

Approach and avoidance movements are unaffected by cognitive conflict: A comparison of the Simon effect and stimulus–response compatibility

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Abstract Participants in this study reached from central fixation to a lateral position that either contained or was opposite to the stimulus. Cognitive conflict was induced when the stimulus and response directions did not correspond. In the Simon task, the response direction was cued by the color of the lateral stimulus, and corresponding and noncorresponding trials varied randomly in the same block of trials, resulting in high uncertainty and long reaction times (RTs). In the stimulus–response compatibility (SRC) task, participants reached toward or away from the stimulus in separate blocks of trials, resulting in low uncertainty and short RTs. In the SRC task, cognitive conflict in noncorresponding trials slowed down RTs but hardly affected reach trajectories. In the Simon task, both RTs and reach trajectories were strongly influenced by stimulus–response correspondence. Despite the overall longer RTs in the Simon task, reaches were less direct and deviated toward the stimulus in noncorresponding trials. Thus, cognitive conflict was resolved before movement initiation in the SRC task, whereas it leaked into movement execution in the Simon task. Current theories of the Simon effect, such as the gating of response activation or response code decay, are inconsistent with our results. We propose that the SRC task was

decomposed as approaching and avoiding the stimulus, which is sustained by stereotyped visuomotor routines. With complex stimulus–response relationships (Simon task), responses had to be coded as leftward and rightward, with more uncertainty about how to execute the action. This uncertainty permitted cognitive conflict to leak into the movement execution.

Keywords Stimulus–response compatibility effect · Simon effect · Reaching · Motor control · Cognitive conflict

Cognitive conflict is frequently studied in paradigms in which the position of a stimulus does not match the required response location, as for instance in the Simon and stimulus–response compatibility (SRC) tasks (Fitts, 1954; Simon & Rudell, 1967). In a simple version of the SRC paradigm (e.g., Umiltà & Liotti, 1987), participants are asked to press a button that spatially corresponds to the lateral position of the stimulus in one block of trials.¹ In another block of trials, participants press a spatially noncorresponding button. Typically, participants respond more quickly and accurately in corresponding than in noncorresponding blocks of trials. In a visual version of the Simon task, participants have to press a lateralized button in response to the color of a stimulus that appears on either the left or the right (e.g., Eimer, Hommel, & Prinz, 1995). Even if the location of the stimulus is irrelevant, better performance is observed when stimulus and response location correspond than when they do not correspond.

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¹ The effect of stimulus–response compatibility is typically associated with the words “compatible” and “incompatible,” whereas the Simon effect is associated with “congruent” and “incongruent.” To keep the article as readable as possible, we decided to use the words “corresponding” and “noncorresponding” to refer to both effects.

Currently, the Simon and SRC effects are both accounted for by dual-route models (De Jong, Liang, & Lauber, 1994; Eimer et al., 1995; Kornblum, Hasbroucq, & Osman, 1990). Presentation of a visual stimulus is assumed to rapidly activate a spatially corresponding response (direct route activation). In contrast, the correct response is selected on the basis of the instruction (indirect route). To explain the longer reaction times (RTs) in noncorresponding trials, it is assumed that it takes time to resolve the conflict between the (wrong) response that is activated by the stimulus and the instructed response. Furthermore, it has been argued on the basis of RT distributions that the rapid response activation via the direct route decays over time, and is therefore more pronounced with fast than with slow responses (for a critical review, see Proctor, Miles, & Baroni, 2011).

Recently, stimulus–response correspondence effects in the Simon and SRC paradigms have been directly compared. Mordkoff and Hazeltine (2011) demonstrated that the magnitude of correspondence effects was larger in the SRC than in the Simon paradigm. Their explanation was that in the Simon task, response activation from the direct route is attenuated (or “gated”) to prevent incorrect responses. Indeed, corresponding and noncorresponding trials vary unpredictably in the Simon task, and the response that is activated by the direct route is incorrect on half of the trials. In the SRC task, compatible and incompatible trials are predictable, since they are presented in separate blocks of trials. Therefore, in a block of corresponding trials the direct route fully activates an overt response, while in a block of noncorresponding trials this activation is entirely suppressed. Mordkoff and Hazeltine proposed that gating reduced the size of correspondence effects in the Simon task relative to the SRC task. They also assumed that the origin of cognitive conflict was response activation from the direct route in both cases. In support of a common origin, their SRC and Simon tasks showed the same interactions between stimulus set (location or arrow stimuli) and response set (buttonpresses or joystick movements).

