Transfer of response codes from choice-response to go/no-go tasks

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The present study investigated the conditions for observing the Simon effect in go/no-go tasks. The Simon effect denotes faster and more accurate responses when irrelevant stimulus location and response location correspond than when they do not correspond. In four experiments, participants performed both in a choice-response task (CRT) and in a go/no-go task, and we varied the order and the similarity of the tasks. In the CRT, participants pressed a left key to one stimulus colour and a right key to another stimulus colour; in the go/no-go task, participants pressed one (e.g., left) key to one stimulus colour and refrained from responding to the other stimulus colour. As expected, Simon effects were consistently observed in the CRT. In contrast, Simon effects in the go/no-go task were only observed when it followed the CRT and when the mapping of stimulus colours to response locations was preserved between tasks (i.e., in Experiment 4). Results suggest that transfer of a particular S–R rule including response location from the CRT to the go/no-go task was responsible for the Simon effect in the latter task. In general, results are consistent with a response-discrimination account of the Simon effect.

Keywords: Go/no-go task; Response-discrimination account; Spatial stimulus–response correspondence; Transfer; Simon effect.

For any behaving agent, processing spatial information is crucial for controlling its behaviour. Therefore, humans and animals show high sensitivity for processing spatial information in the context of motor control. This is evident, for example, in spatial stimulus–response (S–R) correspondence effects: Responses are faster and less error prone when the relative location of the response matches the relative location of the stimulus than when the relative locations do not match (Fitts & Seeger, 1953; Kornblum, Hasbroucq, & Osman, 1990). As a rule, even when participants are not explicitly asked to process stimulus location it will nevertheless affect response efficiency, an impact called the Simon effect (Lu & Proctor, 1995; Simon, 1990). For example, when participants are asked to press a left key to a green stimulus and a right key to a red stimulus, responses are faster for a green stimulus at a left location and for a red stimulus...
at a right location (in spatially corresponding conditions) than for a green stimulus at a right location and a red stimulus at a left location (in spatially noncorresponding conditions; e.g., Roswarski & Proctor, 1996).

There are, however, conditions where the standard Simon effect does not occur (Ansorge & Wühr, 2004; Buhlmann, Umiltà, & Wascher, 2007; Hommel, 1993, 1996; Stoffer, 1991; Valle-Inclán & Redondo, 1998; Wühr, Biebl, & Ansorge, 2008). For example, whereas a Simon effect is regularly observed in choice-response tasks (CRTs) where participants choose between a left or right response, in go/no-go tasks the Simon effect is substantially reduced (Callan, Klisz, & Parsons, 1974) or eliminated (Ansorge & Wühr, 2004). In a typical go/no-go task, participants press a left (or right) key to one stimulus and refrain from responding to another stimulus. Given that even in the go/no-go task the variation of horizontal stimulus location relative to horizontal response location produces spatially corresponding (i.e., left–left) and spatially noncorresponding (i.e., left–right) conditions, one might expect to observe the Simon effect. The fact, however, that the Simon effect is reduced or absent in go/no-go tasks indicates that this task lacks a critical condition for the Simon effect.

Some authors argued that the Simon effect is reduced or absent in go/no-go tasks because this task does not require a response selection, the presumed locus of spatial S–R correspondence effects (e.g., Callan et al., 1974). This account, however, is inconsistent with observations on the conditions for observing the Simon effect in go/no-go tasks. In particular, Ansorge and Wühr (2004, Exp. 3) failed to observe a Simon effect in a go/no-go task (i.e., green stimulus—press left key; red stimulus—do not press left key), when participants performed the go/no-go task before a CRT that required participants to choose between a left and a right response on the basis of the same set of stimulus colours as those used in the go/no-go task. In contrast, Ansorge and Wühr (2004, Exp. 4) observed a significant Simon effect in a go/no-go task, when the same participants performed the go/no-go task after the CRT. Obviously, it makes no sense to assume that in a go/no-go task response selection is involved when performed after a CRT but not when performed before the CRT.

With their response-discrimination account, Ansorge and Wühr (2004) proposed a different explanation for the effects of task order on the observation of the Simon effect in the go/no-go task. The response-discrimination account argues that the Simon effect arises when participants use the location features for representing and discriminating responses in working memory (WM). This regularly occurs in two-choice tasks, when responses vary in location. However, location is less useful for discriminating the possible responses in a go/no-go task because both behavioural alternatives (e.g., pressing the left key versus not pressing the left key) are related to the same location. Thus, it is likely that participants usually use nonspatial features for representing the responses in a go/no-go task (e.g., move the finger on the key vs. not move the finger on the key), unless the go response was also required in a preceding CRT. In this latter case, participants transfer the S–R rule including a reference to response location (e.g., green stimulus—press left key) from the CRT to the go/no-go task, providing the necessary conditions for a Simon effect in the go/no-go task.

The main purpose of the present study is to systematically test our hypothesis that transfer of response representations by their location codes from a CRT to the go/no-go task is necessary for the Simon effect in the go/no-go task. Obviously, with the go/no-go task performed before the CRT, as in Experiment 3 of Ansorge and Wühr (2004), transfer of response representations from the CRT to the go/no-go task is impossible, preventing the Simon effect in the go/no-go task. In contrast, with the CRT performed before the go/no-go task, the likelihood of response-code transfer from the CRT to the go/no-go task should depend upon the similarity between the two tasks. In particular, the likelihood of transfer should be largest when (a) the CRT is performed before the go/no-go task, (b) the same set of stimulus colours is used in both
tasks, and (c) the mapping of stimulus colour onto response location is preserved. These conditions were met in Experiment 4 of Ansorge and Wühr (2004), providing the prerequisites for a full-blown Simon effect in a go/no-go task.

