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Does the Simon effect affect movement execution?

Sandro Rubichi

Dipartimento di Scienze Sociali, Cognitive e Quantitative, Università di Modena e Reggio Emilia, Italy

Antonio Pellicano

Dipartimento di Psicologia dello Sviluppo e della Socializzazione, Università di Padova, Italy

The present work set out to test the prediction of the dual-route response selection account of the Simon effect, which maintains that the Simon effect, and its facilitation and interference components, should show up at the response selection stage irrespective of when it takes place during processing. Previous works have shown that in the case of a movement response, two strategies can be adopted for responding. The main difference between these two response strategies consists of when response selection operations take place. The two experiments reported in the present study showed that when response selection operates clearly before movement initiations, the Simon effect shows up in reaction time and not in movement time.

Performance in choice reaction time tasks is more efficient when the position of the imperative stimulus and the position of the response correspond than when they do not correspond. In the Simon task, for example, subjects are required to make a rapid motor response on the basis of a stimulus dimension other than position, like colour or form (Simon & Rudell, 1967; see Lu & Proctor, 1995, for reviews). The stimulus appears in one of two lateralised positions (left or right), and the response is typically produced by making a right or a left keypress using the right or left hand, respectively. Although the response is selected on the basis of a nonspatial stimulus feature, and thus stimulus location is task irrelevant, responses are usually faster and more accurate when the position of the stimulus and the position of the response

Correspondence should be addressed to S. Rubichi, Dipartimento di Scienze Sociali, Cognitive e Quantitative, Università di Modena e Reggio Emilia, Via G. Valle, 9, 42100 Reggio Emilia, Italy. Email: rubichi@unimore.it

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correspond (corresponding S–R pairings) than when they do not correspond (noncorresponding S–R pairings).

Accounts of the Simon effect are based on two intertwined assumptions originally proposed by Wallace (1971). The first assumption is that a spatial code is generated for the irrelevant stimulus location attribute, and consequently that the Simon effect arises in the process of matching spatial codes associated with the stimulus and the response. There is indeed evidence that multiple spatial codes can be formed for a given stimulus position on the basis of static attributes of the display, considering hemispace (left or right of centre), visual hemifield within hemispace (left or right of a fixation cross located in the hemispace), and relative position within hemifield (left or right) as spatial frames of reference (Lamberts, Tavernier, & d'Ydewalle, 1992; Roswarski & Proctor, 1996; Umiltà & Liotti, 1987). In addition, spatial coding has been found also to be relative to dynamic aspects of processing, such as the position of the attentional focus when the stimulus is presented (Nicoletti & Umiltà, 1989), or in relation to the attention shift that is performed in temporal proximity with response selection operations (Nicoletti & Umiltà, 1994; Rubichi, Iani, Nicoletti, & Umiltà, 1997; Notebaert, Soetens, & Melis, 2001).

The other widely shared assumption is that the Simon effect occurs at the processing stage where the response is selected. The idea is that the response selection machinery selects the response on the basis of two independent and parallel processing routes, one of which is thought to operate only when there is enough dimensional overlap (i.e., similarity) between the stimulus and the response sets (e.g., De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990). By the first route, the task-relevant stimulus dimension activates the response indicated by applying the S–R mapping rules specified in the instructions. This route is called conditional, or indirect, and controls the selection of the correct response on the basis of stimulus identification, irrespective of whether it spatially corresponds to stimulus location. Given that in the Simon task the stimulus and the response sets do overlap in the irrelevant spatial dimension, the imperative stimulus activates the corresponding response via an unconditional direct route. This route is thought to activate the corresponding response automatically and independently of stimulus identification, thus resulting faster than the conditional route. In the corresponding trials, the two processing routes activate the same, quickly executed response. In the noncorresponding trials, on the contrary, the two processing routes activate different responses, thus generating a conflict. The errors and extra time required typical of the noncorresponding trials would be caused by the decision about the correct response.

