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**Psychological Research**
An International Journal of Perception,
Attention, Memory, and Action

ISSN 0340-0727
Volume 79
Number 1

Psychological Research (2015)
79:134-142
DOI 10.1007/s00426-013-0533-5

Psychological Research

An International Journal of Perception, Attention, Memory, and Action

Volume 79 Number 1 January 2015

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ORIGINAL ARTICLE

# Simon in action: the effect of spatial congruency on grasping trajectories

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Received: 24 October 2013 / Accepted: 5 December 2013 / Published online: 18 December 2013

**Abstract** The Simon effect, one of the well-known stimulus–response compatibility effects, is usually explained as an expression of a conflict that occurs at the response selection stage. Here, we extended previous findings to provide evidence for post-response selection expression of the Simon effect. Following a presentation of a visual stimulus, participants grasped one of two objects that differed slightly in size. The results showed that visual stimulus congruency modulated grasping trajectories. Particularly, movements were more lateralized in congruent trials. This lateralization decreased as reaction time (RT) increased and therefore this effect could not be fully dissociated from the response selection stage. However, size sensitivity, as measured by the time taken to reach the maximum grip aperture between the fingers, was decreased for incongruent trials, unrelated to RT. This finding provides novel evidence for an independent expression of the Simon effect in post-response selection stages. Overall, our findings extend previous studies and demonstrate that the spatial conflict evoked by the Simon task encompasses several components and independently affects response selection stages as well as other components of motor execution.

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## Introduction

The Simon effect, one of the well-known stimulus–response (S–R) compatibility effects in cognitive psychology literature, was introduced over more than 40 years ago (Simon & Rudell, 1967; Simon & Small, 1969). In the Simon task, the participant is asked to press one of two buttons in response to an auditory or a visual attribute of a stimulus, while ignoring its spatial location. Although the spatial location of the target is not relevant, when targets appear on the opposite side of the to-be-pressed key (i.e., incongruent condition), responses are relatively slower and less accurate in comparison to responses to targets appearing on the same side as the correct key press (i.e., congruent condition). These differences in reaction time (RT) and accuracy are known as the Simon effect.

Different mechanisms were discussed to explain this effect, and it has been proposed that it occurs during the response selection stage and does not involve later cognitive processes such as motor execution (for a review see Hommel, 2011). This study was aimed at testing whether this assumption holds in a different domain of visuomotor control. To this end, we utilized a basic grasping task in which participants were asked to grasp one of two objects following presentation of a visual stimulus. This design allowed measuring post-response selection effects using different kinematic properties.

### The Simon effect in post-response selection stages

In spite of extensive research, the nature of the cognitive mechanisms that underlie the Simon effect is still under debate. Nonetheless, it is widely accepted that the Simon effect is an expression of a conflict that occurs at the response selection stage (e.g., De Jong, Liang, & Lauber, 1994; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kornblum, Hasbroucq, & Osman, 1990; Nicoletti & Umilta, 1994; Ridderinkhof, 2002; Umilta & Nicoletti, 1992).

Several studies have provided empirical support for this notion (Iani, Baroni, Pellicano, & Nicoletti, 2010; Rubichi, Nicoletti, Umiltà, & Zorzi, 2000; Rubichi & Pellicano, 2004). In these studies, participants were initially asked to press a central button with their right index finger. In response to a visual target, participants moved their finger to one of two lateralized buttons. The stimuli were either spatially congruent or incongruent with the location of the lateralized button. As expected, a Simon effect was observed, with longer RTs (i.e., the time from stimulus presentation to movement onset) for incongruent compared to congruent trials. Conversely, movement times (MTs, i.e., the time from movement onset to movement offset) were not affected by location incongruity (but see also Hietanen & Pia, 1995 showing Simon interference in MTs). These findings support the notion that the Simon effect occurs during the response selection stage and does not influence later cognitive processes such as motor execution.

More recently, Buetti and Kerzel (2008, 2009, 2010), Kerzel and Buetti (2012) criticized this line of studies by pointing out several methodological difficulties. Most important, action execution was measured using a single parameter—movement time—and therefore one could not entirely dismiss the possibility that the Simon effect could have been expressed by other aspects of action execution such as velocity, amplitude or the trajectories of the hand in motion.