In the present four experiments, we investigated how the likelihood of transferring response-location representations from the CRT affected the Simon effect in the go/no-go task: From Experiment 1 to Experiment 4, we systematically increased the likelihood for a transfer of response-location representations from the CRT to the go/no-go task (cf. Table 1). In Experiment 1, the likelihood for transfer was zero because the go/no-go task was performed before the CRT (cf. Experiment 3 of Ansorge & Wühr, 2004). In contrast, in Experiments 2–4, participants performed the CRT before the go/no-go task, providing the first precondition for a Simon effect in the go/no-go task. In Experiment 2, however, the set of stimulus colours differed between the two tasks (i.e., yellow and magenta in the CRT, green and red in the go/no-go task), rendering transfer of a response representation (or S–R rule) from the CRT to the go/no-go task unlikely. Thus, we expected a Simon effect in the CRT but not in the go/no-go task of Experiment 2. In Experiment 3, the same set of colours was used in both tasks (i.e., green and red), but the mapping of stimulus colours to response location(s) changed between the tasks. This set-up prevents transfer of a particular S–R rule from the CRT to the go/no-go task, but transfer of a more general set to represent responses by their locations might occur. Thus, a small Simon effect might be expected in the go/no-go task of Experiment 3. Finally, in Experiment 4 preservation of the same set of colours (magenta and yellow) and mappings of stimulus colours to response locations across tasks provided the optimal conditions for transfer of specific S–R rules from the CRT to the go/no-go task. Thus, we expected to observe the Simon effect in the go/no-go task of Experiment 4.

In addition to testing the transfer hypothesis, in all experiments we analysed the Simon effect as a function of overall reaction time (RT). To that end, separately for each participant and experimental condition, the latencies of correct responses are vincentized—that is, rank ordered (with ties being assigned an averaged rank over the values concerned) and grouped into equally spaced quantiles (Ratcliff, 1979). Then, mean RTs for each condition and quantile are calculated. The reason for analysing the Simon effect as a function of RT is that several studies found the Simon effect with horizontally arrayed stimulus and response locations among the faster responses but not among the slower responses (e.g., Hommel, 1994; Wascher, Schatz, Kuder, & Verleger, 2001; Wiegand & Wascher, 2005; Wühr & Ansorge, 2007). Due to this RT function of the Simon effect, separately testing for the Simon effect among faster and slower responses provides a more exhaustive test for our hypothesis that the Simon effect is absent in the go/no-go task if transfer of response representations by their locations from a preceding CRT is impossible. In other words, with a mere analysis of the Simon effect across fast and slow responses, a small short-lived Simon effect among the fast responses might go (and previously might have gone) undetected.

**EXPERIMENT 1**

The purpose of Experiment 1 was to replicate our failure to observe a Simon effect in a go/no-go task (cf. Experiment 3 of Ansorge & Wühr, 2004) when transfer of response representations from a preceding CRT is impossible. To prevent transfer of the S–R rule or response-location representations from a CRT to the go/no-go task, participants performed the go/no-go task before the CRT (cf. Table 1). In the go/no-go task of Experiment 1, each participant operated only one key at a particular (left or right) location, pressing that key to one stimulus colour (e.g., green) and refraining from the key press to another stimulus colour (e.g., red). Varying the horizontal location of the stimulus produced spatially corresponding and spatially noncorresponding conditions in the go/no-go task, rendering the Simon effect possible.
Table 1. Schematic overview of the four experiments in the present study

<table>
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<tr>
<th>Task</th>
<th>First task</th>
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<th>Likelihood of transfer</th>
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<td>Example of S–R mapping</td>
<td>Example of S–R mapping</td>
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<td>Experiment 1</td>
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<td>CRT</td>
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<td>Experiment 2</td>
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<td>Experiment 3</td>
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<td>Experiment 4</td>
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<td>High</td>
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Note: S–R = stimulus-response. CRT = choice-response task. RT = reaction time. Simon effects were computed by subtracting performance in noncorresponding from performance in corresponding conditions.

*p < .05 (significant difference).
in theory. But when both actions in the go/no-go task refer to the same location (e.g., press the left key vs. do not press the left key) it is unlikely that participants use response location for representing the two actions in WM because location is not suited for discriminating between them. Moreover, performing the go/no-go task before the CRT made any transfer of S–R rules including response location or transfer of a more general set to include location in the WM representation of the responses impossible.

In contrast to our previous study, in which we only analysed the Simon effect in mean RTs, we now analysed it at eight different RT levels (i.e., octiles of the RT distribution). This analysis allows detecting whether a short-lived Simon effect occurs in the very fast responses, or whether a negative Simon effect in the slow responses counteracts a positive Simon effect in the fast responses.

**Method**

**Participants**

A total of 16 students (10 female) with a mean age of 27 years participated in Experiment 1. Participants in this and the following experiments had normal or corrected-to-normal vision, were paid for their participation, and were mostly students at Bielefeld University, Germany. One participant of Experiment 1 was excluded because he did not receive the same colour-response assignment in the two tasks.

**Apparatus**

Participants sat 135 cm in front of a computer screen in a sound-attenuated, electrically shielded, and dimly lit room. Response keys for the left and right index fingers were mounted to the front ends of the arm rests, so that the participant’s fingers rested conveniently on the response buttons. RT was measured to the nearest millisecond from the onset of the target stimulus.

**Stimuli and procedure**

A trial started with the presentation of three grey disks (each with a diameter of 1°), one disk at the centre of the screen and two disks 3.77° lateral of the centre, one on the left and one on the right. The three grey disks were presented for 800, 1,000, or 1,200 ms, with the length of the fixation display varying randomly from trial to trial. Next, one of the disks changed its colour. The colour change was equally likely to occur at each of the three positions. In CRT trials, the colour disk was the target; it was green in half of the trials and red in the other half of the trials. In the go/no-go trials, the coloured disk was equally likely to be the target or a no-go stimulus: If green was the target colour, the no-go stimulus was red, and if red was the target colour, the no-go stimulus was green. All colours were equated for luminance (by measurement with Minolta Chroma Meter CS-100). The coloured disk was presented until the response or for a maximum of 1 s. Trials in which the participant made an error or in which RT exceeded 1 s were repeated at a later pseudorandom position within the block. In case of an error or an RT exceeding 1 s, participants received written feedback on the screen that they had pressed the wrong key or had responded too slowly, respectively.

