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Research Report

Electrophysiological evidence for response priming and conflict regulation in the auditory Simon task

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ABSTRACT

The Simon effect refers to the finding that responses are faster when the task-irrelevant stimulus and response location correspond than when they do not. The present study examined the role of location-based response priming and its regulation by an ancillary monitoring mechanism (AMM) for the auditory Simon effect, manipulating response modality and analyzing event-related brain potentials (ERPs). An auditory Simon effect was obtained for responses with hand, foot, and eyes. Lateralized ERPs revealed a mix of location-based attentional and motor-related activations early on during information processing. The Simon effect in reaction time (RT) was absent or largely reduced when a non-corresponding rather than a corresponding trial preceded, indicating control over location-based response priming. Importantly, RT modulations as a function of the correspondence sequence were mirrored in the amplitude of a negative difference wave (N2c), in accord with the view that response priming is under control of an AMM. In conclusion, both behavioral and electrophysiological measures revealed effect patterns that are consistent with an information-processing model that assumes asynchronous transmission from two separate processing routes to the motor system and top–down control by an AMM over task-irrelevant response priming.

1. Introduction

Speeded performance is strongly influenced by the spatial relationship between stimulus (S) and response (R) attributes, and even so when this relationship is not relevant for the task at hand (for an overview, see Hommel and Prinz, 1997; Proctor and Reeve, 1990). Particularly, strong evidence for the latter notion derives from studies using the Simon paradigm (cf. Simon, 1990), where stimuli are presented laterally and typically a non-spatial stimulus dimension (e.g., color, shape, or pitch) demands choice responses with the left or right hand. Here, responses are found to be faster and less error prone when the task-irrelevant stimulus location and the response are on the same side than on opposite sides, regardless of whether visual stimulation (e.g., Hommel, 1993; Wühr and Ansorge, 2005), auditory (e.g., Craft and Simon, 1970), or somatosensory stimulation (e.g., Hasbroucq and Guiard, 1992) is employed. This intriguing and modality-independent influence of task-irrelevant stimulus location onto reaction time (RT) is referred to as Simon effect.

Recent studies combining behavioral and event-related brain potential (ERP) approaches have considerably advanced our understanding of the mechanisms underlying the Simon effect. However, these studies almost exclusively employed

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visual Simon paradigms; therefore, it remains to be seen whether the same processes are responsible for the Simon effect in other sensory modalities. In fact, this is a question of theoretical significance as the prevailing account receives much of its appeal from the idea that a modality-independent motor mechanism underlies the Simon effect (e.g., De Jong et al., 1994; Hommel, 1993; Kornblum et al., 1990). However, as exactly this assumption has been challenged in a recent study of the auditory Simon effect (cf. Wascher et al., 2001), it is important to further test whether empirical findings and theoretical insights gained for the visual Simon effect neatly translate to the auditory Simon effect. The present chronopsychophysiological study is hence concerned with the potential mechanisms underlying the auditory Simon effect.

Contemporary models explain the Simon effect in terms of two parallel S-R processing routes (cf. De Jong et al., 1994; Hommel, 1993; Tagliabue et al., 2000; Zorzi and Umiltà, 1995). More specifically, it is assumed that in a conditional route the appropriate response is intentionally selected and subsequently activated, whereas a parallel, unconditional route automatically activates the response spatially corresponding to stimulus location. Thus, right-sided stimuli will directly prime right-sided responses and left-sided stimuli will prime left-sided responses. As a result, if stimulus and response location correspond (CO), the correct response is primed and its execution is facilitated. By contrast, if stimulus and response locations are non-corresponding (NC), the primed response conflicts with the intentionally activated response and the resolution of this conflict prolongs the duration of response execution.