These authors developed a paradigm that involved real-time pointing movements. Following the presentation of the visual stimulus, participants were presented with one of two squares displayed on a flat screen and were asked to point directly to one of these squares. In addition to RT and MT, the initial movement angle (IMA) and the angle between the screen and the participant's finger at 20 % of the movement were calculated as a measure of performance that preceded movement online corrections. A Simon effect was found for RTs as well as for MTs. In addition, larger IMAs were observed for incongruent compared to congruent trials, demonstrating the possible influence of a spatial conflict on movement execution. However, this effect was evident only for short RTs. The authors argued that these results reflected the conflict between the automatically activated response and the instructed response over time; for shorter RTs the conflict was not resolved completely prior to action execution, which presumably led to larger IMAs for incongruent trials. Correspondingly, the elimination of the IMA effect for longer RTs reflected the successful resolution of the conflict prior to action execution. Note that Buetti and Kerzel (2008, 2009) suggested that a possible dissociation exists between the Simon effect during response selection and the Simon effect during response programming. However, they argued that further evidence was needed to establish such an idea. Recently, Kerzel and Buetti (2012) extended these findings and reported that the maximum height of the hand was also modulated by congruency, with lower values for congruent compared with incongruent trials.

The IMA and the maximum height are discrete measurements for measuring the S–R compatibility effect. On the other hand, consecutive measurement of movement trajectory from movement onset to movement offset would allow measuring the effect of spatial conflict at different stages of the movement, and at a wider range of post-response selection stages. The existence of a relatively long-term effect could imply that the source of this effect is an independent component of the spatial conflict and is not the mere result of a delayed decision (Rubichi & Pellicano, 2004). Along similar lines, modulations of the motor execution that are independent from RTs could serve as evidence that motor programing is affected by the S–R spatial conflict independently of response selection.

A second issue put forward by Buetti and Kerzel (2008) focuses on the role of spatial locations of the visual stimulus and the response location in the production of the Simon effect. In particular, these authors argued that separation between response and stimulus location in other studies abolished the Simon effect for motor programming. They further argued that stimulus and response locations must be united to create a situation in which motor execution would be influenced by spatial conflicts. However, in the classic design of the Simon task, the S–R compatibility effect is usually observed despite the fact that the stimulus and response location are spatially separated or even presented across different sensory modalities (Simon & Rudell, 1967; Simon & Small, 1969). Moreover, Hommel (1996) found that the Simon effect could be created even with movements to a central position that do not have any particular spatial feature toward the location of the visual stimulus. The inability of early studies to find evidence for motor execution modulation following a spatial conflict could therefore be simply related to the fact that these studies did not use basic kinematic measurements of the movement beyond MT (Iani et al., 2010; Rubichi et al., 2000; Rubichi & Pellicano, 2004). Thus, it is conceivable that even when there is separation between the visual code and the response location, other aspects of motor execution could still be modulated by the spatial conflict.

## The current study

The current study was designed to examine the possible influences of the spatial S–R correspondence evoked by the

Simon task on post-response selection stages. To this purpose, we measured different aspects of the movement trajectory when a separation existed between the visual stimulus and the location of the response. Participants performed a grasping version of a visual Simon task. To test the effect of congruency on motor execution, we recorded the 3D trajectories of the hand's movement in addition to the traditional measures of RT and accuracy.

The advantage of using a grasping task over pointing is the rich additional kinematic data it involves, which includes the aperture between the thumb and the index finger from movement onset to movement offset (aperture), the maximum grip aperture (MGA) prior to grasp, and the time taken to reach the MGA (i.e., time to MGA). Previous studies demonstrated that the MGA and the time to MGA are positively correlated with the size of the goal object (Jeannerod, 1981, 1984; Jakobson & Goodale, 1991). Indeed, the MGA was found to be sensitive to object size even when the size differences between the graspable objects were exceptionally small (e.g., 0.5 mm, see Ganel, Freud, Chajut, & Algom, 2012). Thus, the sensitivity of the MGA to object size serves as a sensitive measure for the quality of motor programming and motor execution. Moreover, in the current study, the utilization of subtle differences between object sizes allows avoiding unwarranted perceptual effects on movement programming and execution.

