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Suppression of irrelevant activation in the horizontal and vertical Simon task differs quantitatively not qualitatively

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ABSTRACT

The Simon effect is usually explained by the assumption that the irrelevant stimulus location automatically activates the corresponding response. In the case of incongruent stimulus–response assignments automatically activated responses therefore have to be suppressed to ensure correct responses. This account, however, has been called into question for other than horizontally arranged visual Simon tasks. We investigated whether there is a qualitative or quantitative difference in suppression of irrelevant activation between horizontally and vertically arranged Simon tasks, using delta-function analyses. Sequential analyses revealed suppression after incongruent trials in both tasks, supporting the idea of a quantitative rather than a qualitative difference between the tasks. We conclude that automatic response activation is weaker in vertical tasks resulting in lower inhibitory demands as compared to horizontal tasks.

1. Introduction

In everyday life conflicting response tendencies have to be solved to guarantee accurate behavior. A widely applied paradigm to investigate conflict control is the Simon task introduced by Simon and Rudell (1967). In its visual version, the task requires categorizing a pre-defined non-spatial stimulus feature (e.g., color or shape) and to signal the result by a spatial choice response (e.g., left or right button press). In addition to the relevant non-spatial stimulus feature, however, the stimulus also has an irrelevant spatial dimension (e.g., it appears left or right of fixation) that overlaps with the spatial dimension of the responses. Usually, participants respond faster and more accurately to congruent stimuli (i.e. when stimulus location corresponds to the side of the required response) than to incongruent stimuli (i.e. when the stimulus appears opposite to the side of the correct response). The difference in response time (RT) and error rate between congruent and incongruent trials is called the *Simon effect* (see Hommel, 2011 for an overview).

Although the Simon task has been investigated extensively, its origin is still not fully understood. A widely accepted basic account, however, is the dual-route model which assumes that information flows from perception to the response along two routes, a conditional and an unconditional one (De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990). Whereas task relevant stimulus information has to be translated to the correct response along the conditional route, irrelevant location information automatically activates the corresponding response via the unconditional route.

That stimulus location automatically affects response selection in the Simon task is supported by the characteristic of the so-called *delta functions* for the latencies of correct responses (delta functions for RT) and of delta functions for accuracy, which reflect how the Simon effect varies with RT in the latencies and error rates, respectively. In delta functions for accuracy, the size of the congruence effect for the fast responses is an indicator of the strength of automatic response activation (Ridderinkhof, 2002b). Usually, the Simon effect in error rates is relatively large for fast responses and decreases quickly towards zero, as late responses are highly accurate. This effect indicates fast automatic response activation by the location of the stimulus.

Also for correct responses, the Simon effect is relatively large for fast responses and decreases with increasing RT (see for example De Jong et al., 1994), hence, the delta function for RT has a negative slope. Interestingly, this effect is contrary to what one would expect, as the variance of RT is positively correlated with the mean RT (Wagenmakers & Brown, 2007), which would usually result in a positively sloped delta function (Pratte, Rouder, Morey, & Feng, 2010). The fact that the Simon effect decreases with RT for correct responses has been explained by suppression of automatic response activation that builds up gradually with time

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(De Jong et al., 1994; Ridderinkhof, 2002a; Ridderinkhof, van den Wildenberg, Wijnen, & Burle, 2004).

Automatic activation of the corresponding response by stimulus location, however, has been called into question as a general account of the Simon effect, primarily, because the effect differs in its dynamics depending on whether stimulus location varies along the horizontal or the vertical meridian (e.g., Wascher, Schatz, Kuder, & Verleger, 2001). The relative positions of the response buttons in both tasks correspond to that of the stimulus locations (e.g., when the stimuli vary along the vertical meridian, the participants are supposed to respond with an upper and a lower button). Thus, the spatial dimension of the stimulus always overlaps with that of the responses. Whereas negatively sloped delta functions for RT are found for the horizontal Simon task (HST), the vertical Simon task (VST) usually produces constant or even positively sloped delta functions for RT (e.g., Proctor, Vu, & Nicoletti, 2003; Wascher et al., 2001). For a detailed review on differences in delta functions for RT between HST, VST, and other variants of the Simon tasks see Proctor, Miles, and Baroni (2011).

In view of such results Wascher et al. (2001) hypothesized that stimulus location does not activate the spatially corresponding response automatically in every case, but rather specific conditions have to be met. Such a condition is given, for instance, when a visual stimulus is processed in the same cerebral hemisphere as the response primed by the location of the stimulus. Obviously, this is the case in the standard HST. If such favorable conditions are not met, as in the VST, stimulus information is transmitted solely via the conditional route. Thus, the Simon effect in a VST is seen to arise during stimulus–response translation. Because no automatic response activation that triggers suppression in a VST is elicited, the Simon effect does not decrease but remains constant or even increases with RT. Several studies reported declining delta functions for RT exclusively in the standard HST (e.g., Vallesi & Umiltà, 2009; Wiegand & Wascher, 2005, 2007), supporting the idea of Wascher et al. (2001).