Electrophysiological evidence supporting the dual-route models comes from event-related brain potential studies, especially from the lateralised readiness potential (De Jong et al., 1994; Eimer, 1995; Sommer, Leuthold, & Hermanutz, 1993; Valle-Inclàn, 1996) in which two activation phases associated with the activation of response codes have been consistently found. A first early phase is supposed to reflect the location-based response priming, whereas a later phase would reflect the rule-based response activation. Recently, the neural mechanisms underlying the early response priming process have been confirmed also by means of electromyographic measures (Hasbroucq, Possamai, & Bonnet, 1999), and of transcranial magnetic stimulation and motor evoked potentials (Stürmer, Siggelkow, Dengler, & Leuthold, 2000).

One implicit prediction of the dual-route models proposed is that the Simon effect should consist of facilitation for corresponding trials, and interference for noncorresponding trials, and that both should arise at the response selection level. In other words, the reaction time (RT) for corresponding trials should be faster than, and the RT for noncorresponding trials should be slower than, the RT for a neutral (nonlateralised) condition. This is because in the case of neutral S–R pairings, speed of response is not affected by either the automatic activation of the correct response or the conflict between the wrong (but automatically activated) response and the correct response. Wallace (1971) developed a Simon task with four stimulus positions, left of, right of, above or below a central fixation cross. The left and right locations were used, as usual, for corresponding and noncorresponding stimulus positions, whereas the above and below locations were the central neutral stimulus positions. The author found that corresponding trials were faster than neutral trials which, in turn, were faster than noncorresponding trials (see also Simon & Acosta, 1982; and Umiltà, Rubichi, & Nicoletti, 1999, for similar results obtained with different Simon tasks).

Another implicit prediction of the dual-route models proposed is that in the case of a movement response, the Simon effect should arise in close connection to response selection processes and should not affect postselection processes such as the execution of a selected movement. More specifically, consider the case of a Simon task with spatially extended movements as responses. This experimental paradigm allows us to explore the relationship between spatial correspondence and coordinated action. Of course, this relationship cannot be studied by means of the standard Simon task with keypress responses, given that, when fingers rest on buttons, there is no room left between target and effector for coordination effects to appear. Spatially extended movements can be performed in different manners, depending on the constraints that are present in a given context. The whole movement, including its spatial component, can be selected before its initiation. Alternatively, the movement can start without our having yet specified the direction feature that will be selected after movement initiation, that is, during movement execution. On the basis of dual-route models, if the direction feature is selected before movement initiation, the Simon effect should be present in the RT for the movement initiation, but should not affect the time of execution of the movement (movement time; MT). In contrast, if the movement starts without our having already specified the spatial component, the Simon effect should arise in MT and not in RT for movement initiation. The empirical evidence on this issue is controversial. Simon (1968) required subjects to move the lever of a joystick to the right or the left from a centre position at the presentation of the imperative stimulus. The author recorded both the RT—from stimulus onset to when the lever moved away from the centre position—and the MT—from when the lever had been moved from the central position to when the lateral movement had been completed. The results showed a normal RT Simon effect and a marginal, but significant, MT Simon effect, which led Simon to conclude that spatial correspondence effects could affect the rate of a subsequent ballistic movement.

Even more problematic was the work of Hietanen and Rämä (1995), which suggested that facilitation and interference effects occur at different processing stages. In their movement Simon task, subjects started holding a central pad until a stimulus was presented in one of three possible locations (that is, left, central and right, in relation to the body midline). After stimulus onset, they had to release the central pad and to reach and press one of two lateralised pads with the same hand, depending on the stimulus colour. The central stimulus position was the neutral condition, whereas the two lateralised locations were for corresponding and noncorresponding conditions. The RT was measured from stimulus onset to the release of the central pad; the MT from the release of the central pad to the contact with the lateralised pad. Surprisingly, results showed that, on the whole, the Simon effect was present for both RT and MT. In addition, the Simon effect in RT was composed by facilitation only, whereas in MT by interference only. These tricky results have been partially reconciled with the dual-route models by hypothesising that in the Hietanen and Rämä Simon task, the two different strategies exposed above could both be adopted for responding (Rubichi, Nicoletti, Umiltà, & Zorzi, 2000; see also Proctor & Wang, 1997, for response strategies when response alternatives are aimed movements). In particular, one can release the central pad as soon as the stimulus appears, before selecting the direction of the movement on the basis of the stimulus relevant attribute. This way, the response selection operations take place after RT (after-RT response selection strategy). As a consequence, the Simon effect was expected in MT only (MT Simon effect). Alternatively, the release of the central pad can take place when the whole response, including the direction of the movement, has been programmed (before-RT response selection strategy). If this response strategy is adopted, the Simon effect can be expected in RT and not in MT (RT Simon effect). In other words, provided that subjects use only one strategy across all trials, the Simon effect should arise either in RT or in MT and should never arise in both of them. Rubichi et al. explored the spontaneous use of one of these two response strategies (Experiment 1), and asked subjects to adopt one of the two strategies (Experiments 2 and 3).