Two types of tasks were used in separate consecutive blocks. In the first block a go/no-go task was administered, and half of the participants responded to a green target and withheld their response to a red stimulus. The mapping of stimulus colours to the go and no-go conditions, respectively, and the use of the left or right key for the go response were counterbalanced across participants. In the second block a CRT was administered, and half of the participants responded to green targets with a left keypress and to red targets with a right keypress. The other half of the participants received the reverse S–R mapping. Participants used the same hand for their responses to the go target of the go/no-go task as for the same colour target in the CRT. For instance, a participant that had to press the right key to a green stimulus in the go/no-go task also had to press the right key in response to a green stimulus in the subsequent CRT.

**Design**

The main dependent variables in both tasks were RTs of correct responses and error rates (ERs).
The RT analyses in both tasks were based on a two-factorial 3 × 8 design, with S–R correspondence (corresponding, neutral, or noncorresponding) and octile (1st to 8th quantile of the RT distribution) as variables with repeated measurement. Error rates were only analysed as a function of S–R correspondence because low error rates were expected, and errors do not linearly and uniformly relate to response latencies: Fast responses should be especially prone to the erroneous impact of the irrelevant location while factors such as the failure to perceive the stimulus or to retrieve the correct S–R mapping should increasingly contribute to errors among the slower responses. Finally, to test for the expected interaction between the effects of spatial S–R correspondence and the type of task (go/no-go vs. CRT), we planned an analysis of variance (ANOVA) on correct mean RTs of go responses and those responses in the CRT that were performed with the same hand as the go response.

Within each block, the two colours and the three positions of the colour disk were presented equally often in a pseudorandom order. Each participant received 80 trials for each combination of 3 S–R correspondence conditions and 2 stimulus colours: altogether 480 trials in the go/no-go task and another 480 trials in the CRT. Participants were allowed to take a rest whenever they wanted, by pressing both response keys simultaneously between two consecutive trials.

Results

Go/no-go task
Less than 1.0% of the responses from the go/no-go task were excluded because they were faster than 100 ms. Correct RTs in the go/no-go task were analysed in a two-factorial ANOVA with S–R correspondence and octile as within-participants variables (see also Figure 1). There was a significant main effect of S–R correspondence, \( F(2, 28) = 26.96, p < .01 \). RT was lower in corresponding (456 ms) and neutral (455 ms) than in noncorresponding (480 ms) conditions (both \( p < .01 \), but neutral and corresponding RTs did not differ. Moreover, there was a tendency toward a significant S–R Correspondence × Octile interaction, \( F(14, 196) = 2.54, p = .07 \) (Greenhouse–Geisser corrected). The interaction was due to the well-known decrease of the Simon effect with increasing RT. The net Simon effect (noncorresponding RT – corresponding RT) was significant among the faster responses (1st–7th octile), all \( t(14) > 2.60, \ all \ p < .05, \ Bonferroni \ corrected \), but not among the slower responses (8th octile), \( t(14) < 1.00, \ Bonferroni \ not \Bonferroni \ corrected \). This pattern of results was complementary to a significant slowing of corresponding RTs relative to neutral RTs only among the slowest responses (8th octile), \( t(14) = 2.57, \ p < .05, \ Bonferroni \ corrected \), but not among the faster
responses (1st–7th octile), all ts(14) < 1.50, all ps > .16; uncorrected.

A one-factorial ANOVA on ERs showed a significant main effect of S–R correspondence, \( F(2, 28) = 14.08, p < .01 \). ER in the noncorresponding condition (6.2%) was significantly higher than that in corresponding (3.9%) and neutral conditions (3.7%), both ps < .05.

Comparison of Simon effect in RTs of go/no-go task and CRT

A three-way ANOVA with the variables S–R correspondence (corresponding vs. noncorresponding), task (go/no-go task vs. CRT), and octile (1st–8th) on correct mean RTs of the same key responses in the go/no-go task and the CRT revealed a significant interaction between S–R correspondence and task, \( F(1, 14) = 9.29, p < .01 \), confirming the presence of a Simon effect in the CRT and its absence in the go/no-go task. In addition, the ANOVA showed significant main effects of S–R correspondence, \( F(1, 14) = 14.11, p < .01 \), and of task, \( F(1, 14) = 118.92, p < .01 \). RTs were shorter in corresponding (416 ms) than in noncorresponding (429 ms) conditions, and RTs were shorter in the go/no-go task (385 ms) than in the CRT (461 ms). Finally, a significant Task × Octile interaction, \( F(7, 98) = 24.81, p < .01 \) (Greenhouse–Geisser corrected), reflected a steeper slope of the RT function in CRT than in go/no-go conditions (compare to Figure 1). The remaining interactions were not significant, both Fs < 1.20, both ps > .32.
Discussion

Experiment 1 revealed two interesting results. First, results replicated that the same participants exhibit the Simon effect in a CRT, but not in a go/no-go task, when the go/no-go task is performed before the CRT (cf. Experiment 3 of Ansorge & Wühr, 2004): In addition, a careful analysis of the Simon effect as a function of response speed demonstrated the absence of the Simon effect across the complete range of go response latencies. This finding is consistent with the response-discrimination account of the Simon effect because the Simon effect should arise (a) if response location is useful for response discrimination (i.e., in the CRT), whereas the Simon effect should be absent when response location is useless for response discrimination (i.e., in the go/no-go task), and (b) if transfer of response representations (in terms of location) from the CRT to the go/no-go task is impossible.

The second finding of Experiment 1 was the typical decline of the horizontal Simon effect in the CRT with increasing RT, reflected in an almost significant S–R Correspondence × Octile interaction. That is, the difference between corresponding and noncorresponding RTs decreased when RT increased. In contrast, the difference between corresponding and neutral RTs increased from intermediate to slower RTs (cf. Figure 1). This pattern of results may indicate either the passive decay (cf. Wascher et al., 2001) or the active suppression of stimulus-based response activation (e.g., Ridderinkhof, 2002; Shiu & Kornblum, 1996).