We predicted that the spatial conflict evoked by the Simon task would be reflected, as in previous studies (Iani et al., 2010; Rubichi & Pellicano, 2004), in RTs and not in MTs. However, we also expected that post-response selection effects would be observed (Buetti & Kerzel, 2008, 2009, 2010; Kerzel & Buetti, 2012). Movement trajectories and grasping properties were expected to differ between congruent and incongruent trials. In particular, in line with Finkbeiner, Song, Nakayama and Caramazza (2008), movements in congruent trials were expected to be more lateralized toward the target object. In other words, to allow online corrections in reaching to grasp the object during incongruent trials, movements in these trials were expected to be more cautious and therefore more centered in comparison to congruent trials.

In addition, the sensitivity to the small differences between object sizes was expected to be modulated by stimulus congruency. In particular, for incongruent trials, the action was expected to be automatically programmed toward the irrelevant stimulus, which could impair size sensitivity. In contrast, congruent trials were expected to enable a more natural movement trajectory toward the object, which could increase the sensitivity to small changes in object size. Thus, we predicted that larger sensitivity to object size would be found for congruent compared to incongruent trials.

## Method

### Participants

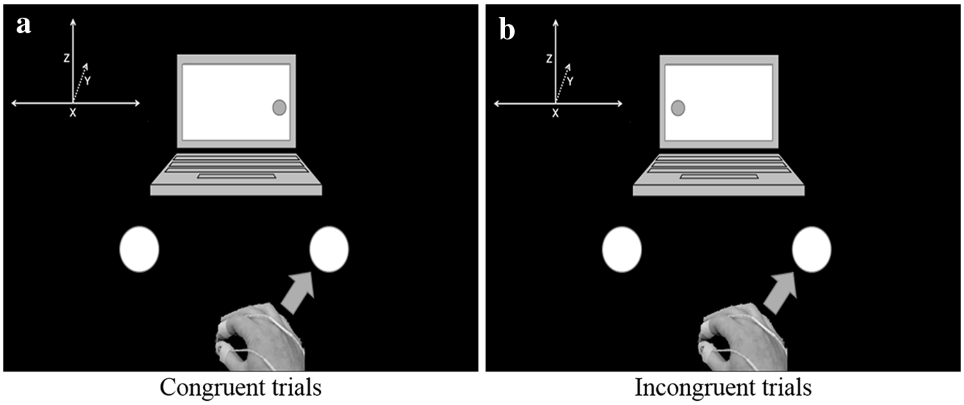
Twelve right-handed healthy undergraduate students with normal or corrected-to-normal vision participated in the experiment and received monetary compensation equivalent to 5$ for their participation. The experimental protocol was approved by the local ethics committee. All participants gave written informed consent before participating in this study.

### Apparatus and stimuli

Participants sat in front of a black tabletop on which the two target objects were placed at a viewing distance of approximately 22 cm (visual angle, 10.5°). A computer monitor was placed at a viewing distance of approximately 45 cm to indicate the designated target for the Simon task (see Fig. 1). Computer-controlled PLATO goggles (Translucent Technologies, Toronto, ON, Canada) with liquid-crystal shutter lenses were worn by participants and allowed controlling stimulus exposure time. Three infrared light-emitting diodes were attached separately to the participant's index finger, thumb, and wrist with small pieces of surgical tape, which allowed complete freedom of movement of the hand and fingers (Fig. 1). Grip scaling was recorded by an Optotrak Certus device (Northern Digital, Waterloo, ON, Canada), which tracked the position of the diodes at a resolution of 0.01 mm and a 200 HZ frame rate. The set of the objects-to-be -grasped was similar to the one used in a previous study (Ganel et al., 2012) and included two circular target discs that were 1 mm thick. The smaller to-be-grasped-disc was 40 mm in diameter and the larger to-be-grasped-disc was 40.5 mm in diameter. The visual stimuli that were presented on the screen were red and blue circles, in identical sizes, presented on the left or on the right of the monitor (visual angle—4°).

### Experimental procedure

Following equipment calibration and a short practice block of 6 trials, two experimental blocks of 64 experimental trials were presented. The participant was instructed to grasp one of the objects based on the color of the circle that appeared on the monitor (e.g., red circle—grasp the left object; blue circle—grasp the right object) while ignoring the visual spatial location. Consequently, half of the trials were congruent (i.e., the location of the visual stimulus was on the same side as the graspable object) and the other half were incongruent (i.e., the location of the visual stimulus was on the opposite side to the spatial location of the graspable object). The color-side mapping was counterbalanced among participants.