According to the prediction, when the after-RT response selection strategy was adopted (either spontaneously or by instructions), the Simon effect was present in MT only. However, contrary to predictions, in the case of the before-RT response selection strategy, both the RT and MT Simon effects appeared. The authors reasoned that this strategy was likely to be less natural than releasing the central pad as soon as the stimulus appeared and then selecting the lateral movement. Post-hoc analyses revealed that the average presence of both RT and MT Simon effects was an artefact due to the arising of the RT (and not MT) Simon effect in a group of trials, and of the MT (and not RT) Simon effect in the remaining trials. In this second group of trials, the response selection stage was likely to be ''moved'' after the RT, that is, subjects did not follow instructions and released the central pad before selecting the direction of the movement which was therefore selected after RT.

To sum up, Rubichi et al. (2000) proposed that the simultaneous presence of the Simon effect in both RT and MT found by Hietanen and Rämä (1995) is a result of the use of two response strategies in different trials. However, independently of the response strategy adopted and according to dual-route models, the Simon effect should arise in each trial either in RT or in MT, depending on when response selection operations take place. The authors demonstrated that when response selection operations take place after RT, the Simon effect appears in MT only. What needs to be clearly shown is whether, when response selection operates before RT, the Simon effect arises in RT only. The simultaneous occurrence of the Simon effect in RT and MT when the before-RT response selection strategy is adopted would mean that the irrelevant spatial stimulus code affects not only response selection operations, but also the speed of execution of a selected lateral movement. If so, response selection accounts would need rethinking.

The aim of the present work was to see whether the Simon effect arises in RT and not in MT when the selection of a lateral movement takes place indubitably before movement initiation. We tested this issue by inserting catch trials in the movement Simon task, originally designed by Hietanen and Rämä (1995), with one responding hand (Experiment 1), and by using two hands for performing the movement responses (Experiment 2). In addition, we were interested in exploring the time courses of the Simon effect on the whole and of its facilitation and interference components.

EXPERIMENT 1

As said before, the purpose of the present experiment was to induce the selection of movement direction before movement initiation in a Simon task similar to that used by Hietanen and Rämä (1995) and Rubichi et al. (2000). In the present version, three boxes, which served for stimulus locations, appeared at the beginning of every trial. Subjects were instructed to release a central pad and to reach and press one of two lateralised pads with the same hand at stimulus presentation. The stimuli were three different coloured squares: Two colours signalled the right/left responses, whereas the other colour signalled refrain from responding (no-go trials). Given that stimulus colour is to be identified before response emission, this manipulation ensured that the selection of movement direction was taken before movement initiation. Thus, a Simon effect composed by both facilitation and interference effects was predicted in RT, whereas no Simon effect should arise in MT.

Method

Subjects. Twelve students of the University of Modena and Reggio Emilia volunteered to participate in the experiment. They were all right-handed, had normal or corrected-to-normal vision, and were not aware of the purpose of the experiment.

Apparatus and display. Response timing and data collection were controlled by the Micro Experimental Laboratory (MEL) software system. The experiment took place in a dimly lit and noiseless room. Subjects were seated facing a cathode-ray tube screen driven by a 386sx computer. The subject's head was positioned in an adjustable head-and-chin rest, so that the distance between the eyes and the screen was about 45 cm. The visual display was composed by the following items: a $1^\circ \times 1^\circ$ fixation cross, which was shown at the geometrical centre of the screen; three empty boxes, $3.8^\circ \times 2^\circ$ in size, positioned at left or at right of the fixation cross (about 4°, 8°, and 12°, respectively, from fixation to the centre of the box); one $2^\circ \times 2^\circ$ filled square (i.e., the stimulus), which was either red, or green, or blue, showed in one of the three boxes. The MEL response box served for RT and MT acquisition. In particular, the central button was for the RT. In order to have enough movement amplitude, two external pads plugged into the response box were used for the MT. They were attached one at the left and one at the right of the response box at the same distance from the central button.

