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# The impact of response frequency on spatial stimulus–response correspondence effects

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ABSTRACT

The present study explored how response preparation, varied by relative response frequency, affects response conflict as expressed in the Simon effect. Previous studies showed that valid response cues, when presented before the imperative stimulus, increase rather than decrease the Simon effect. This finding was explained by the hypothesis that response cues trigger shifts of attention to the side of the prepared response, and that these attention shifts modulate processing of the imperative stimulus. We investigated whether cues are necessary for inducing shifts of attention and thereby modulating the Simon effect, or whether response preparation without cues is sufficient. In two experiments, participants performed a Simon task with one response being more frequent than the other. Results showed larger Simon effects for the more frequent (i.e. prepared) response than for the less frequent (i.e. unprepared) response. These results suggest that response preparation (rather than the cue that induces the preparation) triggers a shift of spatial attention which modulates the Simon effect.



## 1. Introduction

Preparation of responses to imperative stimuli in choice reaction-time (RT) experiments can be varied in two different ways: first, by presenting mostly valid and sometimes invalid response cues before the imperative stimuli, and second, by using different relative frequencies of the responses. Both methods have similar effects on RT: the more likely and better prepared responses are executed more quickly than the less likely and less prepared responses. With respect to (location-based) response competition in a Simon task, it has been found that the better preparation associated with valid response cues serves to increase the effects of response competition on RT as compared to response competition with invalid cues. Whether better preparation associated with a higher relative response frequency has equivalent effects on response competition in the Simon task is not yet known. Therefore, in this study, we investigate the effects of relative response frequency on (location-based) response conflict and compare the observed effects to those found with response cues as reported in the literature.

The Simon task is an established paradigm for the study of response conflict. In a typical Simon task, participants are required to press a left key to a green stimulus and a right key to a red stimulus. Variations of horizontal stimulus location on the computer screen produce spatially corresponding conditions (e.g., when the green square appears to the left, which is also the side of the response), and spatially non-corresponding conditions (e.g., when the green square appears to the right). The typical result is faster RT and lower error rate in corresponding conditions (see, e.g., Proctor & Vu, 2006, for a review). This performance advantage is known as the Simon effect.

According to the prevalent view, the Simon effect arises at the functional level of response selection. Popular accounts distinguish two routes of stimulus–response translation that produce converging or diverging outputs in corresponding and non-corresponding conditions, respectively (e.g., Kornblum, Hasbroucq, & Osman, 1990; Zhang, Zhang, & Kornblum, 1999; Zorzi & Umiltà, 1995). The one route involves controlled processes that translate the relevant stimulus into the instructed response, whereas the other route involves automatic processes that translate stimulus location into a spatially corresponding response. The outputs of the two routes match in corresponding conditions, and the response occurs quickly and accurately. In contrast, the outputs mismatch in non-corresponding conditions, and this response conflict delays a correct response, and sometimes causes an error.

### 1.1. Response preparation and the Simon effect

Response preparation in a choice task should modulate the Simon effect if it affects response selection. During response selection, a set of codes of possible responses is activated, some more and others less depending on the imperative stimulus presented. Most models hold that a response is selected when the activation of its code exceeds a predefined threshold (e.g., Zorzi & Umiltà, 1995, for an application of this type of model to the Simon effect). Response preparation is

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generally conceived as pre-activation of a response code. This should bias response selection in favor of the prepared response because its code requires less stimulus-based activation to exceed the threshold (e.g., Smith & Ratcliff, 2004). In addition to resulting in faster responses, pre-activation of a response code should also modulate the impact of corresponding and non-corresponding stimulus information, as reflected in the Simon effect. In particular, one would expect that different pre-activation levels of two competing responses should decrease Simon effects in the more pre-activated response and increase Simon effects in the less pre-activated response (e.g., Wascher & Wolber, 2004).

Consider the non-corresponding condition of a Simon task: here the relevant stimulus activates the correct response code and the irrelevant position activates the incorrect response code. Interference — or response conflict — results from the mutual inhibition of simultaneously activated response codes (e.g. Zhang et al., 1999; Zorzi & Umiltà, 1995). The inhibition of the correct response, and hence the Simon effect, should be smaller when the (pre-)activation of the correct response code is stronger than that of the incorrect and inhibiting response code. Conversely, the Simon effect should be larger when the (pre-)activation of the correct response code is weaker than that of the incorrect and inhibiting response code. Next, consider the corresponding condition of a Simon task, where both the relevant stimulus and the irrelevant position activate the correct response code. The resulting facilitation of the correct response, and hence the Simon effect, should be smaller when the (pre-)activation of the correct response code is already larger than that of the incorrect and facilitating response code. Conversely, the facilitation from corresponding conditions, and hence the Simon effect, should be larger when the (pre-)activation of the correct response code is weaker than that of the incorrect and facilitating response code.