EXPERIMENT 2

Experiment 2 investigated whether participants will transfer a general set for representing their responses by their respective spatial locations from a CRT to a subsequent go/no-go task, giving rise to the Simon effect in the latter task. To that end, participants made the CRT before the go/no-go task. However, different sets of colours were used for the two tasks (i.e., yellow and magenta in the CRT; green and red in the go/no-go task). This prevents transfer of a particular S–R rule including response location (e.g., if yellow stimulus, then press left key) from the CRT to the go/no-go task. On the one hand, it is possible that the use of location for response discrimination in the CRT induces participants to include location in their response representations for the go/no-go task as well, even though location is unsuited for response discrimination in the go/no-go task. If so, we should observe a significant Simon effect in the go/no-go task of Experiment 2. On the other hand, however, the necessity to represent the S–R rule anew prior to the go/no-go task for each upcoming stimulus makes transfer of response representations from CRT to go/no-go task unlikely.

Method

Participants

A total of 16 students (8 female) with a mean age of 27 years took part in Experiment 2; 1 participant was excluded due to technical error during data acquisition.

Apparatus and stimuli

These were the same as those in Experiment 1, except that two additional colours (yellow and magenta) were used.

Procedure

The procedure was the same as that for Experiment 1, except for the following. First, all participants performed the CRT before the go/no-go task. Second, different sets of colours were used in the two tasks. Participants discriminated between yellow and magenta stimuli in the CRT; they discriminated between green and red stimuli in the go/no-go task. Third, we made electroencephalography (EEG) measurements, but as the data are not reported here the procedure is not detailed.

Design

The experimental design for both tasks was the same as that in Experiment 1.
Results

**CRT**
Responses faster than 100 ms were discarded (<1.0%). Mean RTs from correct responses are shown in Figure 2. Correct RTs from the CRT were subjected to a 3 × 8 ANOVA, with S–R correspondence and octile as within-participant variables. There was a significant main effect of S–R correspondence, \(F(2, 28) = 25.39, p < .01\). Responses were significantly faster in corresponding (461 ms) and neutral (458 ms) than in noncorresponding (482 ms) conditions (both \(p < .01\)). The S–R Correspondence × Octile interaction was not significant, \(F(14, 196) = 1.56, p = .21\) (Greenhouse–Geisser corrected).

A one-factorial ANOVA of ERs failed to reveal a significant effect of S–R correspondence, \(F(2, 28) = 1.97, p = .16\). ERs were 3.3% in the corresponding condition, 2.9% in the neutral condition, and 4.3% in the noncorresponding condition.

**Go/no-go task**
Responses faster than 100 ms were discarded (<1.0%). Mean RTs from correct responses are shown in Figure 2. A two-factorial ANOVA was conducted on correct RTs, with S–R correspondence and octile as within-participant variables. There was a significant main effect of S–R correspondence, \(F(2, 28) = 14.04, p < .01\). Responses were faster in neutral (404 ms) than in corresponding (423 ms) and noncorresponding (424 ms) conditions (both \(p < .01\)). The most important result was the absence of a residual Simon effect (noncorresponding RT – corresponding RT = 1 ms).

![Figure 2. Results of Experiment 2: Reaction time (RT) as a function of stimulus–response (S–R) correspondence (corresponding, neutral, or noncorresponding), octile of the RT distribution (1st–8th), and task (CRT, or go/no-go task). CRT = choice reaction task.](image-url)
The interaction between S–R correspondence and octile was far from significant, $F < 1.00$.

Misses amounted to 0.3% in corresponding, 0.2% in neutral, and 0.9% in the noncorresponding conditions. The effect of S–R correspondence was not significant in misses, $F(2, 28) = 1.04, p = .37$. False alarms amounted to 0.7% in corresponding, 0.7% in neutral, and 1.6% in the noncorresponding conditions. The effect of S–R correspondence was not significant in false alarms, $F(2, 28) = 2.56, p = .10$.

**Comparison of Simon effects in RTs of go/no-go task and CRT**

RTs from responses given with the same hand in both tasks were compared in a three-factorial ANOVA with S–R correspondence (corresponding vs. noncorresponding), task (CRT vs. go/no-go task), and octile (1st–8th) as within-participant variables. The ANOVA revealed a significant S–R Correspondence × Task interaction, $F(1, 14) = 18.56, p < .01$, reflecting the presence of a Simon effect in the CRT and its absence in the go/no-go task. We also found significant main effects of S–R correspondence, $F(1, 14) = 9.48, p < .01$, reflecting faster responses under corresponding (442 ms) than noncorresponding conditions (454 ms), and of task, $F(1, 14) = 22.28, p < .01$, with lower RTs in the go/no-go task (423 ms) than in the CRT (473 ms), and a significant Task × Octile interaction, $F(7, 98) = 7.76, p < .01$ (Greenhouse–Geisser corrected), reflecting a steeper slope of the RT function in the CRT than in the go/no-go task (see Figure 2). The remaining interactions were not significant, both $F$s < 2.00, both $p$s > .17 (Greenhouse–Geisser corrected).

**Discussion**

Experiment 2 showed that participants having a significant Simon effect in the CRT failed to exhibit a Simon effect in the go/no-go task, even though the CRT preceded the go/no-go task. Thus, performing a CRT before the go/no-go task may be a necessary condition for the Simon effect in the latter task, but it is obviously not a sufficient condition. The use of different stimulus colours in the two tasks prevented transfer of a particular S–R rule (e.g., if yellow stimulus, then press left key) from the CRT to the go/no-go task. However, the order of tasks would have allowed for the transfer of a general set including location in WM response representations, providing a representational basis for the Simon effect in the go/no-go task. The failure to observe the Simon effect in the go/no-go task, however, suggests that transfer of such a general set did not occur in Experiment 2.

Besides, the interaction between S–R correspondence and octile in the CRT that we observed in Experiment 1 was not significant in the present experiment. This is probably due to an insufficient power of the present ANOVA to reveal the effect: Looking at Figure 2, a diminished difference between corresponding and noncorresponding RTs was evident among the slowest CRT responses of the present experiment too.