Procedure. On each trial, the sequence of events was as follows. The subject held down the central button with their right index finger to start the trial. The fixation cross and the three boxes appeared simultaneously and were visible on the screen throughout the trial. On each trial a warning tone (25 ms in duration) was delivered. Subsequently, after a 800–1200 ms variable the stimulus (i.e., the red or the green or the blue square) appeared inside one of the three boxes. Subjects were instructed to respond only when the stimulus was either red or green. The response consisted in releasing the central pad and pressing one of the two lateral pads as fast as possible always using their right index finger. The blue square was used for catch trials (20% of trials): Subjects were told to refrain from responding. After 1000 ms, the stimulus disappeared and the new trial started.

RT was measured from stimulus onset to release of the central button. MT was measured from release of the central button to the pressing of one of the two lateralised pads. Half of the subjects used the right-side pad for the red square and the left-side pad for the green square, whereas the other half had the reverse assignment. At the end of each trial, subjects were informed about RT and accuracy through feedback shown below the fixation cross, followed by a 1 s intertrial interval.

Every subject was tested individually in one experimental session, which comprised 300 trials, split into two equal blocks. In one block the three boxes for stimulus appearance were presented at the left of the fixation cross, whereas in the other block they were presented at right.

The first experimental block was preceded by a block of 48 practice trials. Stimulus presentation occurred according to a quasirandom sequence, with the constraints that the red and the green squares appeared equally often in the three boxes. Also in the 20% of catch trials the blue square appeared randomly but equally often in each of the three boxes.

Results

Errors were 2.1% and were not analysed further. Subjects responded to only 1.4% of catch trials, showing that they followed the instruction to discriminate the stimulus before initiating the response. Only those trials where RT was between 150 and 2000 ms and MT was slower than 800 ms were considered. This yielded an additional 1.6% of discarded trials.

The data were rank ordered by using the Vincentisation procedure introduced by Ratcliff (1979). More precisely, separately for RT and MT distributions, the mean for the first to the fifth bin, that is for the 20% fastest values to the 20% slowest values, were calculated. That was done because the magnitude of the Simon effect is known to vary as a function of response speed (e.g., De Jong et al., 1994), and to examine the time courses of RT and MT across conditions.

Two identical analyses of variance (ANOVAs) were performed separately on RT and MT. They had two within-subjects factors: condition (corresponding, neutral, noncorresponding), and bin (first to fifth). Note that, considering the way data were grouped, the bin main effect turned out to be significant in all analyses. Therefore, it will not be reported and discussed here or in the following experiment.

In the RT analysis, on the whole the Simon effect approached significance, $F(2, 22) = 2.83$, $p = .08$. Mean RTs for corresponding, neutral, and non-corresponding trials were 646, 666, and 674 ms, respectively. In addition, the interaction between condition and bin was significant, $F(8, 88) = 2.85$, $p = .007$ (see Figure 1). Pairwise comparisons showed that the RT Simon effect was significant from the first to the third bins (36, 32, and 28 ms, respectively), was positive and not significant at the fourth bin (18 ms) and negative and not