A seminal study of the dual-route model was conducted by De Jong et al. (1994). They analyzed RT distributions[1] (cf. Method section) to trace the time course of the Simon effect and recorded event-related brain potential (ERP) correlates of selective hand activation – the lateralized readiness potential (LRP; cf. Coles, 1989; Eimer and Coles, 2002) – to reveal covert motor processing (see also Sommer et al., 1993; Valle-Inclán, 1996). The distributional RT analysis demonstrated a decrease and even reversal of the Simon effect with increasing RT, suggesting that the initial priming effect by the unconditional route is of transient nature and later followed by inhibition. The LRP analysis took advantage of the fact that negative and positive LRP polarity indicates covert activation of the correct and incorrect response hand, respectively (e.g., Coles, 1989; Eimer and Coles, 2002). Crucially, for correct overt response trials, the LRP showed an initial positive activity (dip) when stimulus and response locations were on opposite sides, followed by a negative LRP maximal prior to response onset. Thus, the LRP revealed initial activation of the incorrect response followed by activation of the appropriate response in accord with the idea of faster unconditional response priming than conditional S-R processing.

[1] Cumulative RT distribution functions (CDFs) (cf. Ratcliff, 1979) that indicate the probability (*P*) that a random variable *T* (e.g., response latency) takes on a value at or below a given value *t*: $F(t) = P(T \leq t)$ were calculated for corresponding and non-corresponding S-R conditions and divided into quantiles. For each quantile, the difference between non-corresponding RT and corresponding RT was plotted against mean RT of these two conditions.

More recently, the assumption that unconditional motor priming is automatic came into doubt because the Simon effect was found to depend on the specific sequence of corresponding and non-corresponding events (cf. Praamstra and Plat, 2001; Stürmer et al., 2002; Stürmer and Leuthold, 2003; Valle-Inclán et al., 2002). That is, a strong Simon effect was observed on the current trial *N* only when a corresponding event was presented on the preceding trial *N* – 1 (CO–*CO* vs. CO–*NC*, current trial italicized), whereas the Simon effect was much reduced (e.g., Praamstra and Plat, 2001) or eliminated (e.g., Stürmer et al., 2002) after a non-corresponding trial *N* – 1 (NC–*CO* vs. NC–*NC*). That is, RT increased for NC–*CO* as compared to CO–*CO* sequences but decreased for NC–*NC* as compared to CO–*NC* sequences. Moreover, RT distribution analysis revealed a Simon effect of zero magnitude independent of RT after a non-corresponding trial *N* – 1 (Stürmer et al., 2002). To account for these findings, Stürmer et al. (see also Stürmer and Leuthold, 2003) proposed that the output of the unconditional processing route is under control of an ancillary monitoring mechanism (AMM). Specifically, upon detection of a response conflict, the AMM is thought to selectively suppress output of the unconditional route whereby location-based signals are prevented from accessing the motor system, whereas the unconditional route is released from suppression if processing conflict is absent as in corresponding trials. It is fair to mention though that other researchers proposed alternative accounts of the suppression pattern in RT (Hommel et al., 2004; Mayr et al., 2003; Notebaert et al., 2001). Whereas multiple mechanisms may contribute to sequential effects in the Simon task (Wühr and Ansorge, 2005), as we will outline in detail in the General Discussion, we focus for the moment on the AMM view because it receives strong support in ERP studies (Stürmer et al., 2002; Stürmer and Leuthold, 2003). In addition, the postulate of response conflict and an AMM accords with prominent ideas about cognitive control and performance monitoring (cf. Botvinick et al., 2001; Stürmer et al., 2005).

Given the role of sensory modality-independent mechanisms such as motor priming and conflict resolution in current models of the Simon effect, it is surprising to see that few studies tested whether the same mechanisms underlie the Simon effect in other sensory modalities. Actually, to our knowledge, the only chronopsychophysiological studies that examined the auditory Simon effect arrived at opposite conclusions (Leuthold, 1994; Wascher et al., 2001). More specifically, in both studies left–right hand choice responses were demanded as a function of the pitch of a tone that was presented via loudspeaker to the left or right side. In accord with the dual-route model, Leuthold (1994) reported LRP evidence for early location-based response priming between 100 and 150 ms after sound onset, followed by correct response activation. A shortcoming of this study, however, is that possible contributions of lateralized sensory activity to the LRP were not controlled. Wascher et al. (2001) indeed found sensory ERP activity maximal over the primary auditory cortex (electrodes T7/8) early after stimulus onset (130 ms); yet, LRP activity over the motor cortex was absent in this time interval. It was only 250 ms after stimulus onset that such motor activation appeared over frontolateral motor areas (electrodes F3/4). In addition, and also in contrast to visual task