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Conflicts During Response Selection Affect Response Programming: Reactions Toward the Source of Stimulation

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In the Simon effect, participants make a left or right keypress in response to a nonspatial attribute (e.g., color) that is presented on the left or right. Reaction times (RTs) increase when the response activated by the irrelevant stimulus location and the response retrieved by instruction are in conflict. The authors measured RTs and movement parameters (MPs) of pointing responses in a typical Simon task. Their results show that the trajectories veer toward the imperative stimulus. This bias decreased as RTs increased. The authors suggest that the time course of trajectory deviations reflects the resolution of the response conflict over time. Further, time pressure did not affect the size of the Simon effect in MPs or its time course, but strongly reduced the Simon effect in RTs. In contrast, response selection before the onset of a go signal on the left or right did not affect the Simon effect in RTs, but reduced the Simon effect in MPs and reversed the time course. The authors speculate about independent Simon effects associated with response selection and programming.

Keywords: Simon effect, pointing movements, stimulus–response compatibility, stimulus–response congruency, distractor interference

It has been shown that irrelevant stimulus information affects performance in choice reaction tasks. In the Simon effect, choice reactions are performed faster when the imperative stimulus location corresponds to the response location, even if the stimulus location is irrelevant for the correct execution of the task (overview in Simon, 1990). For example, participants may be asked to respond with a left button press if the imperative stimulus is a green square and with a right button press if the imperative stimulus is a red square. Even though the horizontal position of the stimulus is irrelevant for the task, responses are typically faster and more accurate when the green square appears on the left (congruent condition) than when it appears on the right (incongruent condition) and vice versa for the red stimulus. The difference in reaction time (RT) between trials in which the response location and the stimulus location are congruent and those in which they are incongruent is referred to as *Simon effect* (Simon & Rudell, 1967).

A generally shared assumption is that the Simon effect occurs during *response selection* (e.g., De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990; Rubichi & Pellicano, 2004) and that two independent and parallel branches (or routes) of the response production system are involved (Kornblum et al., 1990). In one branch, the correct response is identified according to prespecified rules (e.g., press the left button on green stimulus). In the other branch, the stimulus automatically activates the corresponding response. When the response code activated by the irrelevant stimulus is different from the response code retrieved by instruction, a conflict arises. The resolution of this conflict takes time. Therefore, RTs in incongruent trials are slower than RTs in congruent trials. Further, the stimulus-induced response code activation decays over time. Therefore, the conflict is larger for fast than for slow responses (Hommel, 1994). However, this characteristic time course has only been observed with horizontal and not with vertical stimulus arrangements (Vallesi, Mapelli, Schiff, Amodio, & Umiltà, 2005; Wiegand & Wascher, 2005a, 2005b).

A heretofore unanswered question is whether the conflict during response selection has any repercussions on the way the response is executed. The details of an overt response, such as its force, direction, and amplitude, are generally assumed to result from *response programming* (e.g., Theios, 1975). Selection of an abstract response (e.g., left or right) and programming of movement parameters (e.g., direction, force, etc.) overlap in time because responses can be executed even though response selection is incomplete (Ghez, Hening, & Favilla, 1989; van Sonderen & Denier van der Gon, 1991), which led some to assume that response selection and programming are not functionally different (Hommel, Müsseler, Aschersleben, & Prinz, 2001). If participants are forced to initiate a movement even though they do not have sufficient time to select the appropriate response, the parameters of the response will fall back on default parameters (e.g., mean response force; Ghez et al., 1989). As time constraints are relaxed, the target parameters are approached. In sum, response selection does not have to be completed before response programming because participants are able to program a movement that is a mix of desired and default response parameters.

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Effects of Response Conflict on Movement Times

Previous studies have tried to disentangle effects of response conflict on reaction and movement times. Hietanen and Rämä (1995) showed that the Simon effect was present in RTs and movement times (MTs) when they asked observers to execute left- or rightward movements (instead of left or right keypresses). The effect of stimulus–response congruency on MTs seemed to indicate that parameters of the response, such as its trajectory or velocity, were affected by the irrelevant spatial information. However, two studies by Rubichi and colleagues (Rubichi, Nicoletti, Umiltà, & Zorzi, 2000; Rubichi & Pellicano, 2004) refuted the idea that the Simon effect in MTs was due to changes of the movement parameters. Rather, they explained the Simon effect in MTs in terms of delayed response selection. On this view, participants initiated the movement before selecting the response. Therefore, response selection occurred during the execution of the movement. To test their hypothesis, Rubichi et al. (2000) and Rubichi and Pellicano (2004) manipulated the response strategy adopted by their participants. They were asked to move their hand from a central home key to one of two lateral response keys. In one condition, participants were instructed to release the start key as soon as they saw the stimulus, and to select the response after starting the movement. As predicted, the results showed a Simon effect only in MTs but not in RTs. In another condition, participants were instructed to select the response before movement initiation. Because the Simon effect was present only in RTs, but not in MTs, Rubichi and coworkers concluded that response selection, and not response execution, was affected by irrelevant spatial information.

This point is further corroborated by Simon effects with nonspatial, vocal responses (Wühr, 2006). With vocal responses it seems unlikely that parameters of the response (e.g., rate and stress of speech) are influenced by the spatial arrangements of the stimulus. Rather, the Simon effect seems to be due to abstract representations that interfere at the stage of response selection.

Methodological Concerns

In the present study, we reconsidered the question of whether the response conflict in the Simon task affects response programming. There are two concerns that cast doubt on the methodological adequacy of previous studies. First, previous studies did not measure the spatial and kinematic parameters of the motor response. Only the time of response initiation (RT) or the time of response completion (MT) was recorded. Information about important movement parameters such as its direction, amplitude, and velocity was missing. Thus, previous studies may have been insufficiently sensitive to detect modulations of response programming.

Second, previous studies separated response and stimulus locations. Hietanen and Rämä (1995) asked participants to carry out pointing movements to response pads that were situated in the bottom part of a screen while the stimuli appeared at the top. Rubichi and coworkers presented stimuli on the computer screen while the responses were performed on a response box (Rubichi & Pellicano, 2004) or on a keyboard (Rubichi et al., 2000) below the screen. Because the response programming stage determines parameters of goal-directed movements, and no goal-directed movements were ever carried out to the stimuli, it seems unlikely that these stimuli would ever influence response programming. Also, these paradigms are in strong contrast to a related line of research (see below) on the influence of visual distractors on reaching or grasping movements (e.g., Howard & Tipper, 1997; Welsh & Elliott, 2004) where participants are generally asked to directly act on the stimuli, (i.e., reach the target location or grasp the target in spite of the presence of a distractor). Thereby, the irrelevant stimuli have to be considered in ongoing response programming: Notably, response-irrelevant distractors have to be avoided. Additionally, the separation of stimuli and responses necessitates shifts of attention from the screen to the response location (keyboard or response box). As will be evident in the subsequent section, the locus of attention is important for response programming, such that uncontrolled shifts of attention between stimuli and responses should be avoided.

Considerations About the Relation Between Attention and Trajectory Deviation

With regard to the effects of attention on response programming, Simon (1990) considered that there is a "strong natural tendency to respond initially to the directional component of a stimulus rather than to its symbolic content" (p. 75), and he views "the effect in terms of a more primitive reaction to the location of the stimulus that biases the subject to search a particular response buffer first" (p. 76). Simon's view was often characterized as implying attention toward the stimulus as the origin of the natural tendency to respond toward the stimulus (Nicoletti, Anzola, Luppino, Rizzolatti, & Umiltà, 1982; Umiltà & Nicoletti, 1985). Two points are noteworthy here. First, Simon agrees with other researchers that the effect of incongruent information arises at the stage of response selection as the term *response buffer* seems synonymous with the contemporary term *response code*. Second, he believes that the activation of the response code corresponding to the stimulus location is accompanied by a reaction toward the stimulus. Thus, Simon's original explanation is consistent with the idea that response conflict produces a tendency to program directional parameters of the response toward the location of the stimulus. Nonetheless, participants do not always respond to the location of the stimulus in incongruent trials but are able to inhibit the automatically activated response in favor of the instructed response.

Inhibition of Stimulus-Induced Activation

The interplay between activation and inhibition was integrated in a model by Tipper, Howard, and Hougthon (1999). Tipper et al. suggested that the initial analysis of a stimulus activates the corresponding response, regardless of whether the stimulus is to be responded to. Motor programs to the target and distractors will compete for the control of effectors involved in the reach. In order to correctly attain the target, the distractor-related activation has to be inhibited. With weak distractor-related activation, little inhibition emerging from lateral interactions is sufficient to guarantee selection of the correct response. As some distractor-related activity may persist, responses may be biased toward the distractor. With strong distractor-related activation, stronger inhibition of a different type is necessary (reactive self-inhibition). As a consequence, distractor-related activity decreases below baseline, which produces a bias of the correct response away from the distractor. The activity produced by a distractor is proportional to its salience. One factor that is known to determine the salience of a distractor is its distance from the hand. Reach trajectories veer away from the distractor when the distractor is close to the hand but not when it is far (e.g., Howard & Tipper, 1997; Meegan & Tipper, 1998), indicating that only distractors close to the hand are salient enough to produce strong activation that necessitates reactive inhibition.

In a related model, Welsh and Elliott (2004) acknowledged that inhibitory processes take time to develop. Initially, the neural representation of a response would share characteristics of the two conflicting responses. Subsequently, inhibitory processes suppress the distractor-related activity and allow the target response to emerge. Therefore, the characteristics of a movement will depend on how far inhibition of the distractor has progressed. In particular, movements are expected to be biased toward the distractor when inhibition is incomplete. However, if enough time has passed and inhibitory processes have been effective, the movement may deviate away from it.

On the basis of these studies, it is difficult to predict whether deviations toward or away would occur in the Simon task. Predictions are also difficult because the experimental situation differs strongly. In studies on distractor inhibition, two stimuli were presented at the same time. One stimulus was to be ignored (the distractor), while the other was to be reached (the target). In a Simon paradigm with pointing movements, only a single object is presented on a given trial. In the congruent condition, participants move toward the imperative stimulus. In the incongruent condition, participants have to inhibit the response toward the imperative stimulus, which is akin to a "distractor," and move toward an "empty" location in space. As the stimulus onset prompts participants to execute the movement as fast as possible while not making too many errors, inhibition may not be present for the very fast responses. Hence, movements may veer toward the imperative stimulus in incongruent trials because of the summation of activation. Later on, the stimulus-related activation may decrease because reactive inhibition and trajectories would deviate away from it. While this may be a plausible scenario, it may also be the case that inhibition is immediate. For instance, Tipper, Howard, and Jackson (1997) observed that previewing objects did not increase the deviation away from the distractor compared to a protocol in which distractor and target were presented almost simultaneously.

However, strong inhibition in the Simon paradigm is unlikely for the following reasons: Deviations away have mostly been observed with distractors that were at an angle of less than 90° to the target (e.g., Tipper et al., 1997). In the Simon task, the two potential target positions are at an angle of 180° on opposite sides of central fixation. Because the neural representations of the two stimuli are far apart, interactions (inhibition or summation) are less likely. Further, the Simon task typically involves lateral stimulation. However, deviations away have been observed with movements along the body midline (toward and away from the body; e.g., Meegan & Tipper, 1998), but not with lateral movements (Welsh, Elliott, & Weeks, 1999). Despite these speculations, the numerous differences between previous studies on distractor interference and the Simon paradigm do not permit conclusive answers.

Purpose of This Study

The purpose of this study was twofold. First, we wanted to remedy some of the methodological shortcomings of earlier studies that looked at effects of response conflict on response programming. We therefore investigated goal-directed responses and abandoned the spatial separation between stimuli and responses. Also, we recorded the initial movement angle of the pointing movements as an index of response programming before online corrections during the transport phase occur. We were interested in the initial direction of the movement because this parameter captures best Simon's (1990) idea of "reactions toward the source of stimulation" (p. 74) This analysis goes beyond previous studies that only evaluated the time to react and the time to move toward the lateralized stimulus.