The idea of attenuated response priming in the Simon effect has previously been discussed in the context of sequential modulations of the Simon effect. Notably, the Simon effect is smaller or reversed after noncorresponding trials, possibly because participants gate response activation after cognitive conflict (e.g., Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wendt, Kluwe, & Peters, 2006; Wühr & Ansorge, 2005).

In the present contribution, we compared Simon and SRC tasks with choice reaching responses in order to investigate the effects of the gating of response activation on motor planning and execution. Observers reached to one of two lateralized locations in which the imperative stimulus could appear (see Fig. 1a). It has been claimed that the cognitive state of the subject before movement initiation “leaks” into movement execution (Song & Nakayama, 2009). For

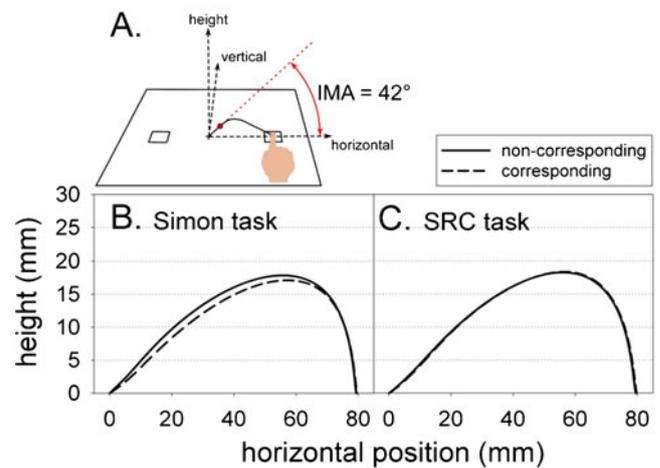


Fig. 1 The experimental paradigm and the mean trajectories in the Simon and stimulus–response compatibility (SRC) tasks are shown in panels a, b, and c, respectively

instance, numerical distance (Song & Nakayama, 2008), unconscious primes (Finkbeiner, Song, Nakayama, & Caramazza, 2008; Schmidt, 2002), lateralized presentation of the cue (Neyedli & Welsh, 2012) or target (Buetti & Kerzel, 2008, 2009; Scherbaum, Dshemuchadse, Fischer, & Goschke, 2010), and cursor–target color correspondence (Miles & Proctor, 2011) have affected not only RTs but also the trajectory of fast reaching movements.

According to Mordkoff and Hazeltine’s (2011) results, we would expect a larger magnitude of the correspondence effect for RTs in the SRC than in the Simon task. If movement trajectories mirror the cognitive state before movement execution, we would also expect larger changes of reach trajectories in the SRC than in the Simon task. For instance, in the SRC task, the full activation of the direct route in corresponding trials should result in more efficient (direct) trajectories toward the correct response. In contrast, the partial response priming in the Simon task may modulate trajectories to a lesser degree.

Method

Participants

A group of 35 undergraduate students participated (29 female, 6 male; 4 left-handed). All were naïve with respect to the purpose of the experiment. The study was approved by the local ethics committee.

Apparatus and stimuli

The 3-D coordinates of manual movements were recorded by an ultrasonic system (CMS20S, zebris Medical GmbH, Isny im Allgäu, Germany) at a sample frequency of 150 Hz

by means of a marker positioned on the nail of the index finger of the preferred hand. An LCD screen was placed in a frame attached to the table at an angle of about 20° between the screen and the table. Two empty boxes (3×3 cm) were displayed on a gray background of 111 cd/m², and the distance (center to center) from the centered cross to the boxes was about 8 cm (see Fig. 1a). The target stimulus was a colored or gray square of 47 cd/m² that filled one of the two boxes.

Procedure

Participants were seated at a distance of approximately 40 cm from the screen in a dimly lit room. When they had placed their finger on the central cross for 500 ms, the placeholder's luminance changed from dark gray to black to signal trial onset. After a random interval between 0.3 and 1.3 s, one of the boxes was filled. In the SRC task, the fill color was dark gray. In the Simon task, the fill color was either red or green. Thus, stimulus variability was higher in the Simon task, but previous research has shown the Simon effect to be unaffected by response-irrelevant stimulus variability (Ansorge & Wühr, 2004). Also, there is no evidence that color is less efficient than brightness in guiding reaching movements (White, Kerzel, & Gegenfurtner, 2006). Participants were instructed to lift their index finger from the screen surface, move the hand toward the correct location, and touch the box. They were told to respond as rapidly as possible without making too many errors.

