Emergence of the go/no-go Simon effect by means of practice and mixing paradigms

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In two experiments, we tested whether the emergence of the go/no-go Simon effect could be determined by the strengthening of one specific S–R link in location-relevant trials performed right before (practice paradigm) or simultaneously (mixing paradigm) with the location-irrelevant (Simon) trials. Results showed a clear carry-over effect of the association between stimulus position and spatial response from the first task to the second one (Experiment 1) and when the two tasks were performed simultaneously (Experiment 2), even if participants were required to respond with the same key to only half of the stimuli (go/no-go tasks). We found that associative learning between the stimulus and response positions occurring during the go/no-go compatibility task, that is when location was relevant, influenced the way the go/no-go location-irrelevant task (Simon task) was performed. Our findings suggest that the STM links formed during a go/no-go spatial compatibility task are strong enough to influence the go/no-go Simon task.

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1. Introduction

In choice reaction tasks (CRT) human performance is more efficient when stimuli and responses are ipsilateral, that is, on the same side (corresponding situations), than when they are contralateral (non-corresponding situations), even if stimulus location is irrelevant for performing the task and the response has to be emitted on the basis of a non-spatial stimulus feature (e.g. color or shape). For instance, when a left key in response to a red square and a right key in response to a green square are requested, responses are faster if stimulus location is irrelevant compared to when they do not correspond. The influence of the irrelevant spatial stimulus feature on performance is known as Simon effect (Rubichi & Nicoletti, 2006; Rubichi, Nicoletti, Iani, & Umiltà, 1997; Rubichi, Nicoletti, Pelosi, & Umiltà, 2004; Simon & Rudell, 1967; for reviews, see Proctor & Vu, 2006; Rubichi, Vu, Nicoletti, & Proctor, 2006).

A large amount of evidence supports the notion that the Simon effect originates at the level of response-selection operations and is the result of the interaction between two parallel and independent processing routes connecting perception to action (e.g., De Jong, Liang, & Lauber, 1994; Kornblum, 1994): an indirect route and a direct route. According to Barber and O'Leary (1997) these two processing routes rely on different memory associations connecting stimuli and responses. When a stimulus appears, the indirect route activates the required response on the basis of task-defined associations which connect a stimulus to a specific response. These stimulus–response (S–R) associations are short-lasting and are supposed to be implemented in Working Memory (WM). The direct route activates the response that spatially corresponds to the stimulus location through pre-existing S–R associations, which are independent from instructions. These associations are supposed to be long-lasting, either genetically determined or overlearned as a result of extensive practice (see Pellicano, Iani, Borghi, Rubichi, & Nicoletti, 2010). When the two activated responses correspond, no competition arises, rather the redundancy of the same response code could generate a facilitation effect (Umiltà, Rubichi, & Nicoletti, 1999). In contrast, when they are different, the incorrect response needs to be aborted thus causing interference, as indexed by the slowing of reaction times (RTs) and the decrease in accuracy.

Normally, the Simon effect is absent (or is significantly reduced) in the go/no-go version of this task, that is, when participants are required to respond to one stimulus value. If we consider the Simon task exposed above, in the go/no-go variant participants are required to respond only to one stimulus color (e.g., red) while refraining from responding to the alternative stimulus color (e.g., green). To note, even in this case there are corresponding and non-corresponding trials since one lateralized key is associated with one colored stimulus that could randomly appear...
on the left or on the right. However, as said, the Simon effect is absent. It has been proposed that the explanation is to be found in the reduced response-selection requirements of the go/no-go version of the task. Since the response key is the same throughout the experiment, response selection processes are not engaged (e.g., Berlucchi, Crea, Di Stefano, & Tassinari, 1977; see also Lu & Proctor, 1995). According to the response-discrimination account, proposed by Ansorge and Wühr (Ansorge & Wühr, 2004, 2009; Wühr & Ansorge, 2007; Wühr et al., 2008), the Simon effect arises depending on the possibility to represent the alternative required responses. Specifically, to perform the task, participants need to represent in WM the S–R mappings specified by task instructions and to use spatial codes to discriminate between the two alternative responses. Since in the go/no-go task only one response has to be emitted, the discrimination of responses with respect to one particular spatial code is not required, and, as a consequence, no Simon effect arises.

