%). The interaction between bin and word-based Simon was also significant, $F(4, 76) = 2.86$, $p = .029$, $MSE = 0.003$, $\eta_p^2 = 0.131$. Trend analysis showed that the Simon effect increased linearly from bin 1 to bin 5, yielding a positive-going delta plot, $F(1, 19) = 4.49$, $p = .048$, $MSE = 0.004$, $\eta_p^2 = 0.191$ (see Fig. 3).

The effects were not significant for bins 1, 2 and 3 (−1.4, 1.6, 1.7%, $ps > 0.088$) but were for bins 4 and 5 (4.4, 2.3%, $ps < 0.018$).

The main effect of location-based Simon was not significant ($F < 1$), but the bin × location-based Simon interaction was significant, $F(4, 76) = 11.30$, $p < .001$, $MSE = 0.003$, $\eta_p^2 = 0.373$. Trend analysis showed that, as in Experiment 1A, the Simon effect had both linearly and quadratically decreasing components from bin 1 to bin 5, $F(1, 19) = 16.98$, $p < .001$, $MSE = 0.003$, $\eta_p^2 = 0.472$; $F(1, 19) = 16.38$, $p < .001$, $MSE = 0.004$, $\eta_p^2 = 0.463$, respectively, resulting in a negative delta plot (see Fig. 3). The effects were not significant for bins 2, 4 and 5 (−0.4, −1.7, −0.4%, $ps > 0.145$) but were

Table 2 Mean percentage of error (PE) and reaction time (RT, in milliseconds), and ex-Gaussian parameter values, with standard deviation (in parentheses), as a function of symbol (location word or arrow)-based Simon and location-based Simon effects in Experiments 2 and 3

	Symbol	Location	PE	RT	μ	σ	τ
Exp. 2	Corr	Corr	2.0 (0.03)	518 (68)	450 (53)	76 (26)	68 (28)
		Noncorr	3.4 (0.02)	546 (71)	478 (52)	68 (22)	67 (33)
	Noncorr	Corr	4.5 (0.04)	533 (85)	446 (57)	86 (35)	87 (45)
		Noncorr	4.6 (0.04)	546 (75)	474 (58)	70 (25)	72 (29)
Exp. 3	Corr	Corr	2.2 (0.04)	468 (79)	389 (59)	42 (17)	81 (53)
		Noncorr	2.7 (0.05)	477 (51)	426 (52)	43 (16)	53 (31)
	Noncorr	Corr	4.4 (0.06)	483 (85)	404 (83)	48 (27)	79 (41)
		Noncorr	3.8 (0.07)	493 (67)	428 (58)	45 (15)	63 (39)