During the experiment, visual feedback about the following errors was shown to the participant: Manual latencies shorter than 100 ms and longer than 1,200 ms were considered anticipations and missed trials, respectively. Manual choice errors were trials in which the wrong box was touched. Hand movements should not glide along the screen (i.e., the hand/finger had to be lifted).

Design

The mapping of color to response direction in the Simon task and the mapping of stimulus position to response direction in the SRC task changed after each block of 80 trials. Participants completed four blocks that were preceded by two training blocks that contained 40 trials for each mapping. The order of blocks was counterbalanced across participants. Four warm-up trials that were not recorded preceded each experimental block and followed a short break with performance feedback in the middle of the block. Overall, participants completed 80 training and 320 experimental trials. Eighteen of the participants were randomly assigned to the Simon task, and 17 to the SRC task. The factor Task was assigned between subjects to avoid effects of order (Iani, Rubichi, Gherri, & Nicoletti, 2009; Mordkoff & Hazeltine, 2011; Proctor & Vu, 2002).

Dependent variables and analyses

Offline, the tangential velocity traces were filtered at 35 Hz. The RT was defined as the first velocity sample greater than 5.9 cm/s. The movement time (MT) was the interval between RT and the first velocity sample that was less than 20% of the peak velocity. Total time (TT) was the sum of RT and MT.

The initial movement angle (IMA) was the angle between two vectors. The first vector went from the position of the index finger at movement onset to the position of the index finger after 1/5 of the total MT (see Fig. 1a). The second vector went from the position of the index finger at movement onset to the position of the index finger at movement offset. Thus, the IMA gives information about trajectory deviations in the early segment of the movement and mirrors the motor plan assembled before movement initiation. Furthermore, we characterized the later parts of the trajectory by the maximal height (i.e., distance from screen).

Choice errors (3%) and the following error types were removed from the data: anticipations, misses, losses of ultrasonic signal, trajectories with submovements (velocity drops, often caused by changes of direction), and trials that were further than three standard deviations from the respective condition mean on any of the dependent variables below. In total, 12% of the trials in the Simon task and 6% of the trials in the SRC task were excluded.

Results

The mean RTs, MTs, TTs, and IMAs are shown in Fig. 2, and mean trajectories are shown in Fig. 1. A mixed-factor ANOVA (Task × Correspondence) on RTs confirmed shorter RTs in the SRC than in the Simon task (291 vs.

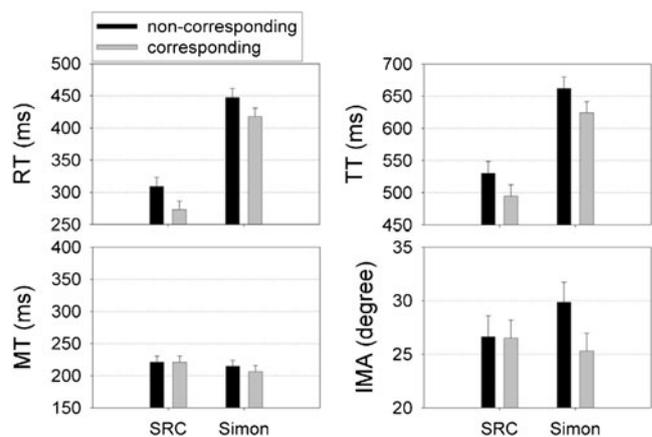


Fig. 2 Experimental results: Mean reaction times (RTs), movement times (MTs), total times (TTs), and initial movement angles (IMAs) in the stimulus–response compatibility (SRC) and Simon tasks are shown. The error bars denote the between-subjects standard errors of the means

433 ms), $F(1, 33) = 56.14$, $p < .001$. RTs were also shorter in corresponding than in noncorresponding trials (346 vs. 378 ms), $F(1, 33) = 131.47$, $p < .001$. The interaction of task and correspondence did not reach significance, $p = .281$, indicating that the Simon and SRC effects were of equal size (30 vs. 36 ms).