There is, however, some evidence that a Simon effect of reduced magnitude could also arise in go/no-go versions of the Simon task (Ansorge & Wühr, 2004, 2009; Callan, Kliz, & Parsons, 1974; Dittrich, Rothe, & Klauer, 2012). For instance, Ansorge and Wühr (2004, 2009) demonstrated that, if participants were required to perform a two-choice task before the go/no-go task (Experiment 4, 2004) and the mapping of stimulus color to response location was preserved between tasks (Experiment 4, 2009), previous representations of the responses might be carried over from the first to the second task, allowing the Simon effect to emerge also in the go/no-go task. In line with the response-discrimination account, their findings were taken as an indication that participants transferred the S–R rules acquired in the two-choice task to the go/no-go task, hence creating the preconditions for the emergence of the Simon effect.

Furthermore, the Simon effect arises in a go/no-go condition also when the Simon task is shared between two participants. In the social variant of the Simon task, two individuals, sitting next to each another, perform two complementary go/no-go tasks that compose the whole task. To this end, two groups of participants were required to perform the spatial compatibility task, acquiring the S–R rules acquired in the two-choice task to the go/no-go task, hence creating the preconditions for the emergence of the Simon effect.

As already said, the Simon effect is absent when the Simon task is performed after a compatible practice, and the alternative required responses. Specifi-

2. Experiment 1

The aim of Experiment 1 was to assess whether a go/no-go spatial compatibility practice can modulate a subsequent go/no-go Simon task. To this end, two groups of participants were required to perform a go/no-go spatial compatibility practice with either a compatible or an incompatible S–R mapping. To clarify, during practice participants were required to respond to the right stimulus with the right response or to refrain from responding to the left stimulus. Participants in the compatible-practice condition were required to respond to the right stimulus with the right response, while participants in the incompatible-practice condition were required to respond to the right stimulus with the left key. If the specific S–R link that is practiced during the spatial compatibility task (that is, for example, right stimulus–right response) remains active and transfers to the subsequent Simon task (that is, red stimulus in the right position–right responses), the Simon effect should be present when the Simon task is performed after a compatible practice, and absent (or reversed) when it is performed after an incompatible practice, despite the fact that participants are required to respond with the same key to only half of the stimuli.

2.1. Method

2.1.1. Participants

Twenty-four undergraduate students (five males; one left-handed; age range: 19–25 years) participated for partial fulfillment of course credit. All were naïve to the experiment and reported having normal or corrected-to-normal vision.

2.1.2. Apparatus and stimuli

Stimuli in the spatial compatibility task were white solid squares (4.5 × 4.5 cm), whereas stimuli in the Simon task were red or green solid squares (4.5 × 4.5 cm). All stimuli were presented on a black screen, 9.5 cm to the left or to the right of a central fixation cross (1 × 1 cm). Stimulus presentation was controlled by an IBM computer. In both tasks, participants were seated in front of the screen at a viewing distance of about 60 cm. Responses were executed by pressing one of the two keys (‘z’ or ‘-’) of a standard Italian keyboard with the left or right index finger, respectively.
2.1.3. Procedure

Participants first performed a go/no-go spatial compatibility task. Five minutes later, they were administered a go/no-go Simon task.

In the spatial compatibility task, a trial began with the presentation of the fixation cross at the center of a black background. After 1000 ms a white square appeared to the left or to the right of the fixation and remained visible for 1000 ms. The inter-trial-interval was 1 s, and it was initiated immediately after the response was made. Half of the participants performed the go/no-go spatial compatibility task with a compatible mapping (72 white stimulus locations were mapped compatibly to response locations), and the other half with an incompatible mapping (72 white stimulus locations were mapped incompatibly to response locations). In each practice condition (compatible and incompatible mappings), half of the participants were required to respond to the right stimulus and to refrain from responding to the left stimulus, while the other half were required to respond to the left stimulus and to refrain from responding to the right stimulus.