The second purpose was to evaluate the time course of effects of response conflict on response programming. In all experiments, the initial movement angle was determined for RT bins that were rank ordered from fastest to slowest. We could thereby evaluate whether trajectory deviations changed as a function of RT. A plausible assumption is that some fast responses are initiated before the response conflict is completely resolved, while slower responses are executed after response selection has been completed. Thus, analysis of movement parameters as a function of RTs allows for the evaluation of effects of incomplete versus complete response selection on response programming. In addition to examining the time course, we varied the completeness of response selection by changing temporal parameters in two subsequent experiments. In Experiment 3, participants had very little time to select the response that forced them to respond without completing response selection. In Experiment 4, participants were told before the onset of a lateralized go signal where to move, which allowed them to finish response selection before starting to move. These experiments will elucidate the dynamic interplay of activation and inhibition. Our working hypothesis is that unresolved response conflict with short RTs produces a deviation toward the imperative stimulus in incongruent trials (cf. summation of activation), while long RTs and advance response selection should bias trajectories away from (or at least less toward) the imperative stimulus location in incongruent trials (cf. inhibition of stimulus-induced activation).

Experiment 1

The purpose of Experiment 1 was to examine whether the Simon effect in RTs would influence response programming. To this end, participants were instructed to perform a left- or rightward pointing movement to one of two boxes displayed on a flat panel screen. A square appeared in one of the boxes and the color of the square indicated whether the left or right box had to be touched. Thus, the square could either appear in the box specified by its color (congruent condition) or in the opposite side box (incongruent condition). Two temporal parameters (RT and MT) and a spatial parameter of the reach (the initial direction of the trajectory) were measured in the *direction selection/large amplitude condition*. The initial direction of the trajectory was coded such that an angle of zero codes a movement along the screen surface from the home position to the instructed target position, while an angle of 180° codes a movement from the home position to the opposite (incorrect) position. Thus, the imperative stimulus was positioned at 0° in congruent trials and at 180° in incongruent trials. To capture the response parameters before online corrections, we determined the initial movement angle (IMA) after one fifth of the movement trajectory had been traversed (see Figures 1 and 2). Gliding along the screen surface (0° or 180°) was not allowed; instead, observers were requested to lift the finger from the screen surface, transport the hand toward the instructed position, and then touch one of the two boxes.

RTs of the direction selection/large amplitude condition were then compared to a second type of response that required participants to lift either the index or the middle finger of the right hand without moving the hand (*effector selection condition*). Hence, participants either selected the finger (effector selection) or the movement direction (direction selection). Rosenbaum (1980) noted that the effector (left or right arm) and the direction of a movement are programmed serially, but not in a fixed order. He also noted that precueing the effector that was to be used in the upcoming movement produced a larger benefit than precueing the movement direction. Given that the two response parameters (effector and direction) are programmed independently, it may be interesting to know which parameter is more strongly affected by response conflict.

Finally, we were interested in the time course of the Simon effect in RTs and MTs. To this end, we rank ordered RTs and MTs and then averaged them across bins including 20% of the trials (quintiles). It has been demonstrated that the Simon effect in RTs decreases with increasing RTs, indicating that response activation by the irrelevant spatial information decays over time (Hommel, 1994). To our knowledge, the time course of congruency effects on MTs has not been investigated. Further, we calculated IMAs for each RT bin. Simon's (1990) allusion to the orientation reflex and Welsh and Elliott's (2004) dynamic interplay between activation and inhibition predict that deviations toward the stimulus are particularly dominant for fast responses and less pronounced for slower responses (due to increasing inhibition).

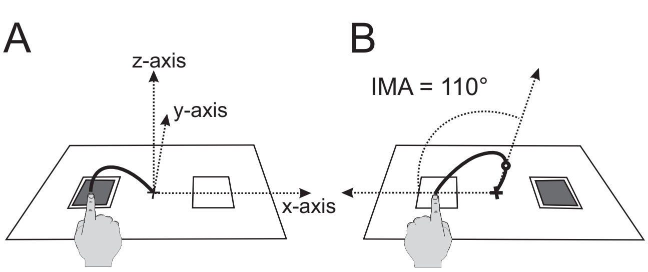

Figure 1. Side view of the experimental situation. A: Lateral movements of the finger were coded along the *x*-axis. The *x*-axis ran through the fixation cross and the possible response locations. Upward movements perpendicular to the screen surface were coded along the *z*-axis. Movements toward or away from the participants were coded along the *y*-axis. B: The initial movement angle was determined by calculating the angle between the position of the hand after one fifth of the trajectory had been traversed (indicated by open circle) and the axis running through the correct response location. In compatible trials (Panel A), an angle of zero denotes a straight movement to the location of the imperative stimulus. In incompatible trials (Panel B), an angle of zero denotes a straight movement to the empty box. Participants were requested to always lift their finger (movement along the *z*-axis), resulting in movement angles larger than zero. The initial movement angles (IMAs) in Panels A and B would be around 45° and 110°, respectively.

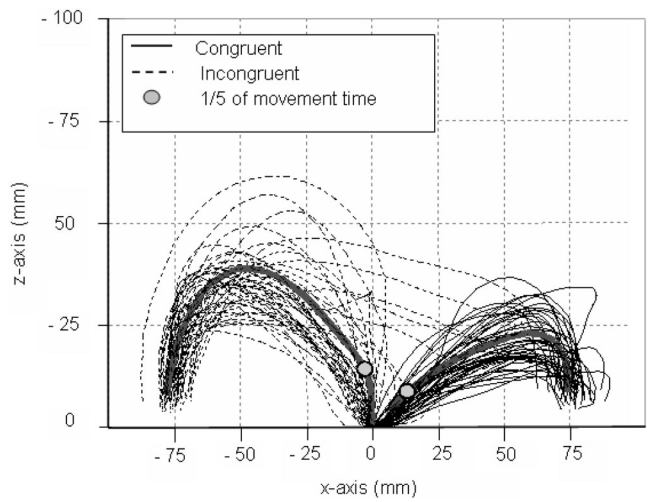

Figure 2. Projections of 1 participant's reach trajectories on two dimensions (*x* and *z*). Variations along the *y*-axis were rather small. Solid trajectories illustrate congruent trials (i.e., the location of the visual stimulus and the response location are on the right), and dotted trajectories show incongruent trials (i.e., the visual stimulus appears on the right while the response location is on the left). The thick gray lines represent the mean trajectories for both congruent and incongruent trials, and the gray points illustrate the sample corresponding to one fifth of the movement time.

Method

Participants. Sixteen psychology students at the University of Geneva (Geneva, Switzerland) participated in the experiment. They were not aware of the purpose of the experiment and had normal or corrected-to-normal vision. Participants were right-handed except for 1 left-handed and 1 ambidextrous participant.

Apparatus and stimuli. A flat screen was placed in a frame and was attached to the edge of a table. The frame allowed changing the inclination of the screen relative to the table. We chose an angle of about 20° between the screen and the table. Two empty boxes (1.8 × 1.8 cm) were displayed on a gray background, and the distance from the fixation cross in the screen center to the center of the boxes was about 7.5 cm; the imperative stimulus was a green or red square of about 1.4 × 1.4 cm that was presented in one of the two boxes. An ultrasonic system (CMS20S, zebris Medical GmbH, Isny im Allgäu, Germany) recorded the X, Y and Z coordinates of manual movements at a sample frequency of 150 Hz by means of a marker positioned on the nail(s) of the finger(s) used to perform the task.

Procedure. The experiment took place in a dimly lit room. Participants were seated at a distance of approximately 40 cm from the flat panel screen. All responses were executed with the right hand. Participants were instructed to respond as fast and as accurately as possible to the color of the square, irrespective of its location.

In the effector selection condition, the right hand was placed on the screen. The hand position was adjusted such that the fixation cross was visible in between the index and middle fingers. A trial was initiated by pressing the space bar of a keyboard with the left hand. Participants responded by lifting either the index or the middle finger of the right hand.

In the direction selection/large amplitude condition, the screen was touched with the right index finger only. A trial was initiated by placing the index on the fixation cross. Participants were instructed to lift the hand, move to one of the two boxes, and touch the box with their index finger.

After a trial was initiated, the two outline boxes changed luminance from gray to black. After a random interval between 0.3 and 1.3 s, a colored square appeared inside one of the boxes, and the participant's response was collected. At the end of the trial, the outline boxes turned bright gray again to signal that a new trial could be initiated.

Latencies shorter than 100 ms and longer than 800 ms were considered anticipations and missed trials, respectively. In the effector selection condition, choice errors were trials in which the wrong finger was lifted. In the direction selection condition, choice errors were trials in which the wrong box was touched. Hand movements with continuous contact to the screen were considered erroneous. Finally, loss of the ultrasonic signal was detected. Error feedback about anticipations, missed trials, choice errors, movement errors, and marker failures was given, and the respective trial was repeated in the remainder of the experiment.

Design. The different response modes were blocked, and each block was preceded by about 10 practice trials. In each block, the four possible combinations of two square locations and two square colors (or response locations) were repeated 50 times for a total of 200 trials per response mode. The order of response mode (effector selection vs. direction selection) and the color-response mapping was balanced across participants. Half of the participants responded to green with a left response and to red with a right response, whereas the other half received the reverse color-response mapping.

Dependent variables and offline analyses. Several dependent variables were calculated online or offline. First, we determined the time between the onset of the colored square and the onset of the movement (RT). Movement onset was defined as the first sample exceeding a velocity of 50 mm/s with the constraint that the velocity stayed above this value for at least 100 ms. Second, we calculated the interval between movement onset and the final contact of the finger with the screen (MT). A position criterion (i.e., a distance of 4 mm to the screen surface) was used to determine the time when participants touched down on the peripheral boxes. Third, the angle between the screen and the finger after one fifth of the total MT was determined (IMA). The angle was calculated with respect to an axis running through the fixation point and the two box positions (see Figure 1). An IMA of 0° indicates that the movement was executed parallel to the screen surface in a straight line from the fixation cross to the required box position. An IMA of 90° indicates that the participant lifted the hand perpendicular to the screen surface. Hence, a small angle indicates a direct movement to the target position. Note that one fifth of the MT captures the initial direction of the movement trajectory (see Figure 2).

Results for Movement Initiation (All Response Modes)

Anticipations, missed trials, and trials containing ultrasonic signal disruptions were excluded from the analyses, and choice errors were analyzed separately (see Table 1). Trials were coded as congruent when the square location corresponded to the response direction or location, and as incongruent when this was not the case. Mean RTs were calculated for congruent and incongruent trials (see Table 1).

To obtain the five quintiles, RTs were rank ordered separately for each participant and condition. Then, the observations were divided in five bins, so that each quintile contained 20% of the observations. The first quintile is composed of the fastest and the fifth of the slowest responses. The main effect of quintile and the interaction of response mode and quintile is mentioned in the *Results* sections but are considered trivial because they reflect the rank ordering of RTs. In cases where the assumption of sphericity was violated, degrees of freedom were corrected using Huynh–Feldt's correction. For follow-up analysis, paired-samples t tests were conducted, and only the p values are reported.

Errors. For effector selection, the mean error rate was significantly larger in the incongruent than in the congruent condition (2.8% vs. 0.9%, respectively, $p < .01$). No difference was found for the direction selection condition ($p = .1$).