**EXPERIMENT 3**

Experiment 3 tested whether participants transfer a set to include location in the WM representation of their responses if a CRT preceded the go/no-go task and whether the same set of stimulus colours (i.e., green and red) was used in both tasks. In Experiment 3, we still prevented the transfer of a particular S–R rule including response location (e.g., if green stimulus, then press left key) from the CRT to the go/no-go task. This was done by changing the colour to response location assignment between the tasks: If the participant had to press a left key to the green stimulus and the right key to the red stimulus in the CRT, the same participant had to press the left key to the red stimulus and to refrain from responding to the green stimulus in the subsequent go/no-go task. We reasoned that remapping colours to response locations between tasks urges participants to explicitly represent the new response location for the go/no-go task in WM in order to counteract the now invalid, but well-practised, colour–location association from the CRT. The fact that the same colour must be...
associated with opposite locations in Experiment 3 might prevent the observation of a Simon effect in the go/no-go task of this experiment.

Method

Participants
A total of 16 students (8 female) with a mean age of 26 years took part in Experiment 3.

Apparatus, stimuli, and procedure
These were the same as those in Experiment 2, with two exceptions. First, the same set of stimulus colours (i.e., red and green) was used in both tasks. Second, for each participant, we changed the mapping of stimulus colour to response location between the CRT and the subsequent go/no-go task (cf. Table 1).

Results

CRT
Responses faster than 100 ms were discarded (<1.0%). Mean RTs from correct responses are depicted in Figure 3. RTs were subjected to a $3 \times 8$ ANOVA with S–R correspondence and octile as within-participant variables. There was a significant main effect of S–R correspondence, $F(2, 30) = 24.66, p < .01$. Responses were faster in corresponding (449 ms) and neutral (450 ms) than in noncorresponding (469 ms) conditions ($p < .01$). The S–R Correspondence × Octile interaction was significant, $F(14, 210) = 3.29, p < .05$ (Greenhouse–Geisser corrected). In accordance with Experiment 1, the interaction reflected the presence of the Simon effect.

Figure 3. Results of Experiment 3: Reaction time (RT) as a function of stimulus–response (S–R) correspondence (corresponding, neutral, or noncorresponding), octile of the RT distribution (1st–8th), and task (CRT, or go/no-go task). CRT = choice reaction task.
Go/no-go task
Responses faster than 100 ms were discarded (<1.0%). Mean RTs from correct responses observed in the go/no-go task are shown in Figure 3. Correct RTs were subjected to a 3 × 8 ANOVA with S–R correspondence and octile as within-participant variables. There was a significant main effect of S–R correspondence, $F(2, 30) = 4.53$, $p < .05$. Responses were faster in neutral (395 ms) than in noncorresponding conditions (407 ms; $p < .05$), but not than in corresponding conditions (415 ms). Most importantly, the small net Simon effect (noncorresponding RT – corresponding RT = 6 ms) failed to reach significance. The two-way interaction was not significant either, $F < 1.00$, $p = .90$.

Misses amounted to 0.3% in corresponding, 0.4% in neutral, and 0.6% in noncorresponding conditions. False alarms amounted to 1.1% in corresponding, 1.3% in neutral, and 1.1% in the noncorresponding conditions. The effects of S–R noncorrespondence were not significant either in misses or in false alarms, both $F$s < 1.00.

Comparison of Simon effects in RTs of go/no-go task and CRT
Mean correct RTs from responses given with the same hand in both tasks were compared in a three-factorial ANOVA with S–R correspondence (corresponding vs. noncorresponding), task (CRT vs. go/no-go task), and octile (1st–8th) as within-participant variables. The ANOVA revealed a significant S–R Correspondence × Task interaction, $F(1, 15) = 9.26$, $p < .01$, reflecting a Simon effect in the CRT (noncorresponding RT – corresponding RT = 19 ms) and its absence in the go/no-go task (noncorresponding RT – corresponding RT = 6 ms). In addition, we found significant main effects of S–R correspondence, $F(1, 15) = 20.83$, $p < .01$, with lower RTs under corresponding (422 ms) than under noncorresponding (437 ms) conditions, and of task, $F(1, 15) = 11.65$, $p < .01$. As before, responses were faster in the go/no-go task (404 ms) than in the CRT (455 ms). Also in agreement with Experiments 1 and 2, RT increases were larger for the CRT than for the go/no-go task (see Figure 3), as reflected in a significant Task × Octile interaction, $F(7, 105) = 9.80$, $p < .01$ (Greenhouse–Geisser corrected). The other interactions were not significant, both $F$s < 1.40, both $p$s > .25.

Discussion
The most important result of Experiment 3 is that we still failed to observe a significant Simon effect in a go/no-go task that followed a CRT, when the same set of stimulus colours was used in both tasks, but the mapping of stimulus colours to response locations was changed between tasks. This finding contrasts nicely with the results of Ansorge and Wühr’s (2004) Experiment 4 where the use of the same sets of stimulus colours sufficed to produce a Simon effect in a go/no-go task performed after a CRT. From these findings, we can conclude that (a) performing a CRT before a go/no-go task and (b) using the same sets of stimulus colours in both tasks are both necessary and yet not sufficient conditions for producing the Simon effect in the go/no-go task. In contrast, preserving the mapping of stimulus colours to response locations across tasks seems to be a necessary condition for the Simon effect in the go/no-go task.

Although the Simon effect observed in the go/no-go task in Experiment 3 was statistically not significant, it was numerically larger (i.e., 6 ms) than that in Experiment 2 (i.e., 1 ms). We believe that the small increment of the Simon effect resulted
from the use of the same set of colours during the CRT and the go/no-go task. Moreover, we think that remapping the same colours onto new locations between the CRT and the go/no-go task urged participants to include location into their WM representations of the go response and that opposing effects from the old and the new colour–location associations almost cancelled each other out. Interestingly, the numerical trend for a Simon effect in the expected direction suggests that the new colour–location association was somewhat stronger than the old one.