There are, however, some reports of declining delta functions for RT in Simon tasks when stimulus processing and response activation were not located in the same hemisphere. For instance, it has been shown that the Simon effect also decreases with increasing RT in a HST when responses are given with fingers of the same hand (Hübner & Mishra, 2013; Proctor & Vu, 2010), by responding with saccadic eye movements (Wijnen & Ridderinkhof, 2007), or by moving one hand to the left or to the right (Buetti & Kerzel, 2008). Furthermore, in some studies the Simon effect also decreased with RT for the VST, e.g., when the stimulus–response mapping was randomized (Wiegand & Wascher, 2007). These studies support the alternative hypothesis that HST and VST merely differ quantitatively. Rubichi, Nicoletti, and Umiltà (2005) suggested that location-induced activation is also present in the VST, but to a lesser degree than in the HST. Tsai, Chen, Jang, and Liao (2013) reported that the cortical magnification factor is smaller for a distance along the vertical axis as compared to the same distance along the horizontal axis. Possibly the larger representation on the visual cortex of the same distance in the HST as compared to the VST results in stronger automatic response activation in the former case. If automatic response activation is generally lower in VST, inhibitory demands are lower as well and less suppression is necessary, so that the Simon effect does not decrease with RT. According to this idea we should find suppression of irrelevant activation in the VST, when the inhibitory demand is relatively high.

The hypothesis that both tasks differ in their response activation is, however, also supported by EEG analyses (Vallesi, Mapelli, Schiff, Amodio, & Umilta, 2005) and by showing different training effects in both tasks (Vu, 2007). More information about automatic response activation in both tasks could be gathered by also considering delta functions for accuracy, which are hardly reported in the literature on the VST. Fast error responses are influenced especially strongly by stimulus location and are not included in the delta functions for RTs, because only correct responses are included. Thus, the strength of automatic response activation is more reflected in the delta functions for accuracy, which, therefore, can be an important source of information for investigating the differences and similarities between the VST and the HST.

With the present study we aimed at further investigating whether the horizontal and vertical versions of the Simon task differ quantitatively or qualitatively. We assumed that any demonstration of suppression in the VST strengthens the idea of automatic response activation. However, automatic response activation should also be observed more directly by considering delta functions for accuracy. But how can we study suppression of irrelevant activation in the VST if there is no decrease of the Simon effect with RT? Our idea was to consider a variable that is well-known to modulate suppression and to see whether it affects performance in the VST in the same way as in the HST. The examined variable was the previous-trial congruency. In numerous studies it has been shown that previous-trial congruency has a substantial impact on the Simon effect (e.g., Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; see Egner, 2007 for a review). More specifically, the Simon effect is usually smaller after an incongruent than after a congruent trial. This modulation has been explained by conflict adaptation (Botvinick, Braver, Barch, Carter, & Cohen, 2001) that serves for reducing the effects of irrelevant information after a conflict has been detected (Stürmer & Leuthold, 2003; Stürmer et al., 2002; see Hommel, 2004, for an alternative account).

For the HST, Ridderinkhof (2002a) has shown that the Simon effect is generally reduced in trials following an incongruent one, and in addition the slope of the corresponding delta function for RT is more negative. This suggests that suppression of automatic response activation is increased after experiencing a response selection conflict in the previous trial. If one could show that previous-trial congruency also modulates the slope of the delta function for RT in the VST, then this could be taken as an indicator of automatic response activation in this task. Furthermore, if there is suppression of automatically induced responses in the VST, one should also observe a significantly declining delta function for RT, at least after incongruent trials.

Indeed, Stürmer et al. (2002) already observed that in a VST the Simon effect was reduced after incongruent trials compared to congruent ones and the slopes of the respective delta function for RT decreased, too. Unfortunately, Stürmer et al. (2002) did not test whether the reduction was significant, nor did they include a HST for comparison. They also did not exclude direct trial repetitions in the graph, which are supposedly confounded with conflict adaptation, as the response in these trials is usually very fast (Mayr, Awh, & Laurey, 2003). In the present study we therefore conducted behavioral experiments to test whether we can find a similar reduction of the Simon effect in the VST with RT. In Experiment 1 we also included a HST in addition to the VST.

2. Experiment 1

In our first experiment we used a similar method as Stürmer et al. (2002). However, additionally to the VST we included a HST to compare the Simon effect and its modulation by previous-trial congruency between the two tasks. Because in the pilot studies we found that suppression decreases in the HST with the duration of the experiment, we used a between-participants design. A comparison of a balanced within-participant design could have been problematic, as the first and the second half of a test block are possibly not comparable.

Whereas predictions on mean Simon effects are not easy, because two opposing factors are at play (suppression and automatic response activation), clear predictions can be made for the delta functions. For accuracy we expected a larger Simon effect in the first quintile in the HST compared to the VST because automatic response activation is supposedly stronger (Rubichi et al., 2005). Further, we expected weaker automatic response activation in both tasks after incongruent trials. In the HST the delta function for RT should be negatively sloped, whereas it should be flat or even positively sloped in the VST. Critically, if these differences in the delta functions for RT merely reflect a quantitative difference between suppression of irrelevant response activation in the two