RTs. Mean RTs as a function of compatibility and response mode are shown in the top row of Table 1. The mean differences between congruent and incongruent trials (mean Simon effect) are graphed as a function of quintile and response mode in the top row and first column of Figure 3. A three-way analysis of variance (ANOVA; 2 [response mode] × 2 [congruency] × 5 [quintiles]) on RTs showed that RTs did not vary between response modes, $F(1, 15) = 2.47$, $p = .14$. Furthermore, responses were faster in congruent than in incongruent trials (432 vs. 477 ms, respectively), $F(1, 15) = 109.08$, $p < .001$. As expected, the main effect of quintile was significant, $F(4, 60) = 713.45$, $p < .001$. The difference between congruent and incongruent trials was larger for effector than for direction selection (57 vs. 34 ms, respectively), $F(1, 15) = 11.59$, $p < .005$. By t test, both differences were significantly different from zero (ps $< .001$). The interaction of congruency and quintile was also significant, $F(4, 60) = 11.77$, $p < .001$, indicating that the effect of congruency decreased with increasing quintile; the mean differences from the first to the fifth quintile were 53, 57, 52, 42, and 24 ms, respectively. Finally, the triple interaction of response mode, congruency, and quintiles approached significance, $F(4, 60) = 3.01$, $p = .072$, indicating that the decrease of the effect of congruency with quintile was more pronounced for effector selection.

Results for Movement Execution (Only Direction Selection)

MTs of pointing movement were treated as RTs. Further, the mean IMAs were calculated for each RT quintile. Effects of congruency and (RT) quintiles on MTs and IMAs were evaluated.

MTs. Mean MTs are shown in the top row of Table 1, and the mean Simon effect in MTs is shown in the top row and second column of Figure 3. A two-way ANOVA (2 [congruency] × 5 [quintiles]) performed on MTs of the pointing movements confirmed faster responses in congruent than in incongruent trials (216 vs. 230 ms, respectively), $F(1, 15) = 14.24$, $p < .005$. The main effect of quintile, $F(4, 60) = 136.74$, $p < .001$, and the interaction of congruency and quintiles, $F(4, 60) = 11.68$, $p < .005$, were significant. The interaction showed that the difference between

Table 1

Mean Reaction Time (in ms), Mean Movement Time (in ms), Between-Subjects Standard Error (in Parenthesis), Percentage of Choice Error (PE), Percentage of Excluded Trials (PX), and Difference (Δ) Between Congruent (C) and Incongruent (I) Means for the Different Response Modes in Experiment 1, 2, and 3

Response mode	Reaction time			Movement time			PE	PX
	C	IC	Δ	C	IC	Δ		
Experiment 1								
Effector	409 (13)	469 (13)	57 (5)***				3	5
Direction/large	448 (15)	482 (19)	34 (6)***	216 (10)	230 (11)	13 (4)**	2	4
Experiment 2								
Effector	400 (11)	460 (10)	60 (7)***				4	3
Direction/large	421 (11)	443 (11)	22 (7)**	236 (9)	254 (10)	18 (6)**	1	2
Direction/small	397 (10)	427 (10)	30 (5)***	170 (5)	177 (5)	7 (2)**	1	5
Experiment 3								
Effector	325 (4)	368 (4)	43 (2)***				8	28
Direction/large	314 (8)	317 (9)	4 (2), *ns*	301 (30)	325 (28)	23 (6)**	3	10
Direction/small	308 (6)	319 (7)	11 (3)**	217 (21)	229 (22)	12 (2)***	4	11
Experiment 4								
Effector	276 (8)	306 (10)	30 (6)***				1	7
Direction/large	294 (8)	318 (10)	24 (4)***	202 (9)	210 (9)	8 (1)***	1	8

Note. Participants were either instructed to select one of two fingers (effector) or the direction of a pointing movement (direction) with small or large amplitude. *ns* = nonsignificant.
** $p < .01$. *** $p < .001$.

congruent and incongruent trials was larger for the slowest MTs than for the other quintiles (40 vs. 4–10 ms, respectively).

IMAs grouped by RT quintiles. Mean IMAs are shown in the top row of Table 2, and the mean Simon effect for IMAs is shown in the top row and third column of Figure 3. Histograms for congruent and incongruent conditions are shown in the top row of Figure 4. Histograms for each combination of congruency and RT or MT quintile are shown in Figure 5. Inspection of Figure 4 suggests a bimodal distribution of the IMAs in the direction selection condition. Figure 5 suggests that bimodality prevailed particularly in the first incongruent RT quintile and in the last incongruent MT quintile. That is, the fastest RTs and the slowest MTs in incongruent trials showed a bimodal distribution of IMAs. While it is clear that a single mean does not capture the central tendencies of two subdistributions, we nonetheless chose to run our ANOVAs on the mean of the complete distribution. We expected these means to be strongly biased toward the smaller distribution. The ANOVA allowed us to test the reliability of this pattern.

A two-way ANOVA (2 [congruency] × 5 [RT quintiles]) was performed on the IMAs calculated for each RT quintile of the pointing movements. IMAs were larger in incongruent than in congruent trials (49° vs. 40°, respectively), $F(1, 15) = 16.82$, $p < .001$. IMAs decreased from the first to the fifth RT quintile (from 53° to 42°), $F(4, 60) = 8.08$, $p < .001$. The interaction of congruency and RT quintile showed that the difference between congruent and incongruent trials was larger for the fastest RT quintile than for the slower RT quintiles (25° vs. 7–0.1°), $F(4, 60) = 6.93$, $p < .01$.

The same ANOVA was performed after excluding IMAs larger than 100° in order to evaluate whether the results were due to the bias induced by the bimodal distribution (see Table 2). The ANOVA showed larger IMAs in incongruent than congruent trials (39° vs. 35°, respectively), $F(1, 15) = 17.15$, $p < .001$, indicating that the Simon effect on initial movement direction was still present. On the other hand, the quintile effect and the interaction between RT quintiles and congruency were no longer significant ($ps > .3$).

Correlations Between RT, MT, RT/MT, and IMA (Only Direction Selection)

We correlated RT, MT, and the ratio of RT/MT with IMA in incongruent trials. First, all observations from all observers were pooled, and the global correlation was calculated. Next, we calculated the correlations for each participant. The individual correlations were transformed to Fisher's z and were compared to zero by means of a t test. For clarity, the mean Fisher's z values were then converted back. Finally, we determined the number of participants who showed a significant correlation. By means of a binomial test we evaluated whether the number of participants exhibiting this feature (i.e., a significant correlation) was significantly different from chance. This was done because the sign of the individual correlations was often consistent across participants such that the t test comparing the Fisher's z values to zero was significant. On an individual level, however, these correlations were often weak and were not significant. The binomial test evaluates how consis-

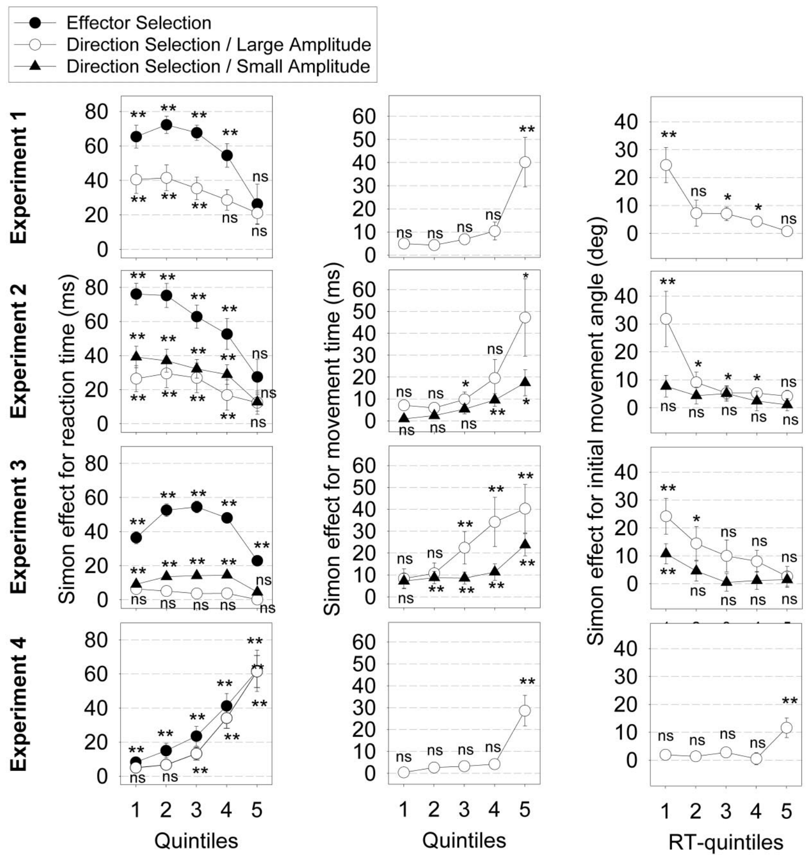

Figure 3. Mean difference between incongruent and congruent trials (Simon effect) in Experiments 1–4 for reaction time (RT) quintiles (on the left), movement time quintiles (in the middle), and initial movement angle grouped by RT quintiles (on the right) as a function of response mode. For each quintile, the statistical significance of the Simon effect was determined by a *t* test. Because five comparisons were run for each condition, the criterion for significance was lowered from 5% to 1% (Bonferroni correction). Error bars indicate the between-subjects standard error. ns = nonsignificant. $^{*} p < .01$. $^{**} p < .001$.

tently a significant correlation was observed in the sample. Correlations are summarized in Table 3, top row.

The global and mean individual correlations between RT and MT were significantly smaller than zero but numerically small (−0.1 to −0.2). Only half of the observers showed a significant correlation. The negative correlation indicates that observers traded RT for MT. When RT was long, the subsequent MT was short and vice versa. This may reflect participants' strategy to postpone response selection on some trials. Such a strategy resulted in short RTs and long MTs. The correlations between RT and IMA were significantly smaller than zero but small (−0.1 to −0.2). Ten observers showed a significant correlation. The negative correlation indicates that fast responses were directed at the stimulus location, which was opposite the required response location (remember that correlations were only performed for incongruent trials). The correlations between MT and IMA were significantly larger than zero and substantial (0.3 to 0.6). All but 1 participant showed a significant correlation. This correlation may be considered trivial because it only reflects the fact that if the IMA was large, a larger trajectory had to be traversed to reach the required response location. As the trajectory was longer, MT was also longer. Finally, the correlation between the ratio RT/MT and IMA was significantly smaller than zero and substantial (−0.2 to −0.4). All but 2 observers showed a significant correlation. The ratio of RT over MT indicates how much time the participant spent on preparing a movement relative to its execution. Poorly prepared movements had short RTs but required a long time to complete (long MTs) because the movements took an indirect way to the correct location. Conversely, carefully prepared movements took longer to prepare but allowed for efficient and rapid execution. The negative correlation between RT/MT and IMA shows that the less time was spent preparing the movement, the larger the IMA.

Discussion

The aim of Experiment 1 was to investigate whether the Simon effect would affect response programming. Results for RTs, MTs, correlations between the two, and IMA are discussed in turn. We replicated the Simon effect in RTs with pointing movements and finger selection. Responses in congruent trials were initiated earlier than in incongruent trials and the size of the Simon effect depended on RT. The quintile analysis showed that the Simon

Table 2
Mean Initial Movement Angle (IMA; in Degrees) and Between-Subjects Standard Errors (in Parenthesis) in Congruent (C) and Incongruent (IC) Trials of Experiments 1–3

Response mode	All trials			Trials with IMA < 100°		
	C	IC	Δ	C	IC	Δ
			Experiment 1			
Direction/large	40 (3)	49 (3)	9 (2)***	36 (2)	39 (3)	3 (1)***
			Experiment 2			
Direction/large	42 (3)	53 (3)	11 (3)**	35 (3)	39 (3)	4 (1)***
Direction/small	62 (3)	67 (2)	4 (2)*			
			Experiment 3			
Direction/large	66 (4)	78 (4)	12 (4)**			
Direction/small	76 (4)	79 (3)	3 (2), *ns*			
			Experiment 4			
Direction/large	36 (3)	39 (3)	4 (1)***	34 (8)	36 (9)	2 (1)*

Note. Results of the direction selection condition with small and large amplitude are shown. The difference between congruent and incongruent trials is indicated by the symbol Δ. The angles were calculated for all correct trials (in which the correct box was touched). In case of a bimodal distribution of IMAs, mean IMAs were additionally calculated for only those trials in which the initial movement was toward the correct box (IMAs < 100°). *ns* = nonsignificant.
* $p < .05$. ** $p < .01$. *** $p < .001$.

effect was larger for the fastest RTs and decreased as RTs increased. This result is consistent with the literature (e.g., Hommel, 1994) and we note that the time course is not different for pointing compared to choice RTs. However, the results showed that the Simon effect in RTs was smaller with direction than with effector selection. To our knowledge, this is the first report of a modulation of the Simon effect by response mode. Previous studies that varied the response mode between two hands and two fingers found no difference (Shulman & McConkie, 1973). However, our results are reminiscent of differential benefits of precueing the direction or the effector of a movement. Rosenbaum (1980) did not conclusively explain why effector selection benefits more from advance preparation than selection of movement direction. One of his explanations is close to Rubichi et al.'s (2000) account of the Simon effect in MTs. He proposed that it may be easier to correct direction errors in the course of the movement than effector errors. Therefore, more time is spent on the selection of the effector than on the selection of direction before movement initiation. In a similar vein, Rubichi et al. (2000) suggested that the Simon effect in MTs is due to the fact that the decision about where to move takes place online, while the movement is executed.