In the go/no-go Simon task, a trial began with the presentation of the fixation cross at the center of a black background. After 1000 ms a colored square appeared to the left or to the right of the fixation and remained visible for 1500 ms. The inter-trial-interval was 1 s, and it was initiated immediately after the response was made. Half of the stimuli were red and half were green. By pressing the same key used in the spatial compatibility task, half of the participants were required to respond to the right square and to refrain from responding to the left square, while the other half were required to respond to the left square and to refrain from responding to the right square.

For each stimulus type, in half of the trials, the stimulus and response locations corresponded, while in the other half they did not, resulting in 50 trials for each of the four S–R combinations.

The spatial compatibility task was composed of 156 trials, 12 of which were considered as training. The Simon task was composed of 200 experimental trials. For both tasks, instructions stressed both speed and accuracy of performance.

2.2. Results and discussion

For both tasks, responses that were 2 standard deviations above or below the participant’s mean and incorrect responses were excluded from the analyses.

2.2.1. Spatial compatibility task

0.3% of the data were excluded because of errors and 1.9% were removed because of outlying RTs. RTs were 277 ms for the compatible-mapping practice and 305 ms for the incompatible-mapping practice. An ANOVA with Mapping as between-subjects variable revealed that this difference was significant, $F(1,22) = 4.18, MSe = 1135.479, p = .05$.

2.2.2. Simon task

In total, 0.6% of the data were excluded because of errors and 2% were removed because of outlying RTs. Correct RTs were submitted to a repeated-measures Analysis of Variance (ANOVA) with Mapping (compatible vs. incompatible) as between-subjects factor and Correspondence (corresponding vs. non-corresponding) as within-subject factor.

RTs in the two mapping conditions did not differ, $F(1,22) = 2.3, MSe = 2855.185, p = .15$ (312 vs. 335 ms for compatible and incompatible mappings, respectively). The main effect of Correspondence was significant, $F(1,22) = 10.17, MSe = 43.614, p < .05$, showing that corresponding trials were faster (320 ms) than non-corresponding ones (326 ms). The emergence of the Simon effect was modulated by the Mapping factor, as indicated by the two-way interaction between Mapping and Correspondence, $F(1,22) = 4.822, MSe = 43.614, p < .05$ (see Fig. 1, top panel). Planned comparisons showed that the 10-ms Simon effect observed in the compatible-mapping practice group (317 and 307 ms for non-corresponding and corresponding responses, respectively) was significant ($p < .01$), while the 2-ms effect (336 and 334 ms for non-corresponding and corresponding responses, respectively) found in the incompatible-mapping practice group was not significant ($p = .49$).

As predicted, the go/no-go Simon effect was significant after a go/no-go spatially compatible practice and was not significant after a go/no-go spatially incompatible practice. This result suggests that the S–R link activated during the compatible practice remained active and influenced performance in the subsequent task.

3. Experiment 2

Experiment 2 was run to investigate whether adopting a mixing paradigm (Marble & Proctor, 2000) in which the association between compatible (incompatible) and corresponding (non-corresponding) mappings is simultaneously relevant could yield an enhanced (mixed-compatible condition) or reversed (mixed-incompatible condition) Simon effect also when participants performed a go/no-go task.

Two groups of participants performed a go/no-go mixing paradigm in which stimuli occurred in left or right locations and were white on 50% of the trials and colored on the other 50%. Instructions required to respond to the color of the red or green stimuli or to the location of the white stimuli. For one group of participants, the mapping in the spatial compatibility trials was compatible, while for the other group, the mapping was incompatible. To clarify, when a white stimulus appeared on the left, participants in the compatible-mapping condition were instructed to respond with the left key, while participants in the incompatible-mapping condition were required to respond with the right key. Both groups were instructed to refrain from responding in the case of a right stimulus. When a colored stimulus appeared, participants were required to respond, with the same key used in the spatial compatibility trials, only if the target was of one particular color and to refrain from responding if it was of the alternative color.
If the specific S–R link activated in response to the spatial compatibility trials (that is, for example, right stimulus–right response) affects performance for those trials in which location is irrelevant (that is, for example, red stimulus in the right position–right responses), the Simon effect should be present when the mapping for the spatial compatibility trials is compatible, and reversed when the mapping is incompatible, despite the fact that participants are required to respond with the same key to only half of the stimuli.