Corr corresponding, *Noncorr* noncorresponding

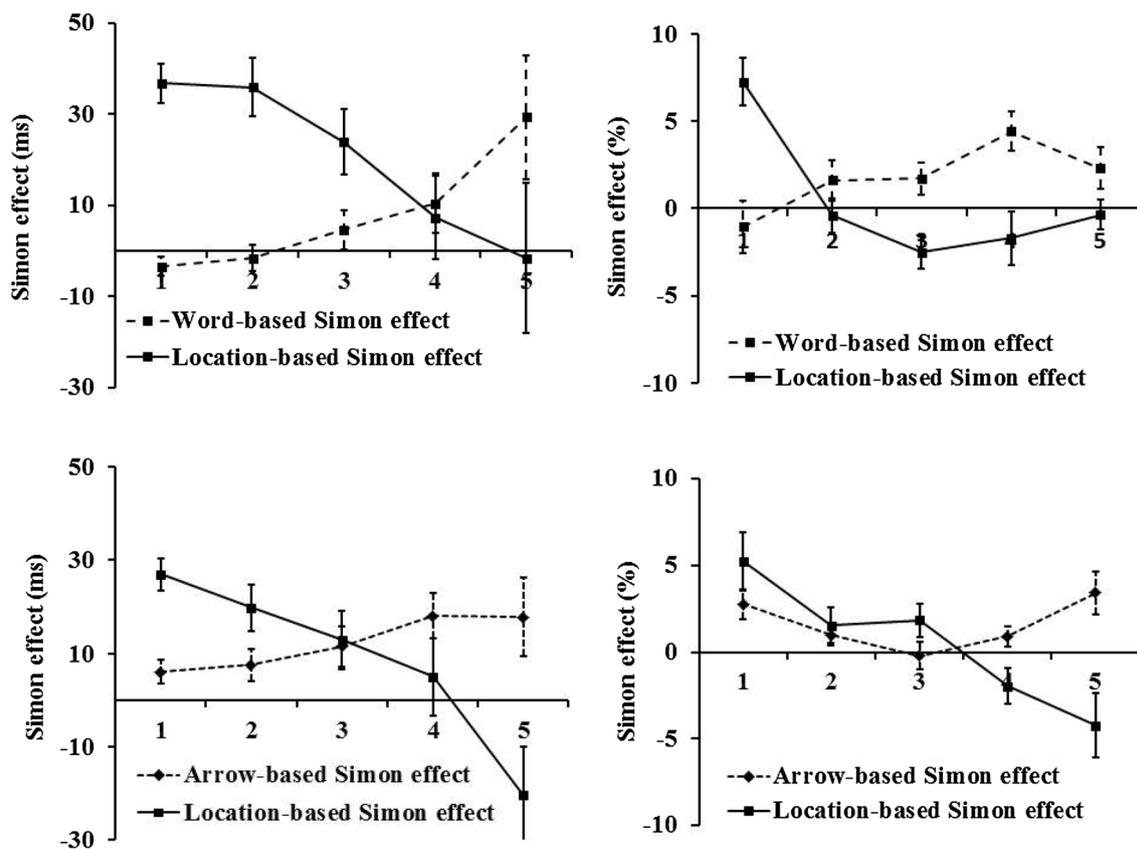


Fig. 3 Mean Simon effects for reaction time (RT) and percent error (PE) as a function of bin and symbol (location word or arrow)-based Simon and location-based Simon effects. Top panels for word- and

location-based Simon effects on RT and PE (Experiment 2) separately, whereas bottom panels for arrow- and location-based Simon effects separately on RT and PE (Experiment 3)

for bins 1 and 3 (7.3, 2.5%, $ps < 0.014$). The interaction between word-based Simon and location-based Simon was not significant, $F(1, 19) = 1.90$, $p = .184$, $MSE = 0.002$, $\eta_p^2 = 0.091$, nor was the three-way interaction of those two variables with bin, $F < 1$.

Vincentile analysis on RT

The main effect of word-based Simon was not significant, with a Simon effect of 8 ms, $F(1, 19) = 2.70$, $p = .117$, $MSE = 2,383$, $\eta_p^2 = 0.125$, whereas the interaction between that factor and bin was, $F(1, 19) = 2.80$, $p = .010$, $MSE = 748$, $\eta_p^2 = 0.128$. Trend analysis showed that the word-based Simon effect increased linearly from bin 1 to 5, $F(1, 19) = 6.58$, $p = .019$, $MSE = 1,821$, $\eta_p^2 = 0.257$ (see Fig. 3). The word-based Simon effect was not significant for bins 1–4 (–4, –2, 5 and 10 ms, $ps > 0.128$), but it was for bin 5 (29 ms, $p = .043$). Comparative analysis showed that the Simon effect was not significantly smaller than that of 19 ms in Experiment 1B, $t(38) = 1.15$, $p = .259$.

The main effect of location-based Simon was significant, $F(1, 19) = 6.55$, $p = .019$, $MSE = 6,300$, $\eta_p^2 = 0.256$, indicating a Simon effect of 21 ms. Comparison to Experiment 1A showed that the effect was not smaller than in that experiment (24 ms), $t(38) = 0.36$, $p = .722$. Location-based Simon interacted with bin, $F(1, 19) = 7.57$, $p < .001$, $MSE = 782$, $\eta_p^2 = 0.285$. Trend analysis showed that the location-based Simon effect decreased linearly from bin 1 to bin 5, $F(1, 19) = 9.88$, $p = .005$, $MSE = 2,244$, $\eta_p^2 = 0.342$ (see Fig. 3). The effects for bins 1 to 3 were significant (37, 36 and 24 ms, $ps < 0.004$), whereas those for bins 4 and 5 (7 and –2 ms, $ps > 0.439$) were not. The interaction between word-based Simon and location-based Simon was not significant, $F(1, 19) = 2.12$, $p = .162$, $MSE = 2,519$, $\eta_p^2 = 0.100$, nor was the three-way interaction between them and bin, $F(1, 19) = 1.27$, $p = .289$, $MSE = 1,128$, $\eta_p^2 = 0.063$.