In line with this interpretation, we observed that participants traded RT for MT in incongruent trials. RT and MT were negatively correlated, which suggests that on some trials, participants selected the direction of the movement after response initiation. These were trials with fast RTs and slow MTs. Conversely, selecting the direction before starting the movement entailed long RTs and fast MTs. While these correlations were significant, they were rather small and significant for only half of the participants. A much stronger correlation was observed between the ratio RT/MT and IMA. This correlation shows that when response preparation was short relative to movement execution, the initial movement angle was biased toward the imperative stimulus (large IMAs). Thus, poorly prepared responses deviated toward the imperative stimulus and went into the wrong direction. Finally, the correlation between MT and IMA was positive and substantial. Large IMAs produced long MTs and small IMAs produced short MTs. These results are unsurprising because large IMAs imply long trajectories that take more time to traverse.

The correlations show that participants traded RT for MT in the direction selection condition. However, these analyses do not tell us why MTs were long when RTs were short. In its extreme form, the "lift and decide" strategy would predict that participants lift their finger straight up (90° in our convention), pause, and then move to the correct location. However, the analysis of mean IMAs as a function of RT quintile suggests a different pattern. In incongruent trials, many of the very fast reactions are attracted by the imperative stimulus, such that online corrections were necessary (see Figures 2 and 5). Additionally, the complete distribution of IMAs, even after sorting out trials with IMAs larger than 100°, was biased toward the stimulus. As large IMAs are positively related to MTs due to the changes in trajectory length, we may conclude that responses toward the source of stimulation underlie the trade-off between RT and MT. On this view, postponing a response does not mean moving straight up and deciding where to go next, but postponing a response means moving to the stimulus first and correcting later on. One may conclude that the "source of stimulation" is the default direction of poorly prepared directional movements. Another way to look at these findings is in terms of response conflict. When the conflict between stimulus-induced and instructed response is strong, responses are directed at the stimulus. As the response conflict is resolved, this tendency decreases.

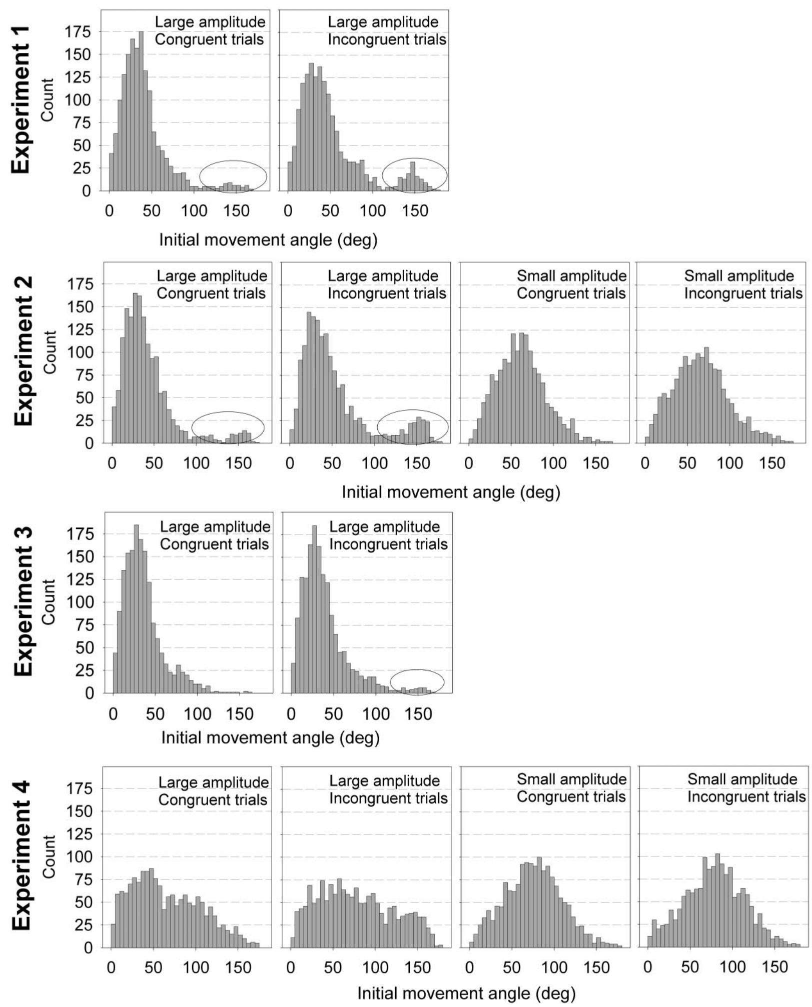

Figure 4. Histograms of the initial movement angle as a function of response mode (direction selection/large amplitude and direction selection/small amplitude) and congruency in Experiments 1–4. Bimodal distributions are marked by an ellipse.

These conclusions are also consistent with Welsh and Elliott's (2004) dynamic interplay between activation and inhibition. As the initial stimulus-induced activation was overcome by inhibition, the tendency to move toward the stimulus decreased. However, we did not observe trajectory deviations away from the stimulus in incongruent trials. In terms of Tipper et al.'s (1999) model, the distractor-related activity was not strong enough to necessitate reactive inhibition that would have reduced activity below baseline. Somewhat surprisingly, we have to conclude that responding to a stimulus in 50% of the trials does not entail reactive inhibition of this stimulus when it is to be avoided. A possible explanation for the lack of reactive inhibition is the large separation between target and distractor.

Experiment 2

In Experiment 1, two response modes were investigated. Effector selection required choosing the instructed finger, while the direction selection required deciding in which direction to move the hand. A trajectory of 7.5 cm had to be traversed during pointing movements, which offered ample opportunity for online corrections. As suggested by our analysis of movement trajectories, participants made use of this opportunity, in particular for fast responses. Thus, we cannot decide whether the smaller Simon effect in RTs with direction compared to effector selection was due to a trade-off between RT and MT or due to intrinsic differences in the programming requirements. In Experiment 2, a response mode was introduced that required directional responses with much shorter trajectories. In the *direction selection/small amplitude condition*, participants were asked to lift the right index finger and to perform a small movement to the left or right (depending on the imperative stimulus color) without moving the hand. We asked whether the size of the Simon effect with such a rather discrete movement would be similar to the size observed in a standard Simon task involving effector selection. Clearly, a movement of short duration will reduce the time for corrections. If online corrections (i.e., a trade-off between RT-MT) explained the smaller

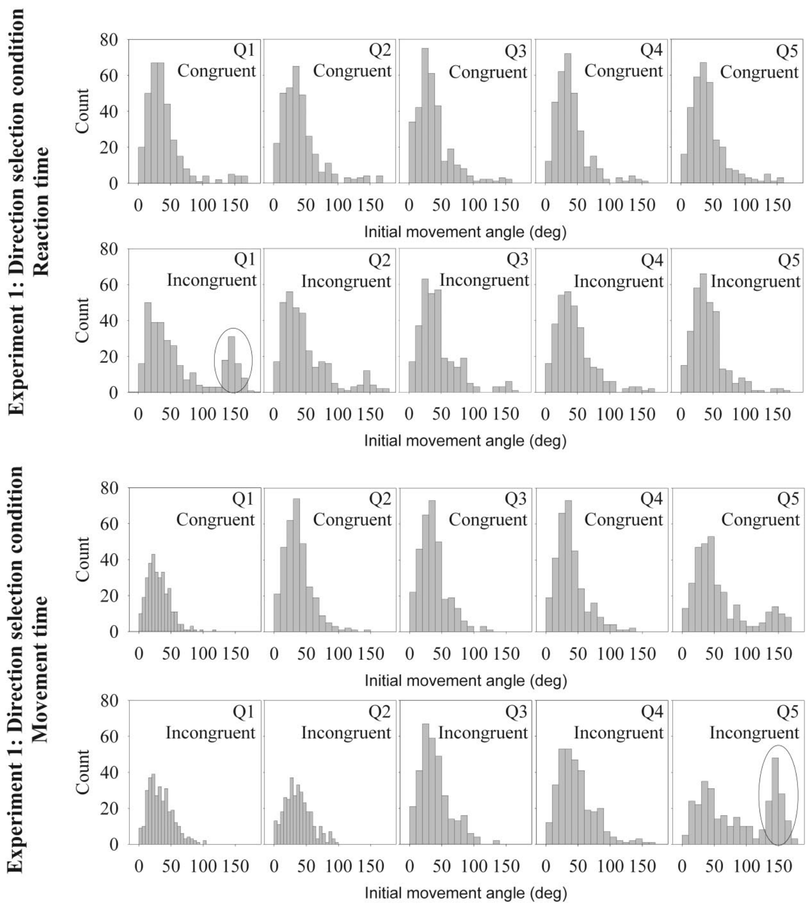

Figure 5. Histograms as a function of congruency and reaction time quintile (top panel) or movement time quintile (bottom panel) for the direction selection conditions of Experiment 1. Bimodal distributions are marked by an ellipse. Q1–Q5 = first to fifth quintile.

Simon effect, we expect the Simon effects in RTs to increase to the degree that MTs are shortened.

Method

Participants. Sixteen students from the same pool as in Experiment 1 participated. One participant was left-handed; the remaining participants were right-handed.

Apparatus and stimuli. The same apparatus and stimuli were used as in Experiment 1.

Procedure and design. The procedure and design were the same as those used in Experiment 1, with the exception that another response was added. In the direction selection/small amplitude condition, participants were instructed to only move their index finger (the hand should not move at all) and to perform a small left- or rightward movement by lifting the index finger. Trial initiation was as in the direction selection condition.

Results for Movement Initiation (All Response Modes)

Dependent variables and offline analyses were as in Experiment 1 with the exception that there were three levels of the factor response mode instead of two.

Errors. A significant difference in the error rate between congruent and incongruent trials was confirmed with effector selection (1.1% vs. 2.8%, respectively, $p < .01$) as well as for the direction selection/large amplitude (0.3% vs. 1.2%, respectively, $p < .001$). The difference in the direction selection/small amplitude condition approached significance (0.005% vs. 0.009%, respectively, $p = .066$).