3.1. Method

3.1.1. Participants

Sixteen new students (four males; four left-handed; age range: 21–27 years), selected as in the previous experiment, took part in Experiment 2.

3.1.2. Apparatus, stimuli and procedure

Apparatus and stimuli were the same as in Experiment 1, whereas the procedure varied as follows. The experiment consisted of a single session in which participants received the white stimuli on half of the trials and the red and green stimuli on the other half, randomly intermixed. Participants were to respond with the right (“z”) or left (“x”) key according to the color of the red and green stimuli or to the location of the white stimuli. Participants were randomly assigned to one of the two mixed conditions. In the mixed-compatible condition, white stimulus locations were mapped to response locations in a compatible fashion: the right response was to be made to stimuli appearing on the right and the left response to stimuli appearing on the left. In the mixed-incompatible condition, white stimulus locations were mapped to response locations in an incompatible fashion: the right response was to be made to stimuli appearing on the left and the left responses to stimuli appearing on the right.

The red and green stimuli were always location-irrelevant trials, 100 for which the stimulus and response locations corresponded and 100 for which they did not. Within each of these trials types, half of the stimuli were red and half were green, resulting in 50 trials for each of the four S–R combinations. The remaining 200 trials were location-relevant trials that were divided equally between each stimulus locations.

Each participant was instructed to respond to only one location-relevant (half “spatial S–R compatibility” task) and only one location-irrelevant (half “Simon” task) stimulus pressing only one key. Half of the participants were instructed to press the right key to both the white right stimulus and the red stimulus (mixed-compatible condition), whereas the other half were instructed to respond with the right key to both the white left stimulus and the red stimulus (mixed-incompatible condition). In both mixed-compatible/ incompatible conditions, the assignments of the left/right responses and the red/green colors were counterbalanced across participants.

In both conditions, a trial began with the presentation of the fixation cross at the center of a black background. After 1000 ms, the stimulus appeared to the left or to the right of the fixation and remained visible for 1500 ms. The inter-trial-interval was 1 s, and it was initiated immediately after the response was made. Each participant completed a block of 24 training trials, which was followed by 400 experimental trials divided into 2 blocks. Instructions stressed both speed and accuracy. Participants were allowed to take a short break between blocks.

3.2. Results and discussion

The data were trimmed according to the same criteria used for Experiment 1.

3.2.1. Spatial compatibility trials

2.5% of the data were excluded because of errors and 2.2% were removed because of outlying RTs. RTs were 423 ms in the mixed-compatible condition and 384 ms in the mixed-incompatible condition.

An ANOVA with Mapping as between-subjects variable revealed that this difference did not reach significance, $F(1,14) = 2.01$, $MSe = 3141.380, p = .18$. This latter result is line with previous studies showing that in the mixing paradigm there is usually no difference between compatible and incompatible mappings (e.g., Marble & Proctor, 2000; Proctor et al., 2013).

3.2.2. Simon trials

0.4% of the data were excluded because of errors and 2% were removed because of outlying RTs. An ANOVA with the same factors as those of Experiment 1 was conducted on correct RTs. The Mapping by Correspondence interaction was the only source of significance, $F(1,14) = 70.32$, $MSe = 403.115, p < .001$. Planned comparisons showed a 61-ms Simon effect in the group that responded to spatial compatibility trials with a compatible mapping (491 and 430 ms for non-corresponding and corresponding trials, respectively, $p < .001$) and, crucially, also a reversed 58-ms Simon effect in the group that responded to spatial compatibility trials with an incompatible mapping (390 and 448 ms for non-corresponding and corresponding trials, respectively, $p < .001$) (see Fig. 1, bottom panel).

As predicted, the go/no-go Simon effect was significant in the compatible-mapping condition and was reversed in the incompatible-mapping one. This result suggests that the S–R link activated during the spatial compatibility trials was transferred to and influenced performance on the Simon trials.