Ex-Gaussian analysis on RT

For μ , the main effect of location-based Simon was significant, $F(1, 19) = 17.16$, $p < .001$, $MSE = 895$ a, $\eta_p^2 = 0.475$,

indicating a 28 ms Simon effect. Comparative analysis across experiments showed that this effect was not significantly smaller than that (33 ms) in Experiment 1A, $t(38)=0.62$, $p=.540$. The main effect of word-based Simon was not significant (-4 ms, $F < 1$), and comparative analysis showed that this effect also was not significantly smaller than that in Experiment 1B (4 ms), $t(38)=1.27$, $p=.213$. The interaction between location-based Simon and word-based Simon was not significant, $F < 1$.

For σ , the main effect of word-based Simon approached significance, $F(1, 19)=3.69$, $p=.070$, $MSE=183$, $\eta_p^2=0.163$, with a 6 ms Simon effect, whereas the main effect of location-based Simon was significant, $F(1, 19)=8.99$, $p=.007$, $MSE=343$, $\eta_p^2=0.321$, indicating a -12 ms Simon effect. The interaction between the two variables was non-significant, $F < 1$. Comparative analysis showed that neither the word-based Simon effect nor the location-based Simon effect differed reliably from the comparable effects on σ in Experiment 1B (9 ms), $t(38)=0.51$, $p=.614$, and Experiment 1A (-7 ms), $t(38)=0.87$, $p=.388$.

For τ , the main effect of location-based Simon (-8 ms) was not significant, $F(1, 19)=2.47$, $p=.133$, $MSE=623$,

$\eta_p^2=0.115$, but that of word-based Simon was significant, $F(1, 19)=4.94$, $p=.039$, $MSE=568$, $\eta_p^2=0.206$, indicating a 12 ms word-based Simon effect. The interaction between the two was not significant, $F(1, 19)=1.17$, $p=.293$, $MSE=458$, $\eta_p^2=0.058$. Comparative analysis showed that the word-based Simon effect was not different from that in Experiment 1B (15 ms), $t(38)=0.41$, $p=.684$, and the location-based effect was not different from that in Experiment 1A (-9 ms), $t(38)=0.22$, $p=.825$.

Discussion

The location-based Simon effect and the decreasing delta plot on RT and PE were obtained, suggesting that the location-based Simon effect decreased gradually with the slowing of responses. Moreover, the location-based Simon effect was positive on μ and negative on σ , and there was no significant effect on τ , suggesting that this effect mainly occurred in the fast responses. The location-based effect on mean RT arose from a shift of RT distribution in the corresponding condition compared to the noncorresponding condition, as shown in Fig. 4. These results were similar to the findings observed