These expectations stand in striking contrast to experimental findings obtained with the response-cueing methodology. In a typical response-cueing experiment, a cue indicates the most likely response to the next stimulus with high validity (e.g., 80%), and performance with valid and invalid cues is compared to performance without response cues. The consistent result of several studies (e.g., Proctor, Lu, & Van Zandt, 1992; Verfaellie, Bowers, & Heilman, 1988; Wascher & Wolber, 2004; Wühr, 2006) is that valid response cues reduce RT, whereas invalid response cues increase RT. The faster RT observed with valid than with invalid response cues is a marker of the different levels of response preparation. In contrast to expectations, however, the Simon effect turned out to be larger for the validly cued (i.e. prepared) responses than for the invalidly cued (i.e. unprepared) responses.

There are basically two accounts of the modulation of the Simon effect by response cues, the response-speed account and the attentional account. According to the *response-speed account* (Proctor & Wang, 1997), response cues modulate the Simon effect through the different RTs of prepared (i.e. fast) and unprepared (i.e. slow) responses. Previous research has shown that the Simon effect declines as RT becomes longer (e.g., Hommel, 1994), and this finding was attributed to the rapid decay of stimulus-location codes (cf. Zorzi & Umiltà, 1995). In particular, it was suggested that a spatial stimulus code is quickly formed after stimulus onset and then dissipates over time. Hence, with short RTs the stimulus location code is stronger during response selection, and therefore produces more interference than with long RTs.

The difference between RTs of prepared and unprepared responses could contribute to the modulation of the Simon effect in some task variants. However, this will not always be the case because the decline of the Simon effect with increasing RT is not a universal phenomenon. It has been shown to depend not only on the horizontal versus vertical arrangement of the stimuli and responses, but also on other task characteristics (e.g. Buhlmann, Umiltà, & Wascher, 2007; Wiegand & Wascher, 2005, 2007a, 2007b). In the present experiments we compared Simon effects in different bins of the RT distributions to test the impact of different overall reaction times of prepared and unprepared responses.

According to the *attentional account* proposed by Wascher and Wolber (2004), unreliable (i.e. sometimes invalid) response cues have two essentially independent effects on performance in the Simon task. First, the response cues induce selective pre-activation of the cued response, producing a main effect of cue validity on RT, and different lateralized readiness potentials (LRPs) for cued and uncued responses. Second, the response cues induce a shift of attention toward the side of the cued response, and this attention shift could increase the Simon effect with valid cues as compared to that with invalid cues. More specifically, with valid response cues, Simon effects should be increased because attention shifts to the side of the correct response facilitate stimulus processing in spatially corresponding conditions, but impair stimulus processing in spatially noncorresponding conditions. In contrast, with invalid response cues, Simon effects should be reduced because attention shifts to the side of the incorrect response facilitate stimulus processing in spatially noncorresponding conditions, but impair stimulus processing in spatially corresponding conditions. A shorter latency of the N2pc, a lateralized ERP related to selective attention, for stimuli presented on the side of the cued response, and a larger amplitude of the N2pc for stimuli presented on the side of the uncued response provided electrophysiological evidence for shifts of spatial attention.

The attentional account of the modulation of the Simon effect by response cues implies that centrally presented *stimulus*-position cues do not modulate the Simon effect. The reason is that valid stimulus-position cues facilitate stimulus processing in both corresponding and non-corresponding conditions, whereas invalid stimulus-position cues hamper stimulus processing in both corresponding and non-corresponding conditions. In fact, consistent with this prediction, several studies failed to observe an effect of the validity of stimulus-position cues on the Simon effect, although overall RTs were shorter with valid than with invalid cues (e.g., Proctor et al., 1992; Verfaellie et al., 1988; Wascher & Wolber, 2004; Zimba & Brito, 1995). However, some recent studies reported smaller Simon effects (e.g. Abrahamse & Van der Lubbe, 2008), or smaller Simon-like effects (e.g. Funes, Lupiáñez, & Milliken, 2007), with valid than with invalid stimulus-position cues. This finding was interpreted in terms of the premotor theory of attention (e.g., Van der Lubbe & Abrahamse, 2011; Van der Lubbe, Abrahamse, & De Kleine, 2012). This theory bears some similarity to the attentional account of the modulation of the Simon effect by response cues and we shall discuss it in more depth in the General Discussion.

Under the attentional account, the effects of response cues on both response preparation and visual attention could be separate, independent effects of the cues, typically arrows or arrowheads. Alternatively, the effect of the cues could be restricted to response preparation, and the attentional shift would be a consequence of such preparation. Buhlmann and Wascher (2006) provided evidence for the former variant of the attentional account, according to which the cue and not response preparation itself induces the attentional shift. Specifically they showed that symbolic and tactile response cues produce cueing effects on RT and thus response preparation, but only slight (symbolic cues) or essentially no (tactile cues) modulations of the Simon effect. Thus, these cues induced response preparation without an associated shift of visual attention which modulates the processing of imperative stimuli.

The conclusion suggested by the findings of Buhlmann and Wascher (2006) is not fully consistent with the general notion of attention-for-action (Allport, 1987; Neumann, 1987). The claim of a tight link between action and attention is based on a variety of observations. For example, Brunia (1993) emphasized the similarities in the structural and functional organization of motor preparation and attention. More recently, visual processing has been shown to be biased toward the target of forthcoming movements (see Baldauf & Deubel, 2010, for review), and to be facilitated in the proximity of the observer's hands (see Tseng, Bridgeman, & Juan, 2012, for review). Attentional orienting