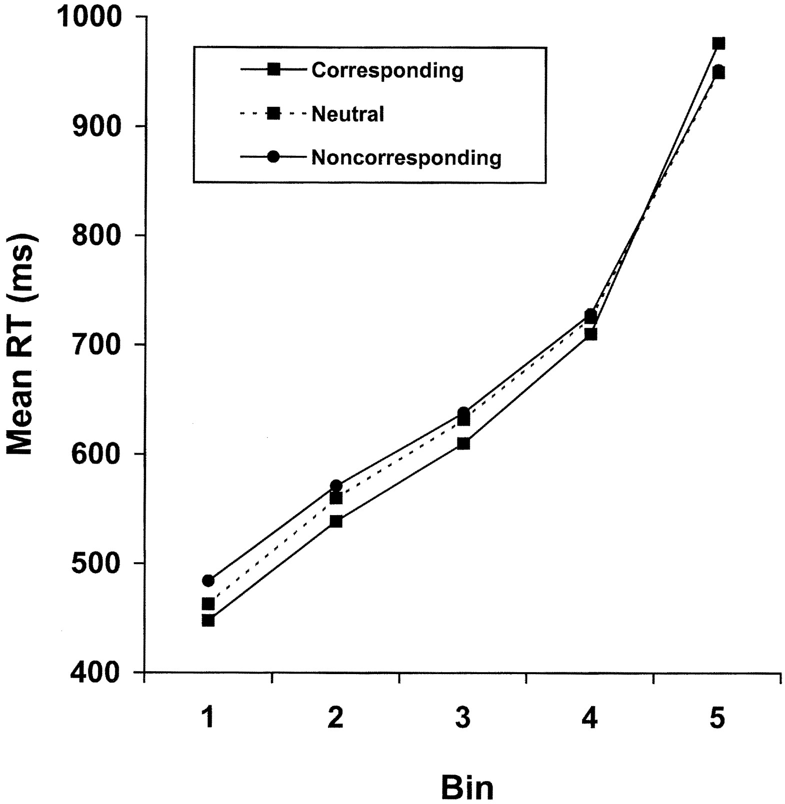

Figure 1. Means of individual reaction time (RT) bins for corresponding, neutral, and noncorresponding trials in Experiment 1.

significant (−25 ms) at the fifth bin. Also the facilitation effect was significant from the first to the third bins (15, 21, and 22 ms, respectively), whereas the interference effect was significant at the first (21 ms) and the second (11 ms) bins, and was small and not significant at the third bin (6 ms).

In the MT analysis, with the obvious exception of the bin main effect, no source of variance was significant. On the whole, corresponding trials were 212 ms, neutral trial 213 ms, and noncorresponding trials 214 ms.

Discussion

In the present movement Simon task, the use of catch trials allowed us to test RT for movement initiation and MT when the direction of the movement was selected before movement initiation. As predicted, the Simon effect was present in RT only. In addition, the experiment yielded additional outcomes, which suggest that the Simon effect observed here has the same features of the standard Simon effect with keypress responses.

First, as predicted by the dual-route models, the RT Simon effect was composed by both facilitation for corresponding S–R pairings and interference for noncorresponding S–R pairings compared to neutral S–R pairings. Second, the distribution analysis revealed a decrease and an inversion of the Simon effect with the increase in RT (e.g., De Jong et al., 1994), which indexes a spontaneous decay of the response-code activation (Hommel, 1994). These findings, together with the absence of correspondence effects in MT, corroborates the idea that response selection effects related to spatial coding terminate their influences on performance before the execution of a selected movement (provided that the movement is selected before its initiation).

EXPERIMENT 2

Experiment 2 was conducted for the following reasons. First, the evidence against the presence of the Simon effect in MT gathered in Experiment 1 rests in part on a null hypothesis. Even if mean MTs of corresponding, neutral, and noncorresponding conditions were substantially equivalent and the Simon effect was significant in the first three bins of the RT distribution, we wanted to provide additional converging evidence to corroborate our conclusions.

Second, it was our intention to eliminate possible sources of problems related to the original movement Simon task of Hietanen and Rämä (1995), regarding both the stimulus display and the movement responses. In Experiment 1, the stimulus appeared in one of three locations arranged linearly and positioned, in different blocks, in the right or in the left visual hemispace; that is, left or right of a central fixation point. Given that in each block the three boxes appeared always to the right or to the left, one may argue that subjects have fixated the central box because it was the more convenient resting position. If this was the case, performance in neutral trials would be facilitated because visual acuity is greater at fixation. Thus, facilitation and interference effects would be underestimated and overestimated, respectively. In the movement Simon task of the present experiment we preferred to adopt the stimulus display designed by Wallace (1971). In it, as described in the introduction to this paper, four boxes were used for stimulus presentation. Two boxes were, as usual, one left and the other right of the fixation point, and they served for corresponding and noncorresponding conditions. The other two boxes were located above and below the fixation cross (at the same eccentricity as the two lateral boxes) and served for the neutral condition.