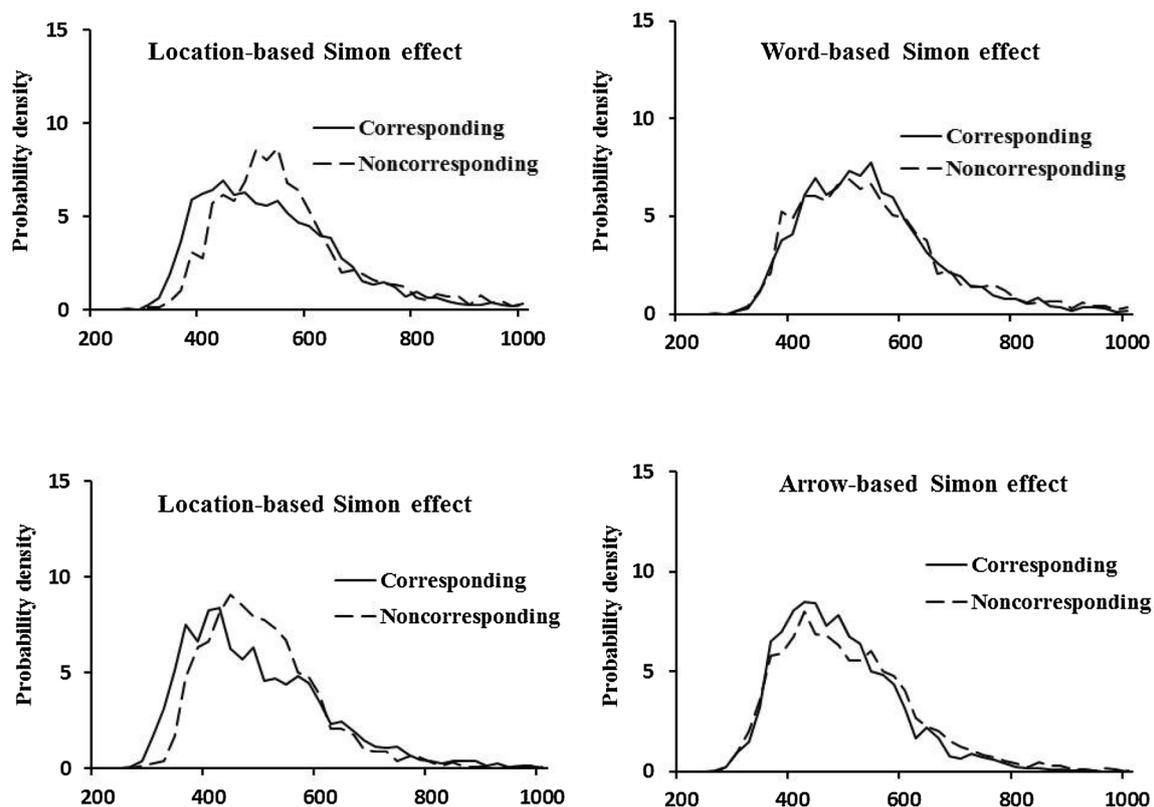


Fig. 4 Probability density (%) functions separately for Corresponding and Noncorresponding conditions in the location- and word-based Simon effects in Experiment 2 (top panels) and in the location- and arrow-based Simon effects in Experiment 3 (bottom panels)

in Experiment 1A, suggesting that the location-based Simon effect occurred at the levels of mean RT and RT distribution, and the effect of the direct route (association of location and response position) on responses was not influenced by the current task context.

The word-based Simon effect and an increasing delta plot on PE were obtained, different from Experiment 1B wherein the increasing delta plot was not obtained. The word-based Simon effect did not occur on mean RT, whereas the increasing delta plot was evident. Likewise, the word-based Simon effect occurred on τ (12 ms) but not on μ , indicating that the effect arose from the tail of the RT distribution in the noncorresponding condition compared to the corresponding condition and that it occurred in the slower responses, as shown in Fig. 4. These results showed that the word-based Simon effect did not occur at the level of mean RT but was evident in the RT distribution. The word-based Simon effects on mean RT and ex-Gaussian parameters were not significantly different from those in Experiment 1B, suggesting that the effect of the direct route (association of location word and response position) on responses was not influenced by being in the context of a location-based Simon effect.

These results of word-based Simon effects were different from the study of Luo and Proctor (2017), in which the location words were presented for only 150 ms. In that study, word-based Simon effects on PE and mean RT and the increasing delta plot were not evident. Because mean saccadic eye-movement latencies range from 150 to 200 ms (Carpenter, 1988), the lack of word-based Simon effect in Luo and Proctor's (2017) study was likely due to the 150-ms duration being insufficient to make necessary eye movements to the eccentric stimuli.

Experiment 3: arrow Simon-like task

For 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. The aim was to examine whether location-based and arrow-based Simon effects could be observed in the same task and whether they were similar to those in Experiments 1A and 1C at the mean RT and RT distribution levels.

Method

Participants

Twenty right-handed participants (11 males), age 18–29 years (mean 23), from the same subject pool as in Experiments 1 and 2, took part.