To note, the effects observed in the present experiment (i.e., the positive Simon effect in the compatible-mapping condition and the reversed effect in the incompatible-mapping condition) were larger than the effects observed in Experiment 1. This difference is thought to depend on the relative contributions of the direct and indirect routes in the two situations. Indeed, while practice effects are considered as due to the short-term associations established for the incompatible location mapping persisting even when they are no longer relevant to the task and contrasting the activation of the direct route (e.g., Tagliahue et al., 2000), the Simon effect in mixed-task conditions is thought to be determined solely by the short-term associations since the long-term associations of the direct route are either suppressed (e.g., Marble & Proctor, 2000) or proactively inhibited (e.g., Proctor et al., 2013).

4. Additional analyses

In order to understand if the go/no-go Simon effect found in the present experiments reflected some of the typical fingerprints of Simon task performance, we submitted the Simon trials to a bin analysis. We rank ordered RTs for corresponding and non-corresponding go trials for each participant by dividing them into five bins, separately for each experiment. Mean RTs for each bin were then submitted to a repeated measure ANOVA with Bin and Correspondence as within-subject variables and Mapping as between-subjects variable. The crucial Mapping × Correspondence × Bin interaction was significant only for Experiment 2, $F < 1$ and $F(4,56) = 6.31$, $MSe = 195.574, p < .001$, for Experiments 1 and 2, respectively. In Experiment 1, the Simon effect was constant across bins in the compatible-practice condition (9, 10, 9, 12, 11 ms, from the first to the fifth bin) and was absent across bins in the incompatible-practice condition (3, 3, 3, 1, 0 ms, from the first to the fifth bin). In Experiment 2, the Simon effect was constant across bins in the mixed-compatible condition (47, 53, 60, 75, 68 ms from the first to the fifth bin), while the reversed Simon effect for the mixed-incompatible condition increased monotonically from the fastest to the slowest bin (−37, −52, −62, −70, −71 ms). This latter result is in line with the results of previous studies using the mixing paradigm (e.g., Marble & Proctor, 2000).

Furthermore, to understand the exact nature of the go/no-go Simon effect found in Experiment 2 we ran an additional analysis. It could be argued that participants responded to Simon trials according to the location-relevant trial rule, that is, by responding compatibly...
It is important to note that the results of the present study do not allow us to untangle whether the effects observed are due to the acquisition of a specific S–R link or of a more general spatial mapping rule. Previous studies using the practice paradigm showed that during a spatially incompatible practice participants may develop a general response-selection strategy. However, it has been shown that a large amount of practice (more than 300 trials) is necessary for the rule acquired in the spatial compatibility task to become a general procedure and be transferred to the following Simon task (e.g., Marinii et al., 2011; Vu, 2007).

If we consider our Experiment 1, it is unlikely that our participants acquired a general rule since they performed only 72 practice trials.

6. Conclusions

Two main conclusions could be drawn from the present findings. First, we provide further evidence on the debated issue on whether the STM links are really short-lived, that is, on whether they are set up to perform the task at hand and then decay (Barber & O’Leary, 1997; see also Umlită & Zorzi, 1997). The present findings suggest that STM links remain active also when the task they were created for ended, being able to modulate the task performed subsequently (as in the practice paradigm) or simultaneously (as in the mixing paradigm). Second, our results extend evidence on the strength of the STM links: we found that these links formed during a go/no-go spatial compatibility task seemed to determine the location associations were cued as being not relevant for the task.

To sum up, our findings showed a clear carry-over effect of the association between stimulus position and spatial response from the first task to the second one both when the two tasks were performed one after the other (Experiment 1) and when they were performed simultaneously (Experiment 2), even when participants were required to respond with the same key to only half of the stimuli (go/no-go tasks).

To our knowledge, it is still a matter of debate if the observation of the Simon effect in a go/no-go task could be hinged on the requirement to choose between responses at different locations (e.g., Callan et al., 1974; Lu & Proctor, 1995) or on the inclusion of location in the WM representation of the response(s) involved in a particular task (Ansorge & Wühr, 2009). It is worth noting that Ansorge and Wühr (2009) acknowledged that their findings could be also explained by taking into account the modulation of the short-term memory (STM) links on the long-term memory (LTM) ones, as discussed by Tagliabue et al. (2000). Based on the results of the current study, the observation that the Simon effect emerged in the go/no-go task could be the result of the acquisition and subsequent transfer of STM links from the spatial compatibility task to the Simon task both when the two tasks are performed one after the other (Experiment 1) and when they are performed at the same time (Experiment 2). Indeed, our findings point to the idea that the STM link acquired during performance of the spatial compatibility task/trials (that is, the association between the spatial location of the stimulus and the spatial location of the response in the spatial compatible/incompatible task) remains active and effective also when the task it was created for ended. In other words, we found that associative learning between the stimulus and response positions occurring during the compatibility task, when location was relevant, influenced the way the location-irrelevant task (Simon task) was performed.