RTs. Mean RTs are shown in the second row of Table 1 and Figure 3. A three-way ANOVA (3 [response mode] × 2 [congruency] × 5 [quintiles]) showed that RTs were faster for direction selection with small amplitude (412 ms) than for direction selection with large amplitude (432 ms) or effector selection (430 ms), $F(2, 30) = 4.24$, $p < .05$. Furthermore, RTs were faster for congruent than incongruent trials (406 vs. 443 ms, respectively), $F(1, 15) = 92.30$, $p < .001$. RTs increased with quintile, $F(4, 60) = 907.50$, $p < .001$, and did so differently for the three response modes, $F(8, 120) = 3.30$, $p < .05$. Response mode interacted with congruency, $F(2, 30) = 8.85$, $p < .005$, showing that the difference between congruent and incongruent trials was larger for effector selection (59 ms) than for direction selection with small (30 ms) or large (22 ms) amplitude. The effect of congruency did not differ significantly between the latter two

Table 3
Pearson Product–Moment Correlations for Reaction Time (RT), Movement Time (MT), Initial Movement Angle (IMA), and the Ratio of RT and MT in Incongruent Trials as a Function of Response Mode and Experiment

	Direction selection/large amplitude			Direction selection/small amplitude		
Variable	Pooled	Mean individual	Participants	Pooled	Mean individual	Participants
			Experiment 1			
RT – MT	-0.19^{***}	-0.08^{*}	8, *ns*			
RT – IMA	-0.20^{***}	-0.081^{*}	10, *ns*			
MT – IMA	$+0.62^{***}$	$+0.34^{***}$	15^{***}			
RT/MT – IMA	-0.43^{***}	-0.23^{***}	14^{**}			
			Experiment 2			
RT – MT	-0.16^{***}	-0.10^{***}	7, *ns*	-0.11^{***}	-0.08^{***}	7, *ns*
RT – IMA	-0.28^{***}	-0.11^{**}	7, *ns*	-0.11^{***}	-0.05^{**}	5, *ns*
MT – IMA	$+0.63^{***}$	$+0.33^{***}$	16^{***}	$+0.42^{***}$	$+0.21^{***}$	16^{***}
RT/MT – IMA	-0.55^{***}	-0.25^{***}	16^{***}	-0.35^{***}	-0.16^{***}	14^{**}
			Experiment 3			
RT – MT	-0.42^{***}	-0.12^{***}	9, *ns*	-0.36^{***}	-0.12^{***}	12, *ns*
RT – IMA	-0.28^{***}	-0.09^{***}	8, *ns*	-0.19^{***}	-0.05^{***}	4, *ns*
MT – IMA	$+0.56^{***}$	$+0.32^{***}$	16^{***}	$+0.35^{***}$	$+0.17^{***}$	11, *ns*
RT/MT – IMA	-0.60^{***}	-0.30^{***}	16^{***}	-0.40^{***}	-0.16^{***}	11, *ns*
			Experiment 4			
RT – MT	$+0.22^{**}$	$+0.05^{**}$	7, *ns*			
RT – IMA	$+0.16^{**}$	$+0.06^{**}$	7, *ns*			
MT – IMA	$+0.50^{**}$	$+0.26^{***}$	15^{***}			
RT/MT – IMA	-0.16^{**}	-0.07^{**}	4, *ns*			

Note. We calculated correlations for all observations from all participants (pooled correlations) and correlations for each participant separately (mean individual correlations). The mean individual correlation was compared to zero using a *t* test after transforming the correlations to Fisher's *z*. The number of participants (among 16) with a significant individual correlation was reported (participants). Whether this number was significant was determined by a binomial test. As the sample size was always 16, at least 13 participants need to show a significant correlation for the binomial test to be significant. *ns* = nonsignificant.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

conditions ($p = .30$). The interaction of congruency and quintiles was significant, $F(4, 60) = 34.07$, $p < .001$, confirming that the effect of congruency decreased from the first to the fifth quintile (47, 47, 41, 33, and 18 ms, respectively). Finally, there was a triple interaction of response mode, congruency, and quintiles, $F(8, 120) = 3.01$, $p < .05$, showing that the decrease of the congruency effect with quintile was more pronounced in the effector selection condition.

Results for Movement Execution (Only Direction Selection)

MTs. Mean MTs are shown in the second row of Table 1 and Figure 3. A three-way ANOVA (2 [response mode] × 2 [congruency] × 5 [quintiles]) on the MTs of the pointing movements showed that MTs were faster with a small than with a large amplitude (174 vs. 245 ms, respectively), $F(1, 15) = 72.34$, $p < .001$. Responses in congruent trials were faster than in incongruent trials (203 vs. 216 ms, respectively), $F(1, 15) = 12.94$, $p < .005$. MTs increased with quintile, $F(4, 60) = 320.37$, $p < .001$, and did so differently for each response mode, $F(4, 60) = 17.82$, $p < .001$. A trend for the interaction of response mode and congruency, $F(1, 15) = 4.52$, $p = .051$, showed that the effect of congruency was more pronounced with a large than with a small amplitude (18 vs. 7 ms, respectively). By *t* test, both differences were significantly different from zero (*p*s < .01). Furthermore, the Congruency × Quintiles interaction, $F(4, 60) = 7.16$, $p < .01$, showed that the effect of congruency increased from the first to the fifth quintile (4, 4, 8, 15, and 32 ms, respectively).

IMAs grouped by RT quintiles. Mean IMAs are presented in Table 2. Inspection of Figure 4, second row, and Figure 6 indicates that for direction selection with large amplitude, the fastest RTs and the slowest MTs showed a bimodal distribution of IMAs. A bimodal distribution of IMAs was not observed for direction selection with small amplitude. Rather, inspection of Figure 4 shows that the distribution of IMAs was unimodal, and we verified that this did not change across RT quintiles (data not shown). A three-way ANOVA (2 [response mode] × 2 [congruency] × 5 [RT quintiles]) on IMAs showed that IMAs were larger with small than with large amplitude (64° vs. 47°, respectively), $F(1, 15) = 26.23$, $p < .001$. IMAs were also larger in incongruent than in congruent trials (60° vs. 52°, respectively), $F(1, 15) = 16.57$, $p < .005$. Furthermore, IMAs decreased from the first to fifth RT quintile

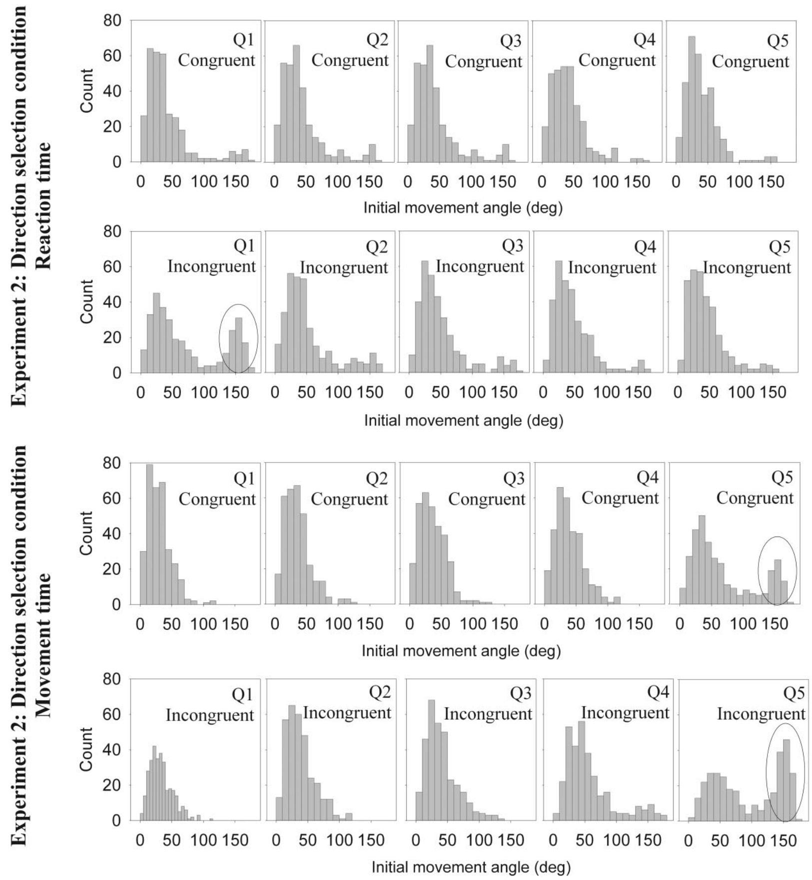

Figure 6. Histograms as a function of congruency and reaction time quintile (top panel) or movement time quintile (bottom panel) for the direction selection conditions of Experiment 2. Bimodal distributions are marked by an ellipse. Q1–Q5 = first to fifth quintile.

(57° to 42°, respectively), $F(4, 60) = 6.41$, $p < .005$, and did so differently for each response mode, $F(4, 60) = 3.25$, $p < .05$. The interaction of response mode and congruency, $F(1, 15) = 7.56$, $p < .05$, showed that the difference between congruent and incongruent trials was more pronounced with large than with small amplitude (11° vs. 5°, respectively). By *t* test, both differences were significantly different from zero (ps $< .01$). The interaction of congruency and RT quintile, $F(4, 60) = 6.06$, $p < .005$, confirmed that the effect of congruency on IMAs decreased from the first to the fifth RT quintile (20°, 7°, 5°, 4°, and 3°, respectively). At last, there was a triple interaction of response mode, congruency, and RT quintiles, $F(4, 60) = 3.21$, $p < .05$, and follow-up ANOVAs (Congruency × Quintiles) showed that the difference between congruent and incongruent trials decreased only with pointing movements of large amplitude (32° in the first RT quintile, 9°–4° in the remaining RT quintiles), $F(4, 60) = 3.78$, $p < .01$. Because the distribution of IMAs was again bimodal, we conducted a follow-up analysis on IMAs smaller than 100°. The results are shown in Table 2 and confirm the effect of congruency.

Correlations Between RT, MT, RT/MT, and IMA (Only Direction Selection)

For the small and large amplitudes, the global and the individual correlations replicate the results obtained for pointing movements with large amplitude in Experiment 1 (see Table 3). The correlations were numerically smaller with movements of small amplitude, but the pattern of statistical significance was the same. Participants traded RT for MT, as evident in the negative correlations. RT and IMA were negatively correlated, showing that fast responses veered toward the stimulus. MT and IMA were positively correlated because large IMAs imply longer trajectories that take more time to traverse. Finally, poorly prepared responses with a small ratio of RT/MT were associated with large IMAs as evident in the negative correlation between RT/MT and IMA.

Discussion

Experiment 2 replicated the results of Experiment 1. For RTs, the Simon effect was larger in a task requiring effector selection than in a task requiring the programming of a directional movement. In the effector selection task, finger selection had to be completed prior to movement initiation. In the direction selection task, complete response selection was not necessary before movement initiation because online corrections of movement direction were possible. Unfortunately, the direction selection condition with small amplitude was not different from the large amplitude condition in this respect. Correlations between RT and MT were significant with small and large movement amplitudes indicating that participants were trading RT for MT. That is, even though movements of small amplitude were executed 71 ms faster than movements of large amplitude (in only 174 ms), participants were able to trade RT for MT. Nonetheless the small amplitude condition is useful because it confirmed a bias toward the source of stimulation in the absence of a bimodal distribution of IMAs. Unlike with displacements of the whole hand, finger responses did not veer toward the stimulus in the first RT quintile (i.e., no interaction of congruency and quintile). It may be that it is impossible to correct large directional errors with such a small-scale movement. Nonetheless, the distribution as a whole was slightly shifted toward the stimulus in incongruent trials. This confirms that in addition to the attraction of fast responses by the imperative stimulus in incongruent trials, all trials, including movements that go into the correct direction, are biased toward the stimulus.

Experiment 3

Rubichi et al. (2000) have already noted that the Simon effect in RTs can be eliminated if participants opt for fast movement initiation and slow movement execution. If the Simon effect in RTs is taken as a measure of conflict at the level of response selection, one would have to conclude that the response conflict is entirely shifted to movement execution when the lift-and-decide strategy is adopted. A less radical proposition would be that some response conflict persists even if there is no Simon effect in RTs. In this case, the Simon effect in RTs does not measure response conflict exhaustively. In any case, response conflict before movement initiation should be reduced to some degree with a lift-and-decide strategy. However, the time course of response conflict resolution is not expected to change. It should be resolved for slow RTs, but not for fast RTs.