Apparatus, stimuli, procedure, design and data analysis

They were the same as in Experiment 2, except for the location words left and right being replaced separately by left- and right-pointing arrows (\rightarrow and \leftarrow , $0.85^\circ \times 0.85^\circ$, with $0.51^\circ \times 0.85^\circ$ for arrowhead and $0.34^\circ \times 0.15^\circ$ for arrow bar).

Results

Test trials with incorrect responses (3.2%) and RTs longer than 1.5 s (0.2%) were excluded from the RT analyses. Moreover, test trials (2.9%) wherein RTs were not within the three standard deviations of the mean in each condition for each participant were excluded from the RT analyses, including the Vincentile and ex-Gaussian analyses.

Vincentile analysis on PE

The main effects of bin and arrow-based Simon were significant, $F(4, 76) = 2.70$, $p = .037$, $MSE = 0.005$, $\eta_p^2 = 0.124$; $F(1, 19) = 10.66$, $p = .004$, $MSE = 0.004$, $\eta_p^2 = 0.359$, with fewer error responses when the arrow direction and response were corresponding (2.5%) rather than noncorresponding (4.0%). The interaction between bin and arrow-based Simon was significant, $F(4, 76) = 2.89$, $p = .028$, $MSE = 0.001$, $\eta_p^2 = 0.132$. Trends analysis showed that the Simon effect did not change linearly from bin 1 to bin 5, $F < 1$ (see Fig. 5).

The main effect of location-based Simon was not significant, $F(1, 19) = 1.08$, $p = .312$, $MSE = 0.002$, $\eta_p^2 = 0.054$, but the interaction between bin and location-based Simon was, $F(4, 76) = 6.38$, $p < .001$, $MSE = 0.004$, $\eta_p^2 = 0.251$.

Trend analysis showed that the Simon effect decreased linearly from bin 1 to bin 5, $F(1, 19) = 7.58$, $p = .013$, $MSE = 0.013$, $\eta_p^2 = 0.285$ (see Fig. 3). The effects for bins 2, 3 and 4 were not significant (1.5, 1.8, -2.0% , $ps > 0.075$), but those for bins 1 and 5 were significant (5.2, -4.2% , $ps < 0.034$), showing positive and negative effects, respectively. The interaction between location-based Simon and arrow-based Simon was not significant ($F < 1$), nor was the three-way interaction between them and bin, $F(4, 76) = 2.16$, $p = .162$, $MSE = 0.021$, $\eta_p^2 = 0.100$.

Vincentile analysis on RT

The main effect of arrow-based Simon was significant, $F(1, 19) = 5.13$, $p = .035$, $MSE = 2,995$, $\eta_p^2 = 0.212$, with a 13 ms

Simon effect, but the interaction between it and bin was not significant, $F(4, 76) = 1.66$, $p = .213$, $MSE = 750$, $\eta_p^2 = 0.081$.

As shown in Fig. 3, the arrow-based Simon effect increased linearly from bin 1 to bin 5, but trends analysis showed that this increase was not significant, $F(1, 19) = 2.50$, $p = .131$, $MSE = 922$, $\eta_p^2 = 0.116$. Comparative analysis showed that the arrow-based Simon effect was smaller than that in Experiment 1C (29 ms), $t(38) = 2.59$, $p = .014$.

The main effect of location-based Simon was not significant, $F(1, 19) = 1.55$, $p = .228$, $MSE = 5,028$, $\eta_p^2 = 0.075$, but the interaction between it and bin was, $F(4, 76) = 8.61$, $p < .001$, $MSE = 782$, $\eta_p^2 = 0.312$. Trend analysis showed that the location-based Simon effect decreased linearly from bin 1 to bin 5, $F(1, 19) = 9.69$, $p = .006$, $MSE = 2,471$, $\eta_p^2 = 0.338$ (see Fig. 3). The Simon effect was significant for bins 1 and 2 (27 and 20 ms, $ps < 0.001$), approached the 0.05 level for bin 3 (13 ms, $p = .058$), and was not significant for bin 4 or 5 (5 and -20 ms, $ps > 0.219$). Comparative analysis showed that the location-based Simon effect (9 ms) was smaller in Experiment 3 than in Experiment 1A (24 ms), $t(38) = 1.90$, $p = .064$. The interaction between arrow-based Simon and location-based Simon was not significant, nor was the interaction between them and bin ($Fs < 1$).