Congruent trials

Incongruent trials

**Fig. 1** Experimental design. **a** Congruent trials: the visual stimulus (*on-screen circle*) and the target object are in the same direction compared to the initial hand position. **b** Incongruent trials: the spatial location of the visual stimulus and the spatial location of the target object are in opposite directions

A trial began with the opening of the goggles, followed by a 500 ms fixation point and then followed by a red or a blue visual stimulus presented for additional 400 ms. To enable natural grasping with visual feedback, the goggles remained open for an additional 2,000 ms and then were kept closed until the beginning of the next trial. The order of trials was pseudo-randomized (counterbalanced across participants) between the two experimental blocks.

### Design

Congruency (congruent, incongruent) and object size (40, 40.5 mm) were manipulated as within-subject variables. An equal number of trials were used for each of the combination of these variables within each of the experimental blocks.

### Data analysis

For each trial, we recorded the 3D trajectories of the fingers during grasping. Data were analyzed using an in-house algorithm (The MathWorks, Inc., Natick, MA, USA). Movement initiation and movement offset were defined for each trial. Movement initiation was defined as the first of ten consecutive frames (50 ms) in which the velocity of the index finger was greater than 25 mm/s. Movement offset was defined as the point in time where wrist velocity was below 50 mm/s for five consecutive frames (25 ms).

Further analyses were conducted using an Excel Macro function (Microsoft cooperation, 2010). The macro automatically identified the MGA and divided each movement into 11 normalized time points (from movement initiation at 0 % to final grasping of the object at 100 %, in gaps of 10 %). Movement trajectories were computed for each of the 11 time points. These included the aperture between the thumb and index finger, and location in 3D space (*x*, *y*, *z* coordinates; see Fig. 1). Since no effects were found for the y and the *z* axes, only the results at the *x* axis will be further described.

Accuracy was defined as the proportion of correct trials in which the participant grasped the goal object cued by the visual stimulus. RT was the time interval between the stimulus presentation and the onset of the movement. For each participant, RTs more than 2.5 standard deviations slower than the mean were excluded from the analysis. MT was calculated by subtracting the time of movement initiation from the time of the final grasping. Both RT and MT were calculated for correct trials only.

## Results

### Accuracy, RT and MT

Accuracy was very high (above 98 %) for congruent and incongruent trials. Nevertheless, a repeated measures analysis of variance (ANOVA) with object size (40, 40.5 mm) and congruency (congruent, incongruent) as independent variables revealed higher accuracy for congruent trials (99.9 %) than for incongruent trials (98.6 %) (i.e., a Simon effect), $F_{(1,\ 11)} = 10.2$, $p < 0.01$, $\eta_p^2 = 0.48$. The two-way interaction was not significant; $F_{(1,\ 11)} = 2.2$, $p > 0.1$.

Mean RTs for correct responses were subjected to a repeated measures ANOVA with object size (40, 40.5 mm) and congruency (congruent, incongruent) as independent variables. A significant effect was found for congruency; $F_{(1,\ 11)} = 86.05$, $p < 0.00001$, $\eta_p^2 = 0.88$. As shown in Fig. 2a, RTs were faster for congruent trials compared to incongruent trials. The main effect of object size, $F_{(1,\ 11)} < 1$, and the interaction between object size and congruency, $F_{(1,\ 11)} < 1$, were both not significant.

Similar to Buetti and Kerzel (2008), RTs were distributed into quartiles for each block and condition. In particular, the fastest 25 % of the trials were set as the first quartile (i.e., Q1), the next slower 25 % of the trials were set as the second quartile (i.e., Q2), and so on. Main effects were found for congruency, $F_{(1,\ 11)} = 54$, $p < 0.00001$, $\eta_p^2 = 0.83$, and quartiles, $F_{(3,\ 33)} = 191$, $p < 0.00001$,