The goal of the present experiment was to examine movement parameters under conditions that shift the response conflict at least partially to movement execution. To this end, we instructed participants to lift their finger before making a decision about where to move their hand. A time limit of 450 ms (about the mean RT in Experiments 1–2) was set for movement initiation. For pointing movements, we expected the Simon effect in RTs to be strongly reduced. If the Simon effect in RTs was a necessary condition for changes of movement trajectories, effects on IMA should also be eliminated.

Method

Participants. Sixteen students from the same pool as in Experiment 1 participated. Participants were right-handed, except for 2 left-handed and 1 ambidextrous participant.

Apparatus and stimuli. The same apparatus and stimuli were used as in Experiment 1.

Procedure and design. As in Experiment 2, participants performed three different response modes (effector selection, direction selection/large amplitude, and direction selection/small amplitude), but the maximally allowed RT was reduced from 800 ms to only 450 ms. Responses that did not meet this criterion were repeated in the remainder of the session. In the direction selection conditions, participants were instructed to first raise the finger and then decide about the direction of the movement. In the effector selection condition, this strategy could not be used. We therefore only emphasized that it was important to associate one color to each finger because the time to respond was very limited.

Results for Movement Initiation (All Response Modes)

Data treatment was as in Experiment 2.

Errors. A significant difference between the mean error rate in congruent and incongruent trials was confirmed for effector selection (1.7% vs. 6.1%, respectively, $p < .001$), and for direction selection with large amplitude (5.7% vs. 7.1%, respectively, $p < .05$), but not with small amplitude (1.8% vs. 2.3%, respectively, $p = .34$).

RTs. Mean RTs are shown in Table 1 and Figure 3. A three-way ANOVA (3 [response mode] × 2 [congruency] × 5 [quintiles]) showed that RTs were slower with effector selection (347 ms) than with large or small amplitude pointing movements (316 and 314 ms, respectively), $F(2, 30) = 14.07$, $p < .001$. Furthermore, responses in congruent trials were faster than in incongruent trials (316 vs. 335 ms, respectively), $F(1, 15) = 173.20$, $p < .001$. The effect of quintile, $F(4, 60) = 863.01$, $p < .001$, and the interaction of response mode and quintile, $F(8, 130) = 4.15$, $p < .005$, were significant. The effect of congruency was larger for effector selection (43 ms) than for direction selection with small (11 ms) and large (4 ms) amplitude, $F(2, 30) = 78.68$, $p < .001$. The t tests showed that the Simon effect was significant with pointing movements of small ($p < .01$) but not of large ($p = .06$) amplitude. Furthermore, the congruency by quintiles interaction, $F(4, 60) = 29.83$, $p < .001$, indicated that the Simon effect was smaller in the last quintile (9 ms) compared to the other quintiles (17–22 ms). Finally, the triple interaction of response mode, congruency, and quintiles was significant, $F(8, 120) = 10.15$, $p < .001$, and follow-up ANOVAs showed that the Congruency × Quintiles interaction was only significant for effector selection, $F(4, 60) = 29.14$, $p < .001$, and direction selection with small amplitude, $F(4, 60) = 5.85$, $p < .001$, but not for direction selection with large amplitude, $F(4, 60) = 2.01$, $p = .13$.

Results for Movement Execution (Only Direction Selection)

MTs. Mean MTs are shown in Table 1 and Figure 3. A three-way ANOVA (2 [response mode] × 2 [congruency] × 5 [quintile]) carried out on pointing movements indicated that MTs were faster with small than with large amplitude (223 vs. 313 ms, respectively), $F(1, 15) = 52.09$, $p < .001$, and confirmed that MTs were faster in congruent than incongruent trials (259 vs. 277 ms, respectively), $F(1, 15) = 22.24$, $p < .001$. There also was a main effect of quintiles, $F(4, 80) = 101.30$, $p < .001$, and a Response Mode × Quintile interaction, $F(4, 60) = 9.37$, $p < .005$. Furthermore, the interaction of congruency and quintiles, $F(4, 60) = 8.36$, $p < .001$, confirmed that the Simon effect increased with increasing quintile (8, 10, 16, 23, and 32 ms, respectively).

IMAs grouped by RT quintiles. A three-way ANOVA (2 [response mode] × 2 [congruency] × 5 [RT quintiles]) conducted on IMAs grouped by RT quintiles indicated that IMAs were larger for pointing movements of small than of large amplitude (77° vs. 72°, respectively), $F(1, 15) = 4.79$, $p < .05$, and confirmed that IMAs were smaller in congruent than incongruent trials (71° vs. 78°, respectively), $F(1, 15) = 9.67$, $p < .01$. There also was a main effect of RT quintile, $F(4, 60) = 10.78$, $p < .001$, showing that IMAs decreased with increasing quintile (80–67°). The interaction of response mode and RT quintile was significant, $F(4, 60) = 3.56$, $p < .05$. Furthermore, the interaction of response mode and congruency, $F(1, 15) = 5.18$, $p < .05$, indicated that the effect of congruency was larger for movements of large than of small amplitude (12° vs. 3°, respectively). The *t* tests showed that the effect of congruency was significant for movements of large amplitude ($p < .01$) but not for movements of small amplitude ($p = .18$). Finally, the Congruency × RT Quintiles interaction, $F(4, 60) = 5.53$, $p < .005$, showed that the effect of congruency on IMAs decreased with increasing RT quintiles (17°, 10°, 5°, 3°, and 2°, respectively). Separate *t* tests for each quintile showed that the effect of congruency was significant for fast RTs with both small and large movement amplitudes (see Figure 4).

Correlations Between RT, MT, RT and MT Ratio, and IMA (Only Direction Selection)

The global and mean individual correlations with small and large movement amplitude replicated the results of Experiment 2 (see Table 3).

Comparison Between Experiments 2 and 3 (Only Direction Selection With Large Amplitude)

In order to evaluate whether time pressure had the desired effects on performance, we conducted mixed-factors ANOVAs (2 [experiment] × 2 [congruency] × 5 [quintiles]) on the direction selection condition with large movement amplitude. This analysis also clarified whether the effects of congruency or the time course of these effects had changed. For ease of exposition, we chose to only present theoretically interesting results: main effects of experiment, significant two-way interactions of experiment and congruency, and significant three-way interactions of experiment, congruency, and quintile. RTs were shorter with time pressure in Experiment 3 compared to Experiment 2 (316 vs. 432 ms, respectively), $F(1, 30) = 80.32$, $p < .001$. The Simon effect was smaller in Experiment 3 than in Experiment 2 (4 vs. 22 ms, respectively), $F(1, 30) = 6.06$, $p < .05$. These results confirm that time pressure made participants respond faster and virtually eliminated the Simon effect in response times. In contrast, MTs increased in Experiment 3 compared to Experiment 2 (313 vs. 245 ms, respectively), $F(1, 30) = 5.19$, $p < .05$, showing that observers initiated responses earlier but took more time to reach the target location. Finally, larger IMAs were confirmed in Experiment 3 compared to Experiment 2 (72° vs. 47°, respectively), $F(1, 30) = 25.89$, $p < .001$, showing that participants took a less direct path to the target location. Nonetheless, the mean IMA of 72° was significantly different from 90° ($p < .001$), indicating that participants did not move straight up.

Discussion

We successfully induced a lift-and-decide strategy by reducing the maximally allowed time to initiate a movement. Participants lifted their hand earlier (shorter RTs) and moved less efficiently (larger IMAs, longer MTs) toward the response location. Nonetheless, responses were directed at the correct response location, showing that, on average, the correct response direction was selected. Despite the evidence for response selection in early movement parameters, the Simon effect in RTs was eliminated for pointing movements of large amplitude and was strongly reduced for movements of small amplitude. In contrast, the Simon effect persisted almost unabated for effector selection because participants could not trade RT for MT. These results demonstrate that the Simon effect during response selection is not a precondition for the Simon effect on response programming. We therefore suggest that the Simon effects in RTs and movement parameters capture partially independent parts of the overall response conflict. In other words, the Simon effect in RTs does not exhaustively reflect response conflict. Even if it is abolished, response conflict arising from residual response selection may produce a Simon effect in movement parameters.

As in Experiment 2, deviations toward the stimulus were larger with fast RTs than with slow RTs. In the present experiment, this time course was also evident for direction selection with small amplitude, showing that it is not fundamentally different from the large amplitude condition. As in Experiment 2, we believe that the decrease of the Simon effect with time reflects the resolution of conflicts at response selection.

A further noteworthy point is that the Simon effect in MTs for direction selection with large amplitude did not change between Experiments 2 and 3 (18 vs. 23 ms, respectively, $p = .54$). If all processes of response selection had been shifted to response execution, the Simon effect in MTs should have comprised the Simon effect in RTs of 22 ms and the Simon effect in MTs of 18 ms that we observed in Experiment 2. The sum of 40 ms is far from the Simon effect in MTs of 23 ms that was actually confirmed. This suggests that the response conflict underlying the Simon effect in movement execution was unaffected by the lift-and-decide strategy. In contrast, the component that underlay the Simon effect in RTs was abolished.

Experiment 4

In the previous experiment, we reduced the time available for response selection and observed that Simon effects in MTs and IMAs were unaffected while congruency effects in RTs were strongly reduced or even eliminated. In the present experiment, we provided ample time for response selection to investigate whether the Simon effect in RTs and MTs/IMAs would be equally affected by this manipulation. The required response was precued and participants were asked to withhold the response until a go signal was presented on the left or right. Hommel (1995) already reported that the Simon effect persisted in this situation and that the irrelevant spatial position of the go signal induced a Simon effect. This shows that the activation of response codes by irrelevant information may produce a response conflict even when response selection is almost complete. The question is whether the same would hold for the Simon effect in MTs and IMAs.

Method

Participants. Sixteen students from the same pool as in Experiment 1 participated. All participants were right-handed.

Apparatus and stimuli. The same apparatus was used as in Experiment 1. The imperative stimulus was a green or red square of about 2.8 × 2.8 cm displayed in the center of the screen. As in Experiment 1, two empty boxes were visible on the left and on the right of the fixation cross. The go signal was a black square that appeared in one of the two lateral boxes.

Procedure and design. Only the effector selection and the direction selection/large amplitude conditions were run. Hand position and trial initiation were the same as in Experiment 1. After trial initiation, a colored square appeared in the center of the screen for 300 ms. The color of the square indicated which of the two fingers had to be lifted (effector selection condition) or which of the two lateral boxes had to be reached (direction selection condition). After a random interval of 400–1,400 ms, a black square appeared in one of the two empty boxes and stayed on the screen until the end of the trial. Participants were instructed to execute the precued response as fast and as accurately as possible after onset of the black square.

Results for Movement Initiation (All Response Modes)

Data treatment was as in Experiment 1, with the exception that trials were coded as congruent when the location of the go signal corresponded to the response direction or location and as incongruent when this was not the case.

Errors. For effector selection, the mean error rate was larger in the incongruent than in the congruent condition (3% vs. 1%, respectively, $p < .005$) but did not differ between conditions for direction selection (2% vs. 2%, respectively, $p = .45$).

RTs. Mean RTs are shown in Table 1 and Figure 3. The ANOVA (2 [response mode] × 2 [congruency] × 5 [quintiles]) performed showed that RTs did not differ between direction and effector selection (306 vs. 291 ms, respectively), $F(1, 15) = 2.74$, $p = .12$. Responses were faster in congruent than in incongruent trials (285 vs. 312 ms, respectively), $F(1, 15) = 61.10$, $p < .001$. Unlike in Experiments 1–3, the interaction of response mode and congruency was not significant, $F(1, 15) = 0.75$, $p = .40$. As expected, the main effect of quintile was significant, $F(4, 60) = 298.49$, $p < .001$. The interaction between congruency and quintiles was significant, $F(4, 60) = 38.54$, $p < .001$, indicating that the congruency effect increased with increasing quintile. The mean differences from the first to the fifth quintile were 7, 11, 18, 38, and 62 ms, respectively. Note that the interaction of quintile and congruency is opposite to the pattern observed in Experiments 1–3.