Ex-Gaussian analyses on RT

For μ , the main effect of arrow-based Simon (9 ms) was not significant, $F(1, 19) = 1.72$, $p = .205$, $MSE = 853$, $\eta_p^2 = 0.083$, but that of location-based Simon was, $F(1, 39) = 21.27$, $p < .001$, $MSE = 876$, $\eta_p^2 = 0.528$, indicating a 31 ms Simon effect. The interaction between the two was not significant, $F(1, 19) = 1.68$, $p = .211$, $MSE = 508$, $\eta_p^2 = 0.081$. Comparative analysis showed that the arrow-based Simon effect was not smaller than that in Experiment 1C (17 ms), $t(38) = 1.08$, $p = .286$, and the location-based Simon effect was not smaller than that in Experiment 1A (33 ms), $t(38) = 0.28$, $p = .785$.

For σ , the main effects of arrow- and location-based Simon were not significant, $F(1, 19) = 1.79$, $p = .197$, $MSE = 197$, $\eta_p^2 = 0.086$; $F < 1$, nor was the interaction between them, $F < 1$. Comparative analysis showed that the arrow-based Simon effect on σ (4 ms) was smaller than that (15 ms) in Experiment 1C, $t(38) = 2.81$, $p = .008$, but the location-based Simon effect (-1 ms) was not different from that (-7 ms) in Experiment 1A, $t(38) = -1.10$, $p = .277$.

For τ , the main effect of arrow-based Simon was not significant (4 ms, $F < 1$), but that of location-based Simon was, $F(1, 19) = 6.21$, $p = .022$, $MSE = 1,534$, $\eta_p^2 = 0.246$, showing

a -22 ms reversed Simon effect. The interaction between them was not significant, $F < 1$. Comparative analysis indicated that the arrow-based Simon effect (4 ms) was not significantly smaller than that (13 ms) in Experiment 1C, $t(38) = 1.30$, $p = .202$, and the reverse location-based Simon effect was not significantly different from that (-9 ms) in Experiment 1A, $t(38) = 1.32$, $p = .196$.

Discussion

The location-based Simon effect on mean RT and PE was not observed, whereas the effect with the decreasing delta plot on RT and PE was obtained. Moreover, the location-based Simon effect was positive on μ and negative on τ ; this opposite effect likely resulted in the absence of the effect on mean RT, given that their sum equals to mean RT. The positive μ suggests that the location-based Simon effect occurred in the fast responses, arising from the shift of RT distribution in the corresponding condition compared to the noncorresponding condition, as shown in Fig. 4. The negative τ suggests that a reverse location-based Simon effect occurred in the slow responses, with there being more slow responses in the compatible condition than in the incompatible condition. The location-based Simon effects on μ , σ and τ were not different significantly from those in Experiment 1A but that on mean RT was. These results showed that the location-based Simon effect may be influenced by the current manipulation at the level of mean RT even though the general properties of the of the RT distribution remain similar.

The arrow-based Simon effect occurred on PE, and the effect on PE did not change linearly from bin 1 to 5, which was similar to the finding in Experiment 1C. The current results showed that the arrow-based Simon effect on PE occurred at the level of mean RT but not of the RT distribution. The arrow-based Simon effect occurred on mean RT, whereas the effect on RT did not change with bin, which was different from the finding in Experiment 1C, wherein the effect on mean RT increased linearly from bin 1 to bin 5. The arrow-based Simon effects occurred on mean RT but not on τ (4 ms) or μ (9 ms). Given that the sample mean equals μ plus τ , this result indicates that the effect on mean RT may have arisen from both a small shift of the RT distribution and of the tail of the RT distribution in the noncorresponding condition, compared to that in the corresponding condition, as shown in Fig. 4. These results, taken together with those on mean RT and delta plot, show that the arrow-based Simon effect occurred at the level of mean RT but not of RT distribution.