The ANOVA on MTs indicated similar MTs in the SRC and Simon tasks (221 vs. 211 ms), $p = .435$. MTs in corresponding trials were faster than those in noncorresponding trials (214 vs. 218 ms), $F(1, 33) = 4.23$, $p = .048$. Also, the effect of correspondence was modulated by task, $F(1, 33) = 4.67$, $p = .038$. Planned t tests showed that the difference between corresponding and noncorresponding trials was significant in the Simon task (206 vs. 215 ms), $t(17) = 3.09$, $p = .007$, but not in the SRC task (221 ms in both conditions), $p = .945$. Consistent with our previous studies (Buetti & Kerzel, 2008, 2009), there were no or only weak correlations between RT and MT for the respective correspondence effects. Therefore, a trade-off between RTs and MTs was unlikely.

The ANOVA on TTs confirmed shorter responses in the SRC than in the Simon task (512 vs. 643 ms), $F(1, 33) = 27.35$, $p < .001$, and in corresponding than in noncorresponding trials (559 vs. 596 ms), $F(1, 33) = 105.11$, $p < .001$. The interaction of task and correspondence was not significant, $p = .772$.

The ANOVA on IMAs indicated similar IMAs in the SRC and Simon tasks (27° vs. 28°), $p = .668$. IMAs were smaller in corresponding than in noncorresponding trials (26° vs. 28°), $F(1, 33) = 6.02$, $p = .02$. The effect of correspondence was modulated by task, $F(1, 33) = 5.39$, $p = .027$. Planned t tests indicated a significant difference between corresponding and noncorresponding trials in the Simon task (25° vs. 30°), $t(17) = 2.56$, $p = .02$, but not in the SRC task (27° in both conditions), $p = .823$. In Figs. 1b and 1c, the early separation between the mean trajectories in the Simon task and the lack thereof in the SRC task is clearly visible. The separation continued until the finger was lowered to touch the target position.

The ANOVA on maximal height showed that the interaction between task and correspondence approached significance, $F(1, 33) = 3.65$, $p = .065$. No other effects were significant, $ps > .15$. Planned t tests showed that the maximal height was smaller in corresponding than in noncorresponding trials in the Simon task (18 vs. 19 mm), $t(17) = 2.96$, $p = .009$, but not in the SRC task (19 mm in both conditions), $p = .796$.

Choice errors were more frequent in the Simon than in the SRC task (6% vs. 1%), $F(1, 33) = 31.83$, $p < .001$, and occurred more often on noncorresponding than on corresponding trials (4% vs. 3%), $F(1, 33) = 4.63$, $p = .039$.

To investigate sequential modulations in the Simon task, we subjected RTs and IMAs to a two-way ANOVA (Correspondence on Previous Trial \times Correspondence on Current

Trial). RTs were faster when the previous trial was corresponding (426 vs. 438 ms), $F(1, 17) = 16.33$, $p = .001$, and also when the current trial was corresponding (416 vs. 447 ms), $F(1, 17) = 49.96$, $p < .001$. Importantly, the effect of correspondence in the current trial was larger when the previous trial was corresponding than when it was noncorresponding (51 vs. 11 ms), $F(1, 17) = 39.51$, $p < .001$. Similar results were obtained for MTs and TTs (not reported for brevity). Furthermore, IMAs were larger when the previous trial was corresponding than when it was noncorresponding (28° vs. 27°), $F(1, 17) = 4.64$, $p = .046$. In contrast, IMAs were smaller when the current trial was corresponding than when it was noncorresponding (25° vs. 30°), $F(1, 17) = 6.45$, $p = .021$. Importantly, the effect of correspondence on IMAs on the current trial was larger when the previous trial was corresponding than when it was noncorresponding (6° vs. 3°), $F(1, 17) = 10.07$, $p = .006$. Thus, both RTs and movement parameters provide evidence for the gating of direct response activation after noncorresponding trials.

Discussion

Mordkoff and Hazeltine (2011) reported an SRC effect twice as large as the Simon effect (61 vs. 29 ms) when they used location stimuli that, as in the present study, were combined with buttonpress responses. We could not replicate this finding with reaching responses: The correspondence effects in RTs were similar in the Simon and SRC tasks, even if TTs were considered. The main novelty of the reaching task was that responses were goal-directed and executed in close proximity to the stimuli. That is, participants had to reach a particular location and touch either the stimulus or the location opposite to it. In previous research, a symbolic movement had to be executed, with low demands on spatial precision and no substantial change in the spatial relation between stimulus and effector (e.g., flexion of left or right index finger with buttonpresses, wrist rotation with joystick movements).