Results for Movement Execution (Only Direction Selection)

MTs. Mean MTs are shown in Table 1 and Figure 3. The ANOVA (2 [congruency] × 5 [quintiles]) showed that MTs were faster in congruent than in incongruent trials (202 vs. 210 ms, respectively), $F(1, 15) = 29.52$, $p < .001$. The main effect of quintiles was significant, $F(4, 60) = 78.97$, $p < .001$. The congruency effect increased with increasing quintiles (0, 3, 3, 4, and 29, respectively), $F(4, 60) = 11.47$, $p < .005$.

IMAs grouped by RT quintiles. Mean IMAs are shown in Table 2 and Figure 3. Histograms are shown in Figure 4. A two-way ANOVA (2 [congruency] × 5 [RT quintiles]) on IMAs of the pointing movements showed that IMAs were larger in incongruent than congruent trials (39° vs. 36°, respectively), $F(1, 15) = 17.02$, $p < .001$. There was a main effect of quintiles, $F(4, 60) = 29.24$, $p < .001$. Finally, the mean difference between congruent and incongruent trials increased with increasing quintiles (2°, 1°, 3°, 1°, 12°, respectively), $F(4, 60) = 4.53$, $p < .05$.

Correlations Between RT, MT, RT and MT Ratio, and IMA (Only Direction Selection)

The global and mean individual correlations replicate results observed for the direction selection condition of Experiments 1–3 (see Table 3). However, the correlations were smaller. The most significant change concerns the correlation between the ratio RT/MT and IMA. In previous experiments, the mean individual correlation was on the order of −0.2 to −0.3. In the present experiment, it dropped to −0.07 and was only significant in 4 participants. This shows that the degree to which a movement was prepared no longer predicted the initial movement angle. Because effects of congruency on IMAs were also much smaller in this experiment, we suggest that the smaller correlations are due to more efficient and stereotyped movements that were also less affected by irrelevant spatial information.

Comparison Between Experiments 2 and 4 (Only Direction Selection With Large Amplitude)

To perform a manipulation check and to evaluate changes of congruency effects or time course, we conducted mixed-factors ANOVAs (2 [experiment] × 2 [congruency] × [5 quintiles]) on the direction selection condition. RTs were shorter in Experiment 4 compared to Experiment 2 (306 vs. 432 ms, respectively), $F(1, 30) = 86.46$, $p < .001$, confirming the benefit of advance response preparation. The interaction of experiment, congruency, and quintile showed that the time course of the Simon effect changed, $F(4, 120) = 26.78$, $p < .001$. While the Simon effect decreased with RT in Experiment 2, it increased with RT in Experiment 4. However, the size of the Simon effect in RTs was unchanged ($p = .84$). Further, MTs decreased in Experiment 4 compared to Experiment 2 (206 vs. 245 ms, respectively), $F(1, 30) = 9.09$, $p < .01$, again confirming the benefit of advanced response preparation. The Simon effect in MTs tended to be smaller in Experiment 4 than in Experiment 2 (8 vs. 18 ms, respectively), $F(1, 30) = 2.99$, $p = .09$. Finally, smaller IMAs were confirmed in Experiment 4 compared to Experiment 2 (37° vs. 47°, respectively), $F(1, 30) = 5.86$, $p < .05$, showing that pointing movements were more efficiently directed at the target. The Simon effect on IMAs was smaller in Experiment 4 than in Experiment 2 (4° vs. 11°, respectively), $F(1, 30) = 6.48$, $p < .05$, and the time course was different, $F(4, 120) = 7.31$, $p < .005$. Whereas the Simon effect decreased with quintile in Experiment 2, it increased with quintile in Experiment 4.

Discussion

The go-signal task used in Experiment 4 assured that response selection occurred mostly before movement initiation. This was evident in fast RTs and MTs as well as small IMAs. Consistent with a previous study (Hommel, 1995), the Simon effect persisted with advance response selection. Further, advance response preparation eliminated the larger size of the Simon effect in RTs for effector compared to direction selection. This was mostly due to a reduction of the Simon effect for effector selection in Experiment 4 compared to Experiment 2 (30 vs. 60 ms, respectively), $F(1, 30) = 9.86$, $p < .005$. The Simon effect in RTs with pointing movements did not change between Experiments 4 and 2 (24 vs. 22 ms, respectively). However, the Simon effect in IMAs with pointing movements was significantly reduced in Experiment 4 compared to Experiment 2 (4° vs. 11°, respectively). A similar tendency was evident in MTs. Thus, advance response preparation affects response selection and response programming differently. When the effector had to be selected, advance preparation diminished the Simon effect in RTs (of course, MTs and IMAs are not available in this response mode). When the movement direction had to be selected for a pointing movement, advance preparation diminished the Simon effect in movement parameters (MTs and IMAs), but not in RTs. A speculative interpretation of these findings is presented in the General Discussion.

Further, the time course of the Simon effect was reversed in Experiment 4 compared to the previous experiments (see Figure 7). For all dependent measures, the Simon effect was larger in slow than in fast quintiles (see Figure 3). The obvious difference between the present and the previous experiments was that participants were precued about the response before onset of the irrelevant spatial information. Previously, Hommel (1996) attributed the changed time course with precued responses to the faster retrieval of the correct response. As outlined in the introduction, the Simon effect is thought to arise from a conflict between the (voluntary) retrieval of the instructed response and the automatic activation of the alternative response. Automatic response activation is thought to build up and decay over time, resulting in an inverted U-shaped function. Typically, the retrieval of the instructed response is relatively slow and coincides with the decay of automatic activation. Therefore, the Simon effect decreases with RT quintile (cf. Experiments 1–2). In contrast, when retrieval of the instructed response is fast (e.g., due to precues), retrieval of the instructed response will overlap with the build-up of automatic activation. In this case, the Simon effect increases with RT quintile (cf. Experiment 4).

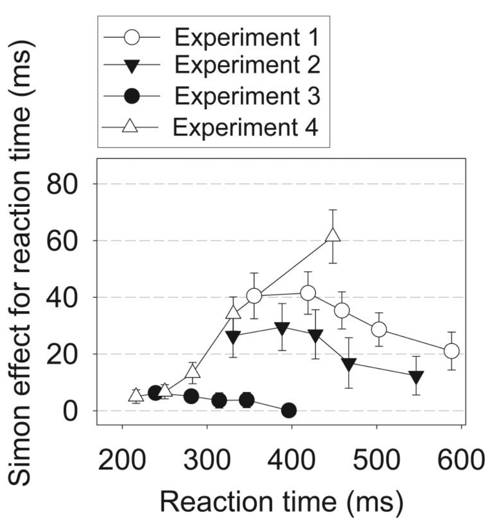

Figure 7. Simon effect as a function of reaction time in the large-amplitude direction-selection condition (pointing task). Data from Experiments 1–4 are shown. Error bars indicate the between-subjects standard error.

Let us now focus on the qualitative differences between fast and slow responses in this and previous experiments. Our interpretation is by no means incompatible with the previous one, but it puts the emphasis on response preparation and conflict, rather than on the time course of automatic response activation. In Experiments 1–2, fast responses were those in which response conflict was high and response selection incomplete. This point is particularly evident in the high correlations between the ratio of RT/MT and IMA: Poorly prepared responses that were quickly initiated went into the wrong direction (large IMAs). Responses with slow RTs, in contrast, were those in which response selection was complete and trajectories were optimal (small IMAs). In the present experiment, participants knew in advance where to go and response selection could—in principle—have been complete by the time the go signal was presented. When the participant was optimally prepared, responses should therefore be fast and goal directed. In contrast, slow responses indicate that the participant had not taken advantage of the time interval available for response preparation. Therefore, response selection was incomplete and response conflict was strong. Finally, response conflict was altogether absent in Experiment 3 because participants decided where to move after initiating the response. This resulted in the near absence of a Simon effect in the RT range of 300–400 ms that gave rise to the largest Simon effects in the remaining experiments.

General Discussion

In the present series of experiments, we investigated the effects of irrelevant spatial information on pointing movements. Our paradigm was a modified version of the standard Simon task in which participants responded to the color of a stimulus by moving their hand or index finger to the left or right. A reliable Simon effect was observed in RTs of the directional movements. However, the Simon effect with pointing movements was smaller than in a task requiring the selection of an effector (index or middle finger). Further, we observed reliable Simon effects in MTs. Responses toward the imperative stimulus in congruent trials were executed faster than responses away from the imperative stimulus (toward an empty location) in incongruent trials. Rubichi and coworkers (Rubichi et al., 2000; Rubichi & Pellicano, 2004) proposed that the Simon effect in MTs was accounted for by participants' strategy of lifting the finger before deciding in which direction to move (lift and decide), which shifted response selection into movement execution.

We reexamined Rubichi and coworkers' proposal (Rubichi et al., 2000; Rubichi & Pellicano, 2004) by measuring 3D movement trajectories. Analysis of the initial movement angle showed that there was a tendency for movements to be biased toward the imperative stimulus location. In incongruent trials, this led to larger IMAs than in congruent trials, indicating that observers had a tendency to initially move toward the imperative stimulus, even if their responses ended on the correct location. This difference was particularly pronounced for fast RTs in incongruent trials, and decreased as RTs increased. We suggest that this time course reflects the resolution of a conflict between automatically activated response and instructed response over time. In Experiment 3, a lift-and-decide strategy was induced by imposing a time limit for movement initiation. This strategy eliminated the Simon effect in RTs for pointing movements, but did not change the Simon effect in movement parameters. In Experiment 4, the requested response was precued, and the go-signal carried irrelevant spatial information. The Simon effect in RTs was reduced for effector selection and unchanged for pointing movements. In contrast, the Simon effect in movement parameters was reduced. Further, precueing the response reversed the time course of the Simon effect: The Simon effect was largest for slow responses. We suggested that insufficient response preparation and high response conflict in slow responses accounts for this pattern.

Simon Effects for Response Selection and Response Programming?

As outlined in the introduction, response selection and response programming overlap to a large degree. Nonetheless, it may be useful to distinguish between an abstract choice of a left or right response and the details of a motor program directing the hand to the left or to the right. We refer to these different levels of detail as *response selection* and *response programming* without claiming that these terms refer to serial stages in motor control. In our view, the assumption of separable Simon effects for response selection and programming may integrate most of the findings reported in this article. We suggest that conflicts between response codes produce the Simon effect in RTs and—somewhat less obviously—the Simon effect in movement parameters. The idea of a common source of both Simon effects is supported by the similarity of their respective time courses. As laid out before, a strong conflict is supposed to produce large Simon effects in RTs and movement parameters (i.e., MTs and IMAs) and as the conflict is resolved, the Simon effects decrease.

While both Simon effects may have a common source, they are not identical as the time constraints for response selection and programming vary. We assume that one part of the overall response conflict has to be solved before response initiation, which leads to a Simon effect in RTs. Another part of the response conflict may be resolved during response programming, which leads to a Simon effect in movement parameters. A necessary condition for measuring effects of response conflict on response programming is the possibility of online corrections. For effector selection, no corrections are possible after movement initiation and responses are highly stereotyped. Therefore, the complete response conflict will be reflected in RTs. For direction selection, online corrections are possible such that the overall response conflict will be expressed in two different measures: A Simon effect in RTs and a Simon effect in movement parameters. Because the response conflict is split in two, the Simon effect in RTs with pointing movements is smaller than with effector selection (cf. Experiments 1–3).

Further, our results show that the Simon effect in RTs and the Simon effect in movement parameters dissociate to some degree. Time pressure may completely abolish the Simon effect in RTs if online corrections are possible (see Experiment 3). However, the Simon effect in RTs did not transfer to movement execution. We suggest that the Simon effect in RTs with pointing movements is accounted for by the abstract decision between left and right that precedes movement initiation if precise pointing movements are to be made. The abstract decision of which movement to execute may be like an image of the desired outcome of the action (a "response effect"; e.g., an image of the right index on the left box). Presumably, evoking the image of a response effect acts like a go signal for the action (Hommel et al., 2001; Kunde, 2001). If participants start to move before deciding where to move, no such image is evoked and most of the abstract response selection is suppressed. The lack of response selection before movement initiation reduces the precision of the movement, as is evident in the flat distribution of IMAs. On average, however, residual response selection directs movements toward the correct location and produces a Simon effect in response programming. The important point to note is that the Simon effect occurring before movement initiation may be suppressed independently of the Simon effect in response programming.