The arrow-based Simon effects occurring on mean RT but not on ex-Gaussian parameters, and the positive-going delta plot not being obtained, were somewhat different from the results in Experiment 1C, wherein the arrow-based

Simon effects on mean RT, ex-Gaussian parameters, and the positive-going delta plot were evident. Moreover, the arrow-based Simon effects on mean RT and σ were reduced, as compared to Experiment 1C. These results suggest that the current manipulation may influence the Simon effect at the levels of mean RT and RT distribution. This finding is similar to recent findings of Luo and Proctor (2017) with 150-ms presentation of the arrows. In that study, arrow-based Simon effects on PE and RT were obtained, but the effect on RT was not modulated by bin. These results, taken together those in Experiment 2, imply that the 150-ms presentation duration in Luo and Proctor (2017) likely influenced the word-based Simon effect but not the arrow-based Simon effect, probably due to computational complexity and attentional requirements underlying comprehension of the word (Gibson & Kingstone, 2006).

General discussion

The current study used Simon-like tasks to investigate whether the word- or arrow-based Simon effect and the location-based Simon effect can be observed in the same task. Stimuli were displayed until a response was made, unlike our prior experiments (Luo & Proctor, 2017), to understand whether and how the two direct routes (the association of stimulus location and response position and of word meaning or arrow direction and response position) affect the indirect route (the association of color and response position) together. In Experiment 1, wherein these direct routes were separately tested, the location-, word- and arrow-based Simon effects on mean RT were obtained, along with a decreasing delta plot for the location-based effect and an increasing delta plot for the word- or arrow-based Simon effect. The location-based Simon effect occurred on μ , and it was reversed on σ or τ . The arrow-based Simon effect occurred on μ , σ and τ , but the word-based Simon effect only occurred on τ . These results showed that these direct routes can separately affect the indirect route at the levels of mean RT and RT distribution.

In Experiment 2, the location-based Simon effect and the decreasing delta plot on RT were obtained, and the effect was positive on μ and negative on σ , with no significant effect on τ . These results show that the location-based effect occurred at the levels of mean RT and RT distribution in the combined location and word task context, almost replicating the findings of Experiment 1A. They suggest that one direct route (the association of stimulus location and response position) can influence responses in a manner that is little influenced by the other direct route (the association of word and response position). The word-based Simon effect on mean RT was not obtained, but it was evident in the increasing delta plots, somewhat different from Experiment

1B wherein the Simon effect on mean RT was significant. The word-based Simon effect was evident on τ but not on μ , and approached significance on σ . Moreover, the word-based Simon effects on mean RT, μ , σ and τ were not significantly different from those of Experiment 1B, suggesting that the direct route of word and response position can influence responses and the effects are little influenced by the direct route of physical location and response position at the level of RT distribution and of mean RT.

In Experiment 3, the location-based Simon effect on mean RT was only a nonsignificant 9 ms, but the decreasing delta plot was evident. The effect was positive on μ but negative on τ , which resulted in the absence of the effect on mean RT. The location-based Simon effects on μ , σ and τ were not significantly different from those in Experiment 1A, but the effect on mean RT was. Thus, no single component from the RT distribution seems to be the cause of the reduction of the location-based Simon effect at the level of mean RT. Together with those in Experiment 1A, the results of Experiment 3 imply that the direct route of physical location and response position can still influence responses but the effects can be influenced by the direct route of arrow and response position.

The arrow-based Simon effect occurred on mean RT, but the effect on RT did not change with bin, which was different from the finding in Experiment 1C, wherein the increasing delta plot was obtained. The arrow-based Simon effects were evident on mean RT but not on μ , σ and τ , that is, not at the level of the RT distribution. Moreover, the arrow-based Simon effects on mean RT and σ were smaller than those in Experiment 1C, wherein the Simon effects on ex-Gaussian parameters and the increasing delta plot were obtained, suggesting that the task context likely eliminated the Simon effect at the level of RT distribution but not mean RT. These findings imply that the direct route on of arrow direction and response position can influence responses, but the effects are affected by the direct route of physical location and response position.