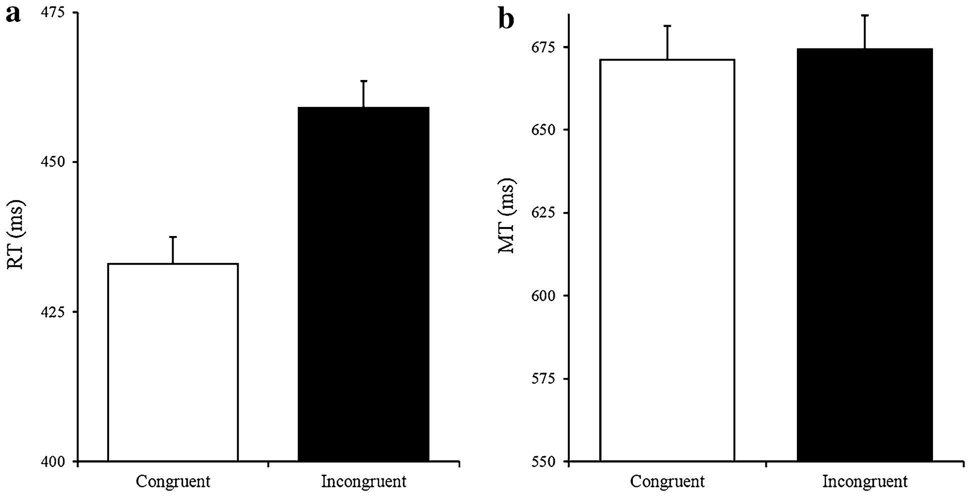


**Fig. 2** **a** Average reaction times (RT) and **b** movement times (MTs) for the different experimental conditions. A Simon effect was observed for RT, with shorter RTs for congruent trials compared to incongruent trials. MTs were not modulated by the Simon effect. *Error bars* represent confidence intervals for repeated measures ANOVAs (Jarmasz & Hollands, 2009)

$\eta_p^2 = 0.94$. More important, this analysis revealed that the congruency effect was not modulated by the RT quartile, $F_{(1,\ 33)} < 1$, and was similar for fast and slow reaction times. Note that this result does not replicate several classic visual Simon studies that demonstrated a decrease in the Simon effect for slow RTs (Buetti & Kerzel, 2009; Hommel, 1994). However, in a recent study that used the tactile variant of the Simon task, the magnitude of the Simon effect did not decrease but stayed rather constant across quartiles (Salzer, Aisenberg, Oron Gilad, & Henik, 2013).

Contrary to the RT results, and in line with previous studies (Iani et al., 2010; Rubichi & Pellicano, 2004), congruency did not modulate MT, $F_{(1,\ 11)} < 1$, which did not differ between congruent and incongruent trials (Fig. 2b). Previous studies have argued that such findings indicate that the Simon effect is a response selection phenomenon. Note that in Buetti and Kerzel's studies (e.g., Buetti & Kerzel, 2009; Kerzel & Buetti, 2012), a Simon effect was observed also in MT.

A marginal interaction between object size and congruency was found for the MT, $F_{(1,\ 11)} = 4.01$, $p = 0.07$, $\eta_p^2 = 0.26$; however, this interaction was probably related to modulation of the time to MGA, which is described below.

## Hand trajectories: horizontal plane

The hand trajectories in the horizontal plane were calculated separately for each trial to test whether the congruency condition modulated motor execution. Figure 3a shows the differences in the lateralization of the movement (movements on the horizontal plane, $x$ axis) between congruent and incongruent trials during the movement. The location coordinates were subjected to a repeated measures ANOVA with movement time point (11 levels of 10 % gaps ranging between 0 and 100 %), location of grasped object (right, left) and congruency (congruent, incongruent) as independent variables. The ANOVA revealed a main effect of congruency; $F_{(10,\ 110)} = 10.12$, $p < 0.01$, $\eta_p^2 = 0.47$. As predicted, movements for congruent trials were more lateralized compared to the movements for incongruent trials. Planned comparisons confirmed that this effect was found both in the first half of the movement (10–50 %), $F_{(1,\ 11)} = 4.72$, $p = 0.05$, and in the second half of the movement (60–90 %), $F_{(1,\ 11)} = 11.24$, $p < 0.01$. This finding suggests that hand position during grasping was modulated by congruency. In addition, a two-way interaction was found between movement time and congruency; $F_{(10,\ 110)} = 2.43$, $p < 0.05$, $\eta_p^2 = 0.18$. Importantly, this interaction reflects similar movement trajectories for congruent and incongruent trials at the initial (0 %) position of the movement, compared to the more lateralized movements found for later stages of the movement for congruent trials.