While the correspondence effects in RTs did not differ between the Simon and SRC tasks, movement parameters revealed a fundamental difference: The conflict before movement initiation leaked into response execution in the Simon task, but not in the SRC task. The observed effects of stimulus–response correspondence in the Simon task are consistent with previous results (Buetti & Kerzel, 2008, 2009; Scherbaum et al., 2010): MTs were shorter, IMAs were smaller, and the height was lower when observers moved toward the stimulus than when they moved away from it. That is, responses toward the stimulus in the Simon task are more efficient than responses away from the stimulus. Also, the dissociation between equal RTs but different

movement parameters that we observed for the SRC and Simon tasks accords with a recent study showing that threatening stimuli affected movement parameters, but not RTs (Buetti, Juan, Rinck, & Kerzel, 2012).

In sum, Mordkoff and Hazeltine's (2011) suggestion that stronger gating occurs in the Simon than in the SRC task is not fully consistent with our data. First, we failed to find larger RT correspondence effects in the SRC than in the Simon task. Second, greater correspondence effects on movement parameters were expected in the SRC than in the Simon task, but the opposite was observed. Simply on the basis of the longer RTs in the Simon task, direct response activation should have dissipated (Proctor et al., 2011), thereby reducing the correspondence effects in movement parameters. However, the opposite was observed. In a similar vein, it is puzzling to note that responses with much longer preparation times were accompanied by larger differences in trajectories than were responses with shorter preparation times. Overall, our data show that RTs and movement parameters are rather independent: Short RTs did not result in long MTs, large correspondence effects in RTs did not result in weak correspondence effects in MTs, and so forth.

While gating of response activation cannot account for the differences between the Simon and SRC tasks, our analysis of sequential modulations confirmed gating of response activation in the Simon task after noncorresponding trials in both RTs and IMAs. Thus, our evaluation of the gating hypothesis is mixed: Gating fails to account for the similarities and differences between the SRC and Simon tasks, but it provides a good explanation of sequential modulations in the Simon task.

So, why does the gating of response activation make the wrong predictions for the SRC condition? We can exclude that the mere blocking of experimental conditions instead of complete randomization (e.g., Grice, 1968) reduced or eliminated correspondence effects in the SRC task. Indeed, RT correspondence effects were the same with blocked and randomized stimulus–response relationships, and Mordkoff and Hazeltine (2011) have even reported larger effects with blocked than with randomized presentation. We suggest that the relatively small correspondence effects in RTs (as compared to those in other studies—e.g., Proctor & Vu, 2002) and the complete absence of correspondence effects in movement parameters results from the goal-directed nature of the movements involved in the SRC task. The compatible mapping required approach-like actions (touching the stimulus), while the incompatible mapping required avoidance-like actions (away from stimulus). Approach and avoidance are two fundamental categories of human behavior (e.g., Chen & Bargh, 1999; Darwin, 1872), and we believe that humans have developed highly stereotyped movement patterns to implement these behavioral tendencies. For

instance, it has become a very common action for users of mobile devices to touch a salient icon or to touch elsewhere if the alternative proposed by the salient icon is not wanted. In the present case, participants could put these stereotyped stimulus–response patterns to work in the SRC task. In contrast, it is unlikely that movements in the Simon task were coded as approach or avoidance, because stimulus position was irrelevant. Rather, the instruction forced participants to translate the stimulus color into “left” and “right” responses, which resulted in more uncertainty about which movement to execute. We think that the absence of a strong visuomotor routine in the Simon task is what allowed cognitive conflict to leak into movement execution.

Finally, the present dissociation between the SRC and Simon tasks may also be compatible with different origins of the SRC and Simon effects. Specifically, Simon effects “leak” into actions because of continuing response conflict—an idea that is consistent with the popular dual-route models. According to the far less popular translational models (Deininger & Fitts, 1955), SRC effects would be resolved prior to execution of the response because they are due to issues of stimulus–response translation: In incompatible trials, translation of a stimulus into the correct response is slow, but there is no activation of the incorrect response. Consistent with translational models, SRC affected RTs but did not change the subsequent response execution.

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