The second change pertains to the movement responses. In Experiment 1, no-go trials were used. This was done because only one effector for responding was used in order to closely replicate the original movement Simon task designed by Hietanen and Rämä (1995). Perhaps, this manipulation may have discouraged subjects to plan their response as fast as possible. In fact, mean RTs were on the whole rather slow; the Simon effect was significant for faster RTS only. In the present experiment, both hands were used for responding. In particular, subjects were required to start the trial with their right and left index fingers holding down two central buttons. Based on stimulus colour, they were to move one hand to a goal position (located to the right for the right finger and to the left for the left finger). Thus, the selection of direction movement was carried out before movement initiation (as in Experiment 1) without the use of no-go trials.

As in Experiment 1, we expected to observe the Simon effect only in the RT for movement initiation, whereas MT was to be of the same magnitude irrespective of spatial correspondence between stimulus and response locations.

Method

Subjects. Twelve new students of the University of Modena and Reggio Emilia were selected as before.

Apparatus and display. They were as before except as follows. There were four boxes for stimulus presentation located 12° right of, left of, above, and below the fixation point, respectively. Only the red and green squares were used as stimuli. The MEL response box as adapted for Experiment 1 served for RT and MT acquisition. The first and the fifth buttons were the central starting positions for the left and the right index fingers, respectively.

Procedure. It was the same as before, except as follows. The subject held down the two central buttons with their right and left index fingers to start the trial. The fixation cross and the four boxes appeared simultaneously and were visible on the screen throughout the trial. The stimulus (i.e., the red or the green square) appeared inside one of the four boxes and signalled the right or the left response. The response consisted in releasing the central pad and pressing on the lateral pad as fast as possible, always using the same finger. The lateral pad to be pressed was at right for the right finger and at left for the left finger.

Results

Errors were 5.6%. An ANOVA with condition (corresponding, neutral, noncorresponding) as within-subjects factor performed on error data was significant, $F(2, 22) = 19.62$, $p < .001$. Planned comparisons showed that in corresponding trials (2.3) there were less errors than in neutral and noncorresponding trials (5.3 and 9.6, respectively). Errors significantly differed in corresponding and neutral trials, too.

The correct data were filtered with the same cut-offs as before. This yielded 1.4% of discarded data. They were analysed in the same manner as for Experiment 1. In the RT analysis, condition was significant, $F(2, 22) = 54.7$, $p <$

.001. Pairwise comparisons showed that corresponding trials (420 ms) were faster than neutral and noncorresponding trials (475 and 484 ms, respectively). Thus, there was a significant Simon effect of 64 ms, comprising a significant facilitation effect of 55 ms and a not significant facilitation effect of 9 ms. Given that it was our aim to see the time course of the Simon effect, planned multiple comparisons on the interaction between condition and bin were performed even if the interaction was not significant (see Figure 2). The Simon effect was always significant and had a magnitude of 72, 69, 68, 59, and 49 from the first to the fifth bin, respectively. Also the facilitation effect was always significant and had a magnitude of 58, 58, 55, 51, and 55 from the first to the fifth bin, respectively. The interference effect was significant at the first bin (14 ms), and was not significant at the remaining bins (11, 13, 8, and −6 ms, from the second to the fifth bin, respectively). It is worth noting that the interference effect at the