The different effects of two direct routes on responses in Experiments 2 and 3 are likely because different time courses underlie the various Simon effects. In Experiment 2, the location-based Simon effect arose from automatic activation of visual-spatial codes of stimulus location that occurs immediately after stimulus onset (Bundesen, 1991; Tipper et al., 1994), whereas the word-based Simon effect arose from activation of semantic-spatial codes from the location word that is delayed, probably due to computational complexity and attentional requirements underlying the comprehension of the stimulus (Gibson & Kingstone, 2006). The disparities make the location- and word-based Simon effects occur separately, being evident in the faster and slower responses, respectively. Consequently, the direct route of stimulus location and response position could

influence responses, and the effects were little influenced by the other direct route of word and response position. Moreover, because the number of slower responses was small, the word-based Simon effect was evident on τ but not on mean RT that equals to μ plus τ . These results are compatible with the predictions of dimensional weighting (Memelink & Hommel, 2013; Yamaguchi & Proctor, 2012), assuming that only one spatial dimension at any given time can cause an impact.

In Experiment 3, the arrow may activate both visual- and semantic-spatial codes, and automatic activation of visual-spatial codes of stimulus location is likely to be faster than of the direction of arrow. This relation likely inhibited the latter, which caused the arrow-based Simon effect in the faster responses to be absent. The location-based Simon effect was reversed in the slower responses, similar to the finding that the location-based Simon effect is eliminated or reversed when location-based Simon task trials are intermixed with ones in which participants respond to the left- and right-pointing arrows with incompatibly mapped keypresses (Notebaert et al., 2007; Proctor et al., 2000; Vu et al., 2010). Likewise, the arrow-based Simon effect was not obtained in the slower responses, like the finding that the arrow-based Simon effect is eliminated or reversed when arrow-based Simon task trials are intermixed with ones in which participants respond to the locations left and right with incompatibly mapped keypresses (Notebaert et al., 2007; Proctor et al., 2000; Vu et al., 2010). Further research is needed to examine whether these similar results for different manipulations have a common basis. The arrow-based and location-based Simon results also are compatible with the predictions of dimensional weighting (Memelink & Hommel, 2013; Yamaguchi & Proctor, 2012), assuming that only one spatial dimension at any given time can cause an impact.

The findings obtained in Experiments 2 and 3—that one direct route did not always influence the effects of the other direct route on the response—imply that although multiple information-processing routes can explain the Simon effect, the mechanisms underlying response activation are more flexible than assumed in previous dual-route models. The current results are compatible with previous findings that the Simon effect does not always occur when stimulus features overlap with responses (Hommel, 2000). For instance, Eimer and Schlaghecken (1998) found that the spatial compatibility between subliminally primed arrows and responses influenced response performance when the target stimuli were also arrows but not when they were letters, suggesting that processing irrelevant subliminal primes depends on what kind of stimuli the observer intends to process. Similarly, Miles, Yamaguchi, and Proctor (2009) demonstrated that the Simon effect can be diluted by a task-irrelevant neutral stimulus when it is categorically similar to a task-irrelevant stimulus that produces

the Simon effect. This result implies that processing of task-irrelevant stimuli is capacity limited and context dependent. Thus, in contrast to the dual-route accounts, these studies and the current findings suggest that the Simon effect is sensitive to the task context.

The findings in Experiments 2 and 3 indicating that one direct route could influence the effects of the other direct route on the response seem incompatible with Wascher's theory of separate mechanisms (Pratte et al., 2010; Wascher et al., 2001; Wiegand & Wascher, 2005, 2007). This theory would predict that in Experiments 2 and 3, the location and location word or arrow will influence separately the responses and not each other, generating the location- and word- or arrow-based Simon effects, as two separate mechanisms are responsible for the location-based Simon effect and the word- or arrow-based Simon effects.

In conclusion, when both stimulus location and location-word meaning varied in a Simon-like task, the location-based Simon effect occurred at the levels of mean RTs and RT distributions, whereas the word-based Simon effect only occurred at the level of RT distributions. When both stimulus location and arrow direction varied, the location-based Simon effect did not occur at the level of mean RT but at the level of RT distribution, whereas the opposite pattern occurred for the arrow-based Simon effect. These results could imply that one direct route influences the effects of the other direct route on the responses, depending on the task context.

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Compliance with ethical standards

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

Informed consent 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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