In contrast to time pressure, advance movement preparation (cf. Experiment 4) reduced the Simon effect in movement parameters for direction selection but left the Simon effect in RTs unaffected. Further, advance movement preparation reduced the Simon effect in RTs for effector selection. We believe that the reduction in RTs with effector selection corresponds to the reduction in MTs/IMAs with pointing movements. For effector selection, the Simon effect on response programming is contained in RTs, and this aspect of the response conflict was reduced by advance response preparation. In our view, the persisting Simon effect in RTs for both response modes reflects the need to evoke an image of the action's effect to initiate a movement with high precision. This process is equally necessary for effector selection and pointing movements and produces Simon effects in RTs that resist advance response preparation. In contrast, the Simon effect associated with response programming was reduced in both cases, but the dependent measure reflecting this reduction differed between the response modes (RTs for effector and IMAs for direction selection). The influence of advance movement preparation on response programming is also evident in the much smaller correlations between the ratio RT/MT and IMA. In Experiments 1–3, this correlation indicated that long preparation times (large ratio RT/MT) were associated with efficient response execution (small IMAs). In Experiment 4, this was no longer true suggesting that details of the movement were not fixed after onset of the go signal but before. Thus, the influence of irrelevant spatial information was reduced.

While the distinction between two Simon effects for response selection and response programming may provide a useful frame for summarizing the present results, it is post hoc at this point and needs further experimental evidence. Nonetheless, there is some evidence in favor of the notion of independent mechanisms subserving response selection and programming. Adam and Pratt (2004) investigated the effects of precues on reaching movements and keypresses. Before target onset, cues narrowed the number of possible target locations from four to two. The spatial arrangement of the cues (left vs. right, inner vs. outer, etc.) strongly affected keypresses but not reaching movements. Further, the preparation interval influenced RTs of keypresses and reaching differently. Overall, the pattern of results was consistent with the idea that precues facilitated effector selection in the keypress task but changed the allocation of visuo-spatial attention in the reaching task. In our view, the allocation of visuo-spatial attention may have enabled participants to more quickly specify the parameters of the movement. Thus, Adam and Pratt's results are consistent with the idea that precues facilitated effector selection in the keypress task and response programming in the reaching task. This conclusion is reminiscent of the differential effects of time pressure and response certainty on reaching movements and effector selection in the present study.

Implications for Current Models

Overall, our results support the view that irrelevant spatial information induces a tendency to respond toward the source of stimulation. This finding is consistent with Simon's (1990) assumption of a "strong natural tendency to respond initially to the directional component of a stimulus" (p. 75) and Welsh and Elliott's (2004) idea that initially, movements are a combination of distractor and target responses. Apparently, inhibition of the distractor was never strong enough to bias movements away from the distractor (cf. Tipper et al., 1999). This may be due to the specifics of our experimental setup, in particular, the large separation between target and distractor. The tendency to move toward the stimulus is also consistent with Kornblum et al.'s (1990) dual-route model. Under the assumption of separable response selection and response programming stages, the model would have to be modified to include the possibility that automatically activated motor programs are not completely aborted but linger in the system and bias subsequent motor programs. That is, the resolution of the conflict between instructed and stimulus-induced responses is not an all-or-none phenomenon but graded. Solving the conflict between response alternatives in favor of the instructed response changes the way an action is performed. At early stages of conflict resolution, the response parameters are biased toward the automatically activated response.

Hommel et al. (2001) argued that stimulus- and response-related stages of information processing are not separate but rather share a common representational domain. The common representational domain is filled with features such as left, up, green, and so forth that are tied together to form events that refer to distal events. For instance, if the stimulus codes are left and green because a green square was presented on the left, a left response will be easier because it uses a feature that has already been activated by the stimulus. In Hommel et al.'s view, both actions and percepts refer to distal events that justify the assumption of common coding. However, the level of common coding remains rather abstract, and as a matter of fact, the authors exclude details of the movement in their definition of action control: "In other words, action control deals with the intended outcome of an action, not with the particularities of the movement or the sensorimotor interplay producing that outcome" (Hommel et al., 2001, p. 862). Our results suggest that details of a movement can nonetheless be influenced by the interaction of abstract response codes. For instance, simultaneous activation of codes by the response-irrelevant stimulus and retrieval of instructed response may produce a response that shares low-level features of both codes.

Related Findings

We are not the first to report trajectory deviations toward distracting information. For instance, hand movements deviate toward distractors when the fixation mark is extinguished 200 ms before the onset of a display containing the target and distractors (Song & Nakayama, 2007). RTs were lower with a gap interval compared to a condition in which the fixation point stayed on until target/distractor onset. However, MTs to reach the target were not reduced because participants had a larger tendency to move toward the distractors. This finding is consistent with the large IMAs that we observed with short RTs in the present study. Further, Welsh and Elliott (2004) instructed their participants to move toward a red light-emitting diode (LED) while ignoring a green LED that was presented in front or behind the target. Measurements of the movement trajectories showed that the maximal elevation of the hand was lower when the distractor was presented in front of the target, showing that trajectories deviated toward the distractor. Further, Welsh and Elliott manipulated the delay between target onset (red LED) and distractor onset (green LED). Their results showed that when the delay between distractor and target onset was sufficiently long to inhibit the distractor-related activation (distractor 750 ms before target), the trajectory deviated away from the to-be-ignored stimulus. On the other hand, the path deviated toward the distractor location when the time to inhibit the distractor activation was short ($\sim$250 ms) and when the distractor was presented simultaneously with the target. These results are consistent with the time course of the Simon effect in IMAs that we observed in Experiments 1–3. The reversed time course in Experiment 4 may be explained by assuming that the retrieval and execution of the instructed response were given a head start because of the precues and consequently summation of the instructed and stimulus-induced responses occurred later (see also Welsh & Elliot, 2005).

To summarize, the present study investigated the effects of conflict during response selection on response programming. In a typical Simon task, such a conflict is produced by presenting a stimulus containing task-relevant color information on the left or right. We observed that movement trajectories veered toward the task-irrelevant location of the stimulus. The correlations between RT, MT and IMAs confirmed that observers were trading RT for MT, which reduced the Simon effect in RTs. Forcing participants to lift their finger before deciding where to go eliminated the Simon effect in RTs but did not affect the Simon effect in movement parameters. In contrast, precueing the correct response strongly reduced the Simon effect in movement parameters while not affecting the Simon effect in RTs. We suggest that dissociable Simon effects exist for response selection and response programming. Both Simon effects follow the time course of conflict resolution. Typically, the conflict is resolved over time and the Simon effect decreases with longer/increasing RT. With advance movement preparation, the conflict is largest for poorly prepared, slow responses and the time course of the Simon effect is therefore reversed.

References

Adam, J., & Pratt, J. (2004). Dissociating visual attention and effector selection in spatial precuing tasks. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 1092–1106.

De Jong, R., Liang, C. C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus-response correspondence. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 731–750.

Ghez, C., Hening, W., & Favilla, M. (1989). Gradual specification of response amplitude in human tracking performance. *Brain, Behavior and Evolution, 33*(2–3), 69–74.

Hietanen, J. K., & Rämä, P. (1995). Facilitation and interference occur at different stages of processing in Simon paradigm. *European Journal of Cognitive Psychology, 7*(2), 183–199.

Hommel, B. (1994). Spontaneous decay of response-code activation. *Psychological Research/Psychologische Forschung, 56,* 261–268.

Hommel, B. (1995). Stimulus–response compatibility and the Simon effect: Toward an empirical clarification. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 764–775.

Hommel, B. (1996). S-R compatibility effects without response uncertainty. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 49*(A), 546–571.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action. *Behavioral and Brain Sciences, 24*(5), 849–878; discussion 878–937.

Howard, L. A., & Tipper, S. P. (1997). Hand deviations away from visual cues: Indirect evidence for inhibition. *Experimental Brain Research, 113,* 144–152.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus–response compatibility—A model and taxonomy. *Psychological Review, 97,* 253–270.

Kunde, W. (2001). Response-effect compatibility in manual choice reaction tasks. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 387–394.

Meegan, D. V., & Tipper, S. P. (1998). Reaching into cluttered visual environments: Spatial and temporal influences of distracting objects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 51*(A), 225–249.

Nicoletti, R., Anzola, G. P., Luppino, G., Rizzolatti, G., & Umiltà, C. (1982). Spatial compatibility effects on the same side of the body midline. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 664–673.

Rosenbaum, D. A. (1980). Human movement initiation: Specification of arm, direction, and extent. *Journal of Experimental Psychology: General, 109,* 444–474.

Rubichi, S., Nicoletti, R., Umiltà, C., & Zorzi, M. (2000). Response strategies and the Simon effect. *Psychological Research, 63,* 129–136.

Rubichi, S., & Pellicano, A. (2004). Does the Simon effect affect movement execution? *The European Journal of Cognitive Psychology, 16,* 825–840.

Shulman, H. G., & McConkie, A. (1973). S-R compatibility, response discriminability, and response code in choice reaction time. *Journal of Experimental Psychology, 98,* 375–378.

Simon, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility: An integrated perspective* (pp. 31–86). North-Holland: Elsevier.

Simon, J. R., & Rudell, A. P. (1967). Auditory S-R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology, 51,* 300–304.

Song, J.-H., & Nakayama, K. (2007). Fixation offset facilitates saccades and manual reaching for single but not multiple target displays. *Experimental Brain Research, V177,* 223–232.

Theios, J. (1975). The components of response latency in simple human information processing tasks. In P. M. A. Rabbit & S. Dornic (Eds.), *Attention and performance V* (pp. 418–440). London: Academic Press.

Tipper, S. P., Howard, L. A., & Houghton, G. (1999). Behavioral consequences of selection form neural population codes. In S. Monsell & J. Driver (Eds.), *Attention and performance XVIII* (pp. 223–245). Cambridge, MA: MIT Press.

Tipper, S. P., Howard, L. A., & Jackson, S. R. (1997). Selective reaching to grasp: Evidence for distractor interference effects. *Visual Cognition, 4,* 1–38.

Umiltà, C., & Nicoletti, R. (1985). Attention and coding effects in S-R compatibility due to irrelevant spatial cues. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 457–471). Hillsdale, NJ: Erlbaum.

Vallesi, A., Mapelli, D., Schiff, S., Amodio, P., & Umiltà, C. (2005). Horizontal and vertical Simon effect: Different underlying mechanisms? *Cognition, 96,* B33–B43.

van Sonderen, J. F., & Denier van der Gon, J. J. (1991). Reaction-time-dependent differences in the initial movement direction of fast goal-directed arm movements. *Human Movement Science, 10,* 713–726.

Welsh, T., & Elliott, D. (2004). Movement trajectories in the presence of a distracting stimulus: Evidence for a response activation model of selective reaching. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 57*(A), 1031–1057.

Welsh, T., & Elliott, D. (2005). The effects of response priming on the planning and execution of goal-directed movements in the presence of a distracting stimulus. *Acta Psychologica, 119,* 123–142.

Welsh, T., Elliott, D., & Weeks, D. J. (1999). Hand deviations toward distractors. Evidence for response competition. *Experimental Brain Research, 127,* 207–212.

Wiegand, K., & Wascher, E. (2005a). Dynamic aspects of stimulus–response correspondence: Evidence for two mechanisms involved in the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 453–464.

Wiegand, K., & Wascher, E. (2005b). Response coding in the Simon task. *Psychological Research,* 1–10.

Wühr, P. (2006). The Simon effect in vocal responses. *Acta Psychologica, 121,* 210–226.

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