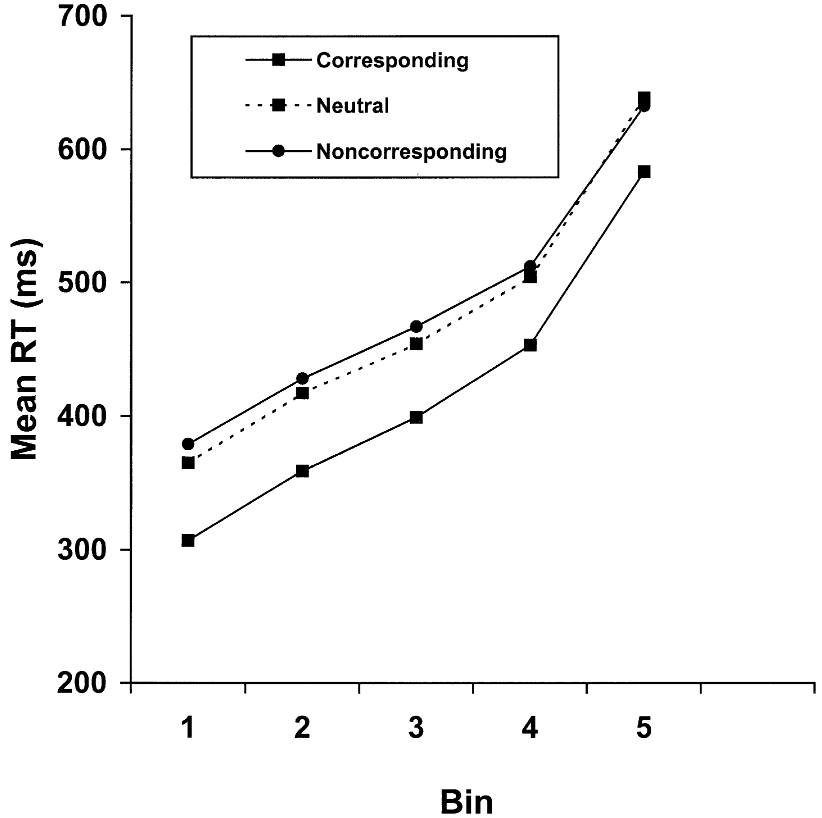

Figure 2. Means of individual reaction time (RT) bins for corresponding, neutral, and noncorresponding trials in Experiment 2.

second and the third bins reached significance with an a priori *t*-test ($p < .035$, one-tailed).

In the MT analysis, with the obvious exception of the bin main effect, no source of variance was significant. On the whole, corresponding trials were 224 ms, neutral trial 221 ms, and noncorresponding trials 224 ms.

Discussion

The results are clear in showing that the Simon effect was present in RT and not in MT. The null MT Simon effect was obtained together with a pronounced RT Simon effect, which here was more than double the size of the Simon effect obtained in Experiment 1. The larger RT Simon effect of the present experiment compared to that obtained in Experiment 1 was likely due to the fact that here no-go trials were not used and RTs were on the whole faster than in Experiment 1. Indeed, it is well known that the Simon effect is larger for fast than for slow RTs (e.g., De Jong et al., 1994).

On the whole, the main outcomes of Experiment 1 were successfully replicated with a different movement Simon task. This strengthens the notion that the Simon effect arises in close relation to response selection processes and rules out the idea that spatial correspondence may exert its influence on post-selection processes, such as movement execution.

Unlike Experiment 1, here the interference effect was less pronounced. We reasoned that the stimulus display used in Experiment 1 may have induced a more efficient performance on neutral trials than on corresponding and noncorresponding trials because visual acuity could have been greater at the central box. Thus, even if results indicated that the Simon effect comprises of both facilitation and interference effects, the size of the facilitation effect seems substantially larger than the size of the interference effect.

GENERAL DISCUSSION

Dual-route models of the Simon effect (e.g., De Jong et al., 1994) assume that the Simon effect is a response selection phenomenon (Wallace, 1971). When the response is a lateral movement, the Simon effect should show up in the RT for movement initiation if the lateral movement is selected before movement initiation, or in MT if the lateral movement is selected after movement initiation. Provided that only one strategy is adopted during the task, the Simon effect should show up either in RT or in MT (depending on when the lateral movement is selected), and never in both of them simultaneously. Rubichi et al. (2000) clearly show that when response selection takes place after movement initiation, the Simon effect arises in MT and not in RT. The present work set out to test the prediction that when response selection operations are completed clearly before movement initiation, the Simon effect shows up in RT and not in MT.

This prediction has been confirmed by using two types of movement response. In Experiment 1 subjects used one hand for responding. Subjects were required to release a central location and to reach a lateral location on the basis of stimulus colour. The selection of movement direction was taken before movement initiation because one stimulus colour indicated no-go trials, that is, subjects were required to refrain from responding. In Experiment 2 subjects used two hands for responding. They were required to move one hand from the central location to a lateral location on the basis of stimulus colour. Thus, the selection of movement direction was taken before movement initiation, because it included the selection of the hand that executes the movement. In both experiments, results were clear in showing that the Simon effect arises in the RT for movement initiation. On the contrary, the time of execution of the lateral movement was not affected by the correspondence between stimulus and response locations.