The position of the hand on the x axis during the movement was subjected to a repeated measures ANOVA with congruency (congruent, incongruent), RT quartiles (Q1, Q2, Q3, Q4), and movement time point (11 levels) as independent variables. Similar to previous findings (e.g., Buetti & Kerzel, 2009), this analysis revealed a significant interaction between quartiles and congruency; $F_{(3,\ 33)} = 5.97$, $p < 0.01$, $\eta_p^2 = 0.35$. Planned comparisons revealed lateralization effects only for the fastest RTs (Q1); $F_{(1,\ 11)} = 16.9$, $p < 0.01$ (see Fig. 3b).

To ensure that movement initiation reflected the end of the motor programing stages rather than delayed response selection processes, we compared right versus left movements as early as 10 % after the initiation of the movement. Significant differences in the hand position were found between left and right movements for congruent, $F_{(1,}$

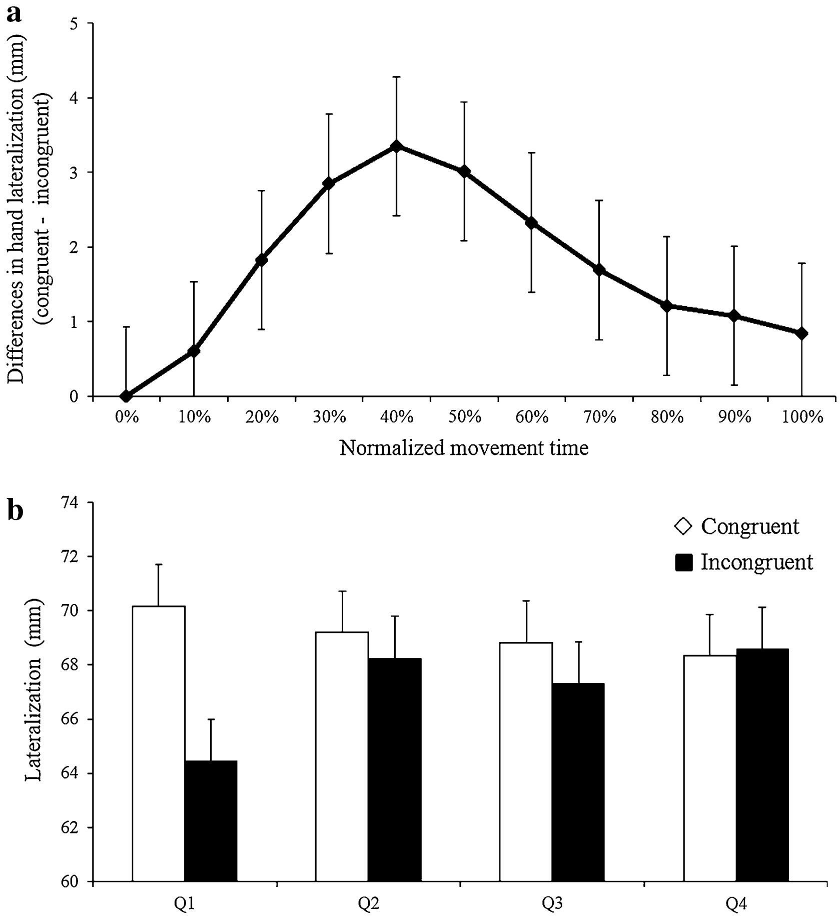


**Fig. 3** Hand trajectory data. **a** Differences in lateralization of the hand movements on the horizontal plane between congruent and incongruent trials; more lateralized movements were found for congruent trials in the first and second parts of the movement. **b** Lateralization of the hand movement as a function of reaction time for within-subject quarterly division of the entire movement; more lateralized movements for congruent trials were found only for the fastest (Q1) RTs. *Error bars* represent confidence intervals for repeated measures ANOVAs (Jarmasz & Hollands, 2009)

$_{11)} = 45.9$, $p < 0.0001$, and incongruent trials, $F_{(1, 11)} = 53.3$, $p < 0.0001$. This finding indicates that participants did not postpone their decision for incongruent trials, suggesting that the modulations of hand position during later phases of the movement were not related to the response selection stage.