A final result concerned the time-course of the Simon effect in the CRT. Consistent with Experiment 1, we observed a decrease of the Simon effect with increasing RT. In contrast to Experiment 1, however, RTs in corresponding and in neutral conditions remained indistinguishable across the range of RT quantiles.

EXPERIMENT 4

Experiment 4 finally aimed to provide both necessary and sufficient conditions for the Simon effect in a go/no-go task. Therefore, (a) the CRT was performed before the go/no-go task, (b) the same set of stimulus colours (i.e., yellow and magenta) was used in both tasks, and (c) the mapping of stimulus colour onto response location was preserved. When, for example, a participant in Experiment 4 had pressed the left key to a yellow stimulus and the right key to a magenta stimulus in the CRT, the same participant pressed the left key to the yellow stimulus and refrained from responding to the magenta stimulus in the subsequent go/no-go task. We expected to observe a Simon effect of about similar size in the CRT and in the subsequent go/no-go task.

Method

Participants
A total of 16 students (7 female) with a mean age of 27 years took part in Experiment 4. The results from 2 participants were excluded because the colour–response mapping was erroneously changed from the CRT to the go/no-go task for these participants.

Apparatus, stimuli, and procedure
These were the same as those in Experiment 2's go/no-go task. Yet we used the same set of colours in CRT and go/no-go task and took care that the participants preserved the mapping of stimulus colour to response location between the tasks (cf. Table 1).

Results

CRT
Responses faster than 100 ms were discarded (<1.0%). Correct mean RTs from the CRT are shown in Figure 4. Mean RTs of correct responses were subjected to a 3 × 8 ANOVA with S–R correspondence and octile as within-participant variables. There was a significant main effect of S–R correspondence, \( F(2, 26) = 30.77, p < .01 \). Responses were faster in corresponding (453 ms) and neutral (445 ms) than in noncorresponding (471 ms) conditions (both \( p < .01 \)), and they were faster in neutral than in corresponding conditions too (\( p < .05 \)). There was also a significant two-way interaction between S–R correspondence and octile, \( F(14, 182) = 2.77, p < .01 \). One aspect of the interaction consisted in the selective presence of significant Simon effects (noncorresponding RT – corresponding RT) among faster responses—1st–5th octiles; all \( t(13) > 3.00 \), all \( p < .05 \), Bonferroni corrected—and their absence among slower responses: 7th and 8th octiles; all \( t(13) < 1.50 \), all \( p > .17 \), uncorrected.

Another aspect of the interaction consisted in an increase of the RT difference between neutral and corresponding conditions. Neutral RTs were not different from corresponding RTs among faster responses (1st–4th octiles; all \( t < 1.00 \)) but neutral RTs were significantly faster than corresponding RTs among slower responses: 7th and 8th octiles, both \( t(13) > 3.10 \), both \( p < .05 \).

A one-factorial ANOVA revealed an almost significant effect of S–R correspondence on ERs, \( F(2, 26) = 3.26, p = .06 \). ER was lower under corresponding (2.1%) than under noncorresponding...
conditions (3.4%), and ER in the neutral condition (2.6%) was of intermediate size.

**Go/no-go task**

Responses faster than 100 ms were discarded (<1.0%). Mean correct RTs from the go/no-go task are depicted in Figure 4. Mean RTs of correct responses were subjected to a 3 × 8 ANOVA with S–R correspondence and octile as within-participant variables. There was a significant main effect of S–R correspondence, $F(2, 26) = 22.98, p < .01$. Responses were faster in neutral (399 ms) than in corresponding (414 ms) and noncorresponding (426 ms) conditions (both $ps < .05$). Most importantly, a significant net Simon effect of 12 ms (noncorresponding RT – corresponding RT) was also observed ($p < .05$, one-tailed). The two-way interaction was not significant, $F(14, 182) = 1.58, p = .22$ (Greenhouse–Geisser corrected).

Misses amounted to 1.1% in corresponding, 0.8% in neutral, and 0.9% in noncorresponding conditions. False alarms amounted to 1.2% in corresponding, 0.7% in neutral, and 1.2% in the noncorresponding conditions. The effects of S–R correspondence were not significant either in misses or in false alarms, both $Fs < 1.00$.

**Comparison of Simon effects in RTs of go/no-go task and CRT**

Mean correct RTs from responses given with the same hand in both tasks were compared in a three-factorial ANOVA with S–R correspondence (corresponding vs. noncorresponding), task (CRT, or go/no-go task), and RT octile (1st–8th) as within-participant variables. There was a significant main effect of S–R correspondence, $F(2, 26) = 13.18, p < .01$. Responses were faster in neutral (393 ms) than in corresponding (418 ms) and noncorresponding (429 ms) conditions (both $ps < .05$). Most importantly, a significant net Simon effect of 12 ms (noncorresponding RT – corresponding RT) was also observed ($p < .05$, one-tailed). The two-way interaction was not significant, $F(14, 182) = 1.58, p = .22$ (Greenhouse–Geisser corrected).
vs. no-go task), and octile (1st–8th) as within-participant variables. In contrast to the results of Experiments 1–3, we now failed to observe a significant interaction between S–R correspondence and task, $F(1, 13) = 1.05, p = .33$. This result confirmed that the Simon effect in the CRT (noncorresponding RT – corresponding RT = 18 ms) and in the go/no-go task (noncorresponding RT – corresponding RT = 12 ms) were of comparable size in Experiment 4. In addition, the main effects of S–R correspondence, $F(1, 13) = 19.80, p < .01$, and of task, $F(1, 13) = 32.15, p < .01$, turned out to be significant. RTs were shorter in corresponding (435 ms) than in noncorresponding (450 ms) conditions, and RTs were shorter in the go/no-go task (420 ms) than in the CRT (464 ms). None of the remaining interactions was significant, all $Fs < 1.50$, all $ps > .21$.