On the whole, the present results and those of Rubichi et al. (2000) support the notion that the Simon effect occurs at the response selection stage, regardless of whether the response is a keypress or an aimed lateralised movement. Indeed, the Simon effect manifests itself in RT or MT, depending on the response strategy adopted or required by the instructions (Rubichi et al., 2000), or imposed by experimental constraints (the present work). The present results are in contrast with the view that movement execution is influenced by spatial correspondence (Hietanen & Rämä, 1995; Simon, 1968). Hietanen and Rämä found out that with left–right aimed movement responses the Simon effect was present in both RT (the facilitation component only) and MT (the interference components only). In light of the present results and those of Rubichi et al., it seems reasonable to suppose that Hietanen and Rämä's task allowed one to adopt different response strategies. More precisely, subjects could have distributed their response decision processes across RT and MT, or some of them could prefer to decide during RT and others during MT. In addition, the same person may adopt both strategies in different trials.[1]

The outcomes of the present work also allow us to discuss some specific features of the Simon effect with movement responses, pertaining to its size and its time course. Considering both experiments, RTs in the present works ranged in between 300 and 1000 ms and the Simon effect ranged in between 72 and −25 ms. Thus, as in the standard Simon effect with keypress responses (e.g., De

[1] It is less obvious why Simon (1968) found the Simon effect in both RT and MT when subjects had to move the lever of a joystick to the left or right in response to the presentation of the imperative stimulus. In principle, correct responses should be those where the movement of the joystick was initiated when the direction of the movement was already selected, that is, only the before-RT response strategy should have been adopted. A tentative explanation could be that correct responses also included some trials in which subjects moved the joystick slightly (and thus the RT was recorded) and then decided on a direction. In support for this explanation, it is worth noting that the MT Simon effect found by Simon was of a very small magnitude.

Jong et al., 1994), we found a decrease and an inversion of the Simon effect with the increasing of RT. Recall that this phenomenon has been taken as an indication of a spontaneous decay of the irrelevant spatial response code that is automatically activated by stimulus location (Hommel, 1994).

Despite this general agreement between the Simon effect with keypress responses and with movement responses, it is worth noting that the size of the movement Simon effect found in the present work is considerably greater than the Simon effect usually found with keypress responses. In addition, the distribution analysis revealed that the effect of the irrelevant spatial dimension is more persistent across time. This outcome can be interpreted by invoking the notion of dimensional overlap between stimulus and response set that is incorporated in the dual-routes models of the Simon effect (e.g., Kornblum et al., 1990). The dimensional overlap specifies the similarity between stimulus and response sets, and the degree of similarity is determined by the number of features shared. The automatic activation of the corresponding response by the direct route of the response selection machinery takes place because the stimulus and the response sets do overlap in the irrelevant spatial dimension. The fact that with a movement response the effect of the irrelevant spatial dimension is larger and more persistent can be interpreted as indicating that the dimensional overlap between stimulus and response sets is larger when the response is a lateral movement. In other words, for spatial tasks the degree of similarity between stimulus and response sets is greater in the case of spatially extended movement responses than in the case of lateralised keypress responses.

An implication that seems relevant for real-life situations is that even if the irrelevant spatial dimension does not affect the time of execution of a selected movement, we should expect more pronounced effects of the irrelevant spatial dimension in the case of movement responses than in the case of simple lateralised keypress responses.

A final observation regards theories of movement preparation and the relation between response selection and response execution. The literature on chronometric aspects of motor behaviour often assumes that the RT for movement initiation is a pure measure of selection, planning, and preparation processes for movement execution (see, for example, Erlhagen & Schöner, 2002). This notion heavily relies on the assumption that information stages are completely serial and discrete. Especially for motor processing, there is evidence that does not support this view (e.g., Kalaska & Crammond, 1992; Wiesendanger, 1990). Also, the results obtained with one responding hand in the movement Simon task do not support this view. Subjects can start the movement without having yet specified the goal destination. In some cases this strategy is adopted even if subjects are explicitly required to adopt the alternative strategy, that is, to start the movement once the goal destination has been selected (Rubichi et al., 2000). Here we suggest that, provided that there are no experimental constraints such as those used in the present study, movement can initiate as soon as sufficient activation reaches the level where the motor program is prepared, even if response selection might still be incomplete at that point in time.

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