## Grasping apertures

In addition to the spatial position of the hand, we also tracked the aperture of the grasping (i.e., the distance between the thumb and the index finger). We focused our analysis on the MGA. It has been previously shown that the MGA and the time taken to reach the MGA are positively correlated with the size of the goal object (Jeannerod, 1981, 1984 Jakobson & Goodale, 1991).

A repeated measures ANOVA was conducted, with object size (40, 40.5 mm) and congruency (congruent, incongruent) as independent variables and fingers aperture as the dependent variable. As in previous experiments with the same set of objects (Ganel et al., 2012), larger MGAs were found for the larger compared to the smaller object; $F_{(1, 11)} = 3.04$, $p = 0.05$, one tailed, $\eta_p^2 = 0.21$ (see Fig. 4a). Interestingly, no main effect of congruency or an interaction between congruency and object size was found (both $F_{(1, 11)} < 1$). The main effect for object size replicated Ganel et al.'s (2012) results and again illustrated the fine spatial resolution of the visuomotor system. This resolution seems to be uncompromised by the position-based conflicts inherent in the Simon task design.

A different pattern of results was observed for the time taken to reach the MGA. Importantly, this measure has been shown to be correlated with the object's size (Jeannerod, 1981, 1984; Jakobson & Goodale, 1991). A significant interaction was found between size and congruency; $F_{(1, 11)} = 7.17, p < 0.05, \eta_p^2 = 0.39$ (see Fig. 4b). In particular, for congruent trials, the time to reach MGA was, as expected, longer for the larger object; $F_{(1, 11)} = 3.25$, $p > 0.05$, one tailed. An opposite effect was observed for incongruent trials, for which the time taken to reach the MGA was longer for the smaller object; $F_{(1, 11)} = 5.01, p < 0.05$. On the other hand, the time from the MGA to the movement offset remained similar between conditions, $F_{\mathrm{s}} < 1$, resulting in a marginal interaction between congruency and object size for MT, as described above. This result shows that sensitivity for object size was

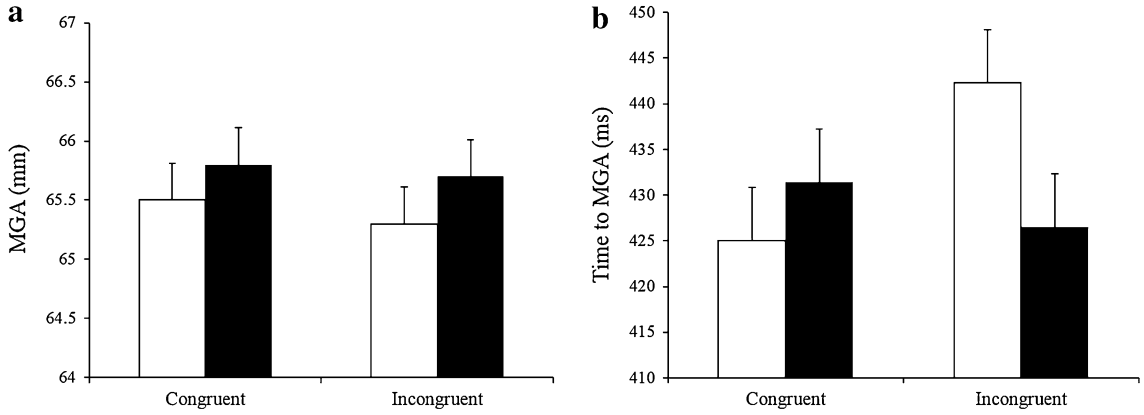


**Fig. 4** **a** Maximum grip apertures (MGAs) and **b** time to MGA. Sensitivity to object size was found for both congruent and incongruent trials, with larger MGAs for the 40.5 mm disc compared to the 40 mm disc. MGA was reached later in time for the large object in the congruent trials, with the reverse pattern of results observed for incongruent trials. Error bars represent confidence intervals for repeated measures ANOVAs (Jarmasz & Hollands, 2009)

modulated by congruency and therefore provides additional evidence for post-response selection effects on movement execution. The interaction between congruency and RT quartiles was not significant, $F_{(3,\ 33)} < 1$, which suggests that the Simon conflict affected grasping kinematics even for long reaction times and provides novel evidence that the Simon effect could be independent of the response selection stage.