It is worth noting that, differently from Ansorge and Wühr (2004, 2009) and similarly to both Tagliabue et al.’s (2000) and Marble and Proctor’s (2000) studies, in our paradigm participants performed a spatial compatibility task, where the spatial information was explicit, before or simultaneously to the go/no-go Simon one. Due to this manipulation, our results clearly demonstrate that the STM links were more efficient when they gave a generic spatial imprinting that was then retrieved in the Simon task. More specifically, participants learned to associate the spatial information of the stimulus to the response location (right stimulus–right response) and transferred this spatial STM association to a different task (red stimulus on the right–right response), in which the spatial information was not relevant. This is particularly true in Experiment 2, where the two tasks were performed simultaneously and, in line with our hypothesis, the Simon effect was stronger when the two tasks were relevant at the same time.

The bin analysis on RTs demonstrated that, as in the two-choice version of the mixing paradigm (e.g., Marble & Proctor, 2000), the positive Simon effect in the mixed-compatible condition and the reversed Simon effect in the mixed-incompatible condition were present in all bins, with the reversed effect increasing monotonically as RT increased. Importantly, the results of Experiment 2, that is the positive Simon effect when the mapping in the spatial compatibility task was compatible and the reversed Simon effect when it was incompatible, were found even when Simon go-trials were preceded by a location-relevant trial. This result rules out the possibility that participants did not follow the instructions and responded to Simon trials applying the same rule used for the location-relevant trials.

5. General discussion

On the whole the results of Experiments 1 and 2 showed that the emergence of the Simon effect in a go/no-go task can be modulated, similarly to what occurs in the two-choice version of the task. On the whole the results of Experiments 1 and 2 showed that the emergence of the Simon effect in a go/no-go task can be modulated similarly to what occurs in the two-choice version of the task. Interestingly, this association created to perform the go/no-go compatibility task remained active and affected the go/no-go Simon task, leading either to a significant Simon effect in the compatible-mapping condition (in the practice and mixing paradigms), to a non-significant effect following a spatially incompatible practice or to a reversed effect in the incompatible-mapping condition (in the mixing-paradigm). In other words, the association between stimulus and response locations defined for the previous or simultaneous go/no-go spatial compatibility task seemed to determine which response was activated on the go/no-go Simon task: the STM association between the stimulus and the response locations defined by task instructions could not be inhibited, even when the location associations were cued as being not relevant for the task.

To sum up, our findings showed a clear carry-over effect of the association between stimulus position and spatial response from the first task to the second one both when the two tasks were performed one after the other (Experiment 1) and when they were performed simultaneously (Experiment 2), even when participants were required to respond with the same key to only half of the stimuli (go/no-go tasks).

To our knowledge, it is still a matter of debate if the observation of the Simon effect in a go/no-go task could be hinged on the requirement to choose between responses at different locations (e.g., Callan et al., 1974; Lu & Proctor, 1995) or on the inclusion of location in the WM representation of the response(s) involved in a particular task (Ansorge & Wühr, 2009). It is worth noting that Ansorge and Wühr (2009) acknowledged that their findings could be also explained by taking into account the modulation of the short-term memory (STM) links on the long-term memory (LTM) ones, as discussed by Tagliabue et al. (2000).
go/no-go task. It is worth noting, in fact, that also when the STM links are created during a go/no-go task, the association formed between the spatial information of the stimulus and the response location turns out to be strong enough to influence the effect of the preexisting LTM links, interfering with the subsequent or simultaneous go/no-go spatial irrelevant task and being able to modulate the emergence of the Simon effect.

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