**Comparison of Simon effects in RTs of go/no-go tasks between Experiments 3 and 4**

Mean correct RTs from the go/no-go tasks of Experiments 3 and 4 were also compared in an ANOVA with the two within-participant variables S–R correspondence (corresponding vs. neutral vs. noncorresponding) and octile (1st–8th) and the between-participants variable experiment (3 vs. 4). This ANOVA testified to different Simon effects in the go/no-go tasks of Experiments 3 and 4 by way of a significant interaction between S–R correspondence and experiments, $F(2, 56) = 3.73, p < .05$.

**Discussion**

The most important result of Experiment 4 was that equivalent net Simon effects can be observed in a CRT and in a go/no-go task if (a) the CRT is performed before the go/no-go task, (b) the same set of stimulus colours (i.e., yellow and magenta) is used in both tasks, and (c) the mapping of stimulus colour onto response location is preserved. In other words, these three conditions are both necessary and sufficient for the Simon effect in a go/no-go task. In our view, this observation reflects that the conditions of Experiment 4 allow participants to transfer an S–R rule representation that maps a stimulus colour to a response location from the CRT to the go/no-go task. In other words, even though it is impossible to discriminate the go response from the no-go response on the basis of different locations, the location code intrudes from the CRT to the go/no-go task by means of an inert WM representation, and this provides the basis for a Simon effect in the go/no-go task.

This is not to say that other factors do not contribute to the likelihood of a transfer of the Simon effect from the CRT to the go/no-go task. In particular, it is our contention that interindividual differences between the exact functions relating the Simon effect to the overall RT, as well as the different individual amounts of slowing down of the responses in the CRT (relative to the go/no-go task), moderate the individual amount of the transfer of the Simon effect from the CRT to the go/no-go task.

Even between conditions, the time-course of the effects differed: We observed a significant decay of the Simon effect in the CRT, but not in the go/no-go task. Inspection of Figures 4 and 5 suggests that there was actually no decrease of the Simon effect with increasing RT in the go/no-go task of Experiment 4, although a follow-up ANOVA failed to confirm a significant interaction (between task and octile), and, thus, the following interpretation of the different time-courses should be considered with caution. In the CRT definitely the usual pattern of an RT-dependent decrement of the Simon effect was observed. Failure to observe a decay of the Simon effect in the go/no-go task may be (partly) due to the faster RT level in the go/no-go task than in the CRT: Participants typically responded about 50–60 ms faster to the go stimulus in the go/no-go task than to the choice stimulus in the CRT. Thus, to some extent Simon effects are present for the slower responses in the go/no-go task because these responses had RTs comparable to intermediate responses in the CRT (where Simon effects were also present). However, it is also possible that some additional factor accounted for (part of) the differences between RT functions of the Simon effect in the go/no-go task and in the
The main purpose of the present research was to explore the necessary and sufficient conditions for observing effects of irrelevant spatial S–R correspondence (i.e., the Simon effect) in go/no-go tasks. In a typical go/no-go task, participants perform a spatial response to one stimulus (i.e., they press the left key with the left hand to the green stimulus) and refrain from responding to another stimulus. Variations in spatial stimulus location relative to spatial response location produce corresponding (e.g., green stimulus at left location) and noncorresponding (e.g., green stimulus at right location) S–R conditions, providing the prerequisites for computing the Simon effect. However, previous authors disagreed about whether the Simon effect should actually occur in go/no-go tasks. On the one hand, Callan et al. (1974) proposed that the Simon effect should be absent, or significantly reduced compared to the Simon effect in a CRT, because the former task requires only minimal or no response selection, which is seen as the origin of the Simon effect (cf. Proctor & Vu, 2006). On the other hand, Shi and Kornblum (1999) predicted the Simon effect in the go/no-go tasks because they attributed the effect to strongly automatic, stimulus-based response activation on the basis of “hard-wired” S–R associations.

Our previous research suggested that the Simon effect in the go/no-go task depends upon having participants perform a CRT before administering the go/no-go task (Ansorge & Wühr, 2004), which appears inconsistent with both proposals. Performing the go/no-go task before or after a CRT should not alter the response-selection requirements of this task. Similarly, performing the go/no-go task before or after a CRT should not affect hard-wired response activation on the basis of stimulus location. In contrast, our own account claims that the Simon effect requires the inclusion of location codes in the WM representation of the possible responses in a task, and this requirement is usually not met in a go/no-go task because location does not discriminate between the different responses. If, however, participants perform a CRT before the go/no-go task they can transfer a general set of representing responses in terms of their locations, or they can transfer a particular S–R rule including location from the CRT to the go/no-go task. Our previous study did not allow deciding between these possibilities because the mapping of stimulus colour on response location was preserved between CRT and subsequent go/no-go task.

The results of our present study showed that (a) performing the CRT before the go/no-go task (e.g., Experiment 2) and (b) using the same sets of stimulus colours in the CRT and the go/no-go task (e.g., Experiment 3) are not sufficient to produce the Simon effect in the latter task, if (c) the mapping of stimulus colours to response locations is changed between tasks. In this case, a careful comparison of RT distributions demonstrated the absence of the Simon effect in the complete range between fast and slow responses. In contrast, the Simon effect can be observed in a go/no-go task if the mapping of stimulus colours to response locations is preserved between tasks (Experiment 4), suggesting that the transfer of a
particular S–R rule between tasks, and not the transfer of a general set of representing responses, produces the Simon effect in the go/no-go task. Interestingly, when these conditions were met, the Simon effect in the go/no-go task was statistically equivalent to the Simon effect in the preceding CRT. Thus, the previously observed reduction of Simon effects in go/no-go tasks compared to CRT most likely resulted from averaging RTs from conditions with normal Simon effects (i.e., the go/no-go task performed after a CRT) and from conditions with null effects (i.e., the go/no-go task performed before a CRT).

The results of the present study are in perfect agreement with the response-discrimination account of the Simon effect (cf. Ansorge & Wühr, 2004; Wühr & Ansorge, 2007; Wühr et al., 2008). According to this account, the Simon effect arises between representations of stimulus location and representations of response location in WM if participants include location in their WM representation of the possible responses. We have now identified two conditions that lead to the inclusion of location (or any other spatial feature) in the WM representation of responses. The first condition is that location (or another spatial feature) allows discrimination among different responses, which is typically the case in a choice-response Simon task (e.g., Ansorge & Wühr, 2004; Wühr et al., 2008). The second condition is that participants transfer an S–R rule including response location from one task to another task, in which location does not discriminate between responses (e.g., the present study).