## Discussion

The Simon effect has been commonly described as a response selection phenomenon (Hommel, 2011). In the current study we aimed to explore whether the spatial S–R conflict evoked by the Simon task could affect post-response selection components of motor execution. We utilized a novel design that enabled measuring diverse kinematic properties of visuomotor performance. In contrast to the classic view, our results suggest that the spatial conflict evoked by the Simon task modulates several aspects of the motor execution response, beyond response selection.

Two different aspects of the motor execution were measured in the current experiment. First, we measured the spatial location of the hand during movement and found that more lateralized movements were made in congruent trials. This lateralization of the movements was not restricted to the beginning of the movement and therefore reflected long-term effects of the spatial conflict. However, and similar to previous studies (e.g., Buetti and Kerzel, 2008, 2009), this effect was evident only for fast responses. Therefore, based on that finding alone, we cannot rule out the notion that the Simon effect stems from movements that were conducted before the response selection stage was completed and, hence, were affected by the spatial conflict.

The second set of measurements was related to grasping. We predicted that for incongruent trials, the motor response would be automatically directed to the irrelevant stimulus, which would result in a decrease in sensitivity to object size compared to the results for congruent trials. Particularly, the MGA and the time taken to reach the MGA were calculated based on previous studies that showed that these measurements were positively correlated to an object's size (Ganel et al., 2012; Jeannerod, 1981, 1984; Jakobson & Goodale, 1991). In the current study, the time taken to reach the MGA was modulated by congruency. In particular, for congruent trials, sensitivity for size was preserved for MGAs reached earlier in time for smaller compared to larger objects. In contrast, for incongruent trials, a reversed pattern was found. Crucially, these differences were found to be equivalent both for long RTs and short RTs. This finding shows that the post-response selection effect could be dissociated from the classic RT Simon effect. Note that in contrast to the time to reach MGAs, size sensitivity measured by differences in MGAs for larger compared to smaller objects was not modulated by Simon congruency. It is possible that the lack of differences between the two conditions could be related to online corrections of the aperture during grasps.

The results of the current study demonstrate that the Simon effect in post-response selection stages can be observed even when the visual stimulus and the response location are spatially separated. Note that Buetti and Kerzel (2009) have argued that previous studies failed to find evidence for motor execution modulation due to such a spatial separation. However, in the current study the visual stimulus affected performance even though it was presented on a computer screen and the objects were placed against a different surface on a tabletop. This finding indicates that conceptual rather than physical coupling between visual stimulus and response location is sufficient to produce a Simon effect that modulates action execution. This interpretation is in line with previous findings that showed that the Simon task can affect movements that do not have any particular spatial relation to the location of the visual target (Hommel, 1996).

The effect of spatial conflict on movement trajectories is not restricted to the Simon task and may describe an important entity of visual spatial attention. Diesendruck et al. (2010) have found that several aspects of the movement trajectories were affected by spatial congruency defined based on a synesthetic experience (i.e., months arranged in spatially defined configuration). The effects of spatial conflict that were evident both in Diesendruck et al.'s study and in the current study may highlight the importance of visual spatial attention in motor programming and execution. Moreover, the relevance of spatial information for vision-for-action could also be observed even in cases in which the spatial component is symbolic and indirect in nature. For example, in a numerosity task, Song and Nakayama (2008) demonstrated that the modulation of movement trajectories was affected by the spatial representation of the mental number line.

Nevertheless, the Simon effect was also found in non-spatial tasks. For example, Kunde and Stöcker (2002) showed the existence of Simon effect in a temporal version of the Simon task in which the S–R correspondence effect was between the length of the stimulus presentation and the duration of the required response. This effect was found independently from the spatial S–R correspondence effect, and therefore may reflect a dissociable mechanism. To the best of our knowledge, all previous studies, including the current one, that investigated the modulation of the movement trajectories following the Simon task, have used spatial versions of the Simon paradigm. Hence, it is not clear whether non-spatial versions would affect movement trajectories to the same extent. Importantly, such line of investigation would enable further characterization of the relative contributions of S–R correspondence and spatial conflict on movement programming and execution.

To summarize, the current study provides novel evidence for the expression of the Simon effect in post-response selection stages. Our results extend previous studies related to the link between perception and action, and demonstrate that the spatial conflict evoked by the Simon task independently affects response selection stages as well as other elements of motor execution.

**Acknowledgments** The authors would like to thank Desiree Meloul for her comments on earlier versions of this paper.

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