The results of the present study have some general implications for our understanding of the Simon effect. First, the results demonstrate that the Simon effect does not primarily hinge on the requirement to choose between responses at different locations (e.g., Callan et al., 1974; Lu & Proctor, 1995), but rather on the inclusion of location in the WM representation of the response(s) involved in a particular task. It is possible that stimulus features and their required responses are represented as event-files (cf. Hommel, Müsseler, Aschersleben, & Prinz, 2001) or in visual WM (cf. Luck & Vogel, 1997). Second, the results of the present study also demonstrate that the Simon effect does not rest on hard-wired processing (e.g., Kornblum et al., 1990; Shiu & Kornblum, 1999; Zhang, Zhang, & Kornblum, 1999; Zorzi & Umilta`, 1995) because it violates the principle that hard-wired processes should run independent of the intentions of the perceiver/actor. The results of the present investigation and our related studies, however, demonstrate that Simon effects critically depend upon the current intentions of the perceiver/actor—that is, the representation of the current task in WM.

An alternative explanation for the pattern of results observed here is that participants learned to associate particular colours with particular (response) locations during the CRT and that these associative short-term memory (STM) links were transferred to the go/no-go task and were responsible for the Simon effect in the latter task. Consistent with this possibility, some authors found that responding spatially incompatible to stimulus location in a first task reverses the Simon effect in a subsequent Simon task (e.g., Taglibue, Zorzi, Umiltà, & Bassignani, 2000). This observation has been attributed to STM links modulating long-term memory (LTM) links.

Whether STM or WM representations account for the present findings cannot be determined with certainty. However, further observations neatly dovetail with a WM account but cannot easily be understood on an STM account. For example, changing the particular spatial labels for nonspatial responses on a trial-by-trial basis can also produce a Simon effect (Wühr & Ansorge, 2007). This can be nicely understood on a WM account, for WM allows that responses are quickly and flexibly represented as is actually necessary or afforded. It is by far less clear whether and how such swift and malleable response representations could be brought about by learning associations, because under the conditions of Wühr and Ansorge (2007) there were no consistent associations between specific responses and their spatial codes. It is almost needless to add that a WM account would be also fit to explain the results of Tagliaabue et al. (2000) in the first place, too.
Another interesting question concerns the kind of “format” used in WM representations. It is possible that WM representations are relatively abstract or purely semantic. However, we certainly do not want to preclude the possibility that the WM representations accounting for the Simon effect are more sensory-like as emphasized in episodic retrieval explanations of correspondence effects (Neill, 1997).

A final interesting result concerned the time-course of the Simon effect in the go/no-go task, compared to the time-course of the Simon effect in the CRT with horizontally arrayed responses. Whereas the Simon effect in the CRT with horizontally arrayed responses tended to decrease with increasing RT in the present experiments, the Simon effect in the go/no-go task of Experiment 4 remained rather constant with increasing RT. Thus, the emerging picture is that the Simon effect decreases with increasing RT when participants discriminate between a “left” and a “right” response, regardless of whether the actual responses are spatial (e.g., Proctor, Vu, & Nicoletti, 2003; Van der Lubbe & Woestenburg, 1999; Wiegand & Wascher, 2005; the present CRT experiments) or verbal (e.g., Wühr, 2006; Wühr & Ansorge, 2007). By contrast, the Simon effect does usually not decrease with increasing RT if participants choose between responses with the left and the right hand (in uncrossed position) to stimuli at left or right locations. In contrast, according to Wascher and colleagues, nondecreasing effect functions reflect cognitive interference of codes representing stimulus and response locations.

A problem with the dual-mechanism account of Wascher and colleagues results from the fact that decreasing effect functions have also been observed when participants made verbal responses based on a left–right distinction to stimuli varying on the horizontal dimension. There is no obvious spatial anatomical mapping between horizontal stimulus locations and the verbal responses “left” and “right”.

According to an alternative account, the decay of the Simon effect with increasing RT may reflect top-down inhibition of stimulus-induced response activation (Ridderinkhof, 2002; Shiu & Kornblum, 1996). For example, Ridderinkhof proposed that stimulus-driven response activation in conflict tasks is followed by top-down inhibition of activated responses. Top-down inhibition can not only decrease and finally eliminate Simon effects with increasing RT, but can even reverse the Simon effect with very slow responses, as has sometimes been observed (e.g., Ridderinkhof, 2002). The response-suppression account has some difficulties in explaining why stimulus-based response activation is suppressed for some variants of the Simon task (i.e., those requiring a discrimination between responses referring to horizontal locations), but not in others (e.g., those requiring a discrimination between responses referring to vertical locations). To conclude, there is not yet a consistent explanation for the different time-course functions of Simon effects in different variants of the Simon task. Therefore, possibly, a third explanation holds true. According to this explanation, both RT increments and Simon effect decrements are due to increasing variances of RTs in corresponding
and noncorresponding conditions (e.g., Roswarski & Proctor, 2003). Variances, however, not only are reflecting one particular principle or mechanism but can be increased by all kinds of additional processes required in a particular condition. Depending on the exact stimuli used, for instance, perceptual factors (e.g., discrimination ability) and memory factors (e.g., capacity) could be contributing to RT variances in different amounts.

To summarize, our main results suggest that whereas participants routinely decide to use response location for representing the responses of a CRT in WM, they usually do not use response location for representing the responses of a go/no-go task in WM. However, if one of the S–R rules in a CRT happens to match the go rule in a subsequent go/no-go task, the location of that response intrudes into the WM representation of the go response, providing the necessary conditions for a Simon effect in the go/no-go task.

Thus, Simon effects do not arise from “hard-wired” S–R associations, but from interactions between stimulus-location codes and flexible response representations in WM.

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