Neuroscience and Biobehavioral Reviews 77 (2017) 48–57

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Review article

Sensory neural pathways revisited to unravel the temporal dynamics of the Simon effect: A model-based cognitive neuroscience approach

Yael Salzer[a,*], Gilles de Hollander[a], Birte U. Forstmann[a,b]

[a] Integrative Model-Based Cognitive Neuroscience Research Unit, University of Amsterdam, The Netherlands
[b] Netherlands Institute for Neuroscience, an Institute of The Royal Netherlands Academy of Arts and Sciences, Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 16 November 2016
Received in revised form 23 January 2017
Accepted 22 February 2017
Available online 24 February 2017

Keywords:
Simon task
Model-based cognitive neuroscience
Diffusion model for conflict

ABSTRACT

The Simon task is one of the most prominent interference tasks and has been extensively studied in experimental psychology and cognitive neuroscience. Despite years of research, the underlying mechanism driving the phenomenon and its temporal dynamics are still disputed. Within the framework of the review, we adopt a model-based cognitive neuroscience approach. We first go over key findings in the literature of the Simon task, discuss competing qualitative cognitive theories and the difficulty of testing them empirically. We then introduce sequential sampling models, a particular class of mathematical cognitive process models. Finally, we argue that the brain architecture accountable for the processing of spatial ('where') and non-spatial ('what') information, could constrain these models. We conclude that there is a clear need to bridge neural and behavioral measures, and that mathematical cognitive models may facilitate the construction of this bridge and work towards revealing the underlying mechanisms of the Simon effect.

Contents

1. Introducing the Simon effect and its temporal dynamics

The Simon task was first described by Simon and colleagues (Simon and Rudell, 1967; Simon and Small, 1969). It captures an intuitive phenomenon: we perform much better when the source of information and appropriate response are spatially aligned (Fitts and Deininger, 1954). In the original Simon task, participants are asked to identify tones played to their right or left

* Corresponding author at: Nieuwe Achtergracht 129B, 1018 WT Amsterdam, The Netherlands.
E-mail address: salzerit@gmail.com (Y. Salzer).

http://dx.doi.org/10.1016/j.neubiorev.2017.02.023
0149-7634/

ears. High and low pitch sounds are assigned to right or left keys, as instructed. The spatial location of the auditory stimulus is task-irrelevant. Nevertheless, participants respond faster and more accurately when the appropriate key spatially matches the stimulated ear (i.e., corresponding condition) than when it does not (i.e., non-corresponding condition). The calculated mean difference in response times (RT) and in error rates between the corresponding and non-corresponding conditions is called the *correspondence effect*, or simply, the *Simon effect*. Spatial compatibility effects have been found for auditory (Wascher et al., 2001; Xiong and Proctor, 2016), visual (Forstmann et al., 2008a; see for review Lu and Proctor, 1995), and tactile stimuli (Hasbroucq and Guiard, 1992; Salzer et al., 2014). The effect generalizes to paradigms where the response modality is manipulated: for example when the hands are crossed versus uncrossed (Hommel, 1993; Riggio et al., 1986; Wascher et al., 2001), when using foot pedals (Medina et al., 2014), when using the middle and index fingers of the same hand (Forstmann et al., 2008c; Hübner and Mishra, 2013; Töbel et al., 2014), when using eye-movements (Duprez et al., 2016; Lugli et al., 2016), and when using hand-reach motor responses (Buetti and Kerzel, 2008; Finkbeiner and Heathcote, 2016; Freud et al., 2015). These studies suggest that the Simon effect is not simply due to which cortical hemisphere encodes the stimulus or controls the response.

Distributional analyses of RT are commonly used to evaluate the temporal dynamics of the Simon effect (De Jong et al., 1994). In distributional analyses, the distributions of RTs for corresponding and non-corresponding trial types are partitioned into quantiles or proportional bins (De Jong et al., 1994; Ratcliff, 1979; Ridderinkhof, 2002). For example, the 0.2 quantile of an RT distribution indicates for which RT 20% of the RTs are faster, the 0.4 quantile indicates for which RT 40% of the RTs are faster, etc. The Simon effect can be defined for each quantile separately: the difference in quantile RTs between the corresponding and non-corresponding trial types. The dynamics of the Simon effect across the distribution can be visualized by plotting the relative effect for each quantile *(e.g., 0.2 quantile of incongruent minus the 0.2 quantile of the congruent)* as a function of the mean RT quantile across conditions. Such a plot is known as a *delta plot* (Ridderinkhof, 2002). The pattern of the change in the effect across the distribution is assumed to provide insight into the temporal dynamics of the processes that underlie the effect (De Jong et al., 1994; Proctor et al., 2011). A typical left-right visual Simon task, in which the participants are asked to recognize a non-spatial dimension of a lateralized visual stimulus (e.g., color or shape), yields a decreasing effect across the RT distribution (see Fig. 1A) (Hedge and Marsh, 1975; Hommel, 1994; Lu and Proctor, 1995; Ridderinkhof, 2002). The following models have been proposed to explain why.

2. Dual-route models and the role of cognitive control

De Jong, Liang and Lauber (De Jong et al., 1994) proposed a dual-route model to explain the decreasing delta plots in the Simon task (see Fig. 2). They suggested that two processes take place in parallel. One process refers to a task-relevant indirect route that processes the deliberate response decision based on task demands. The other process refers to a task-irrelevant process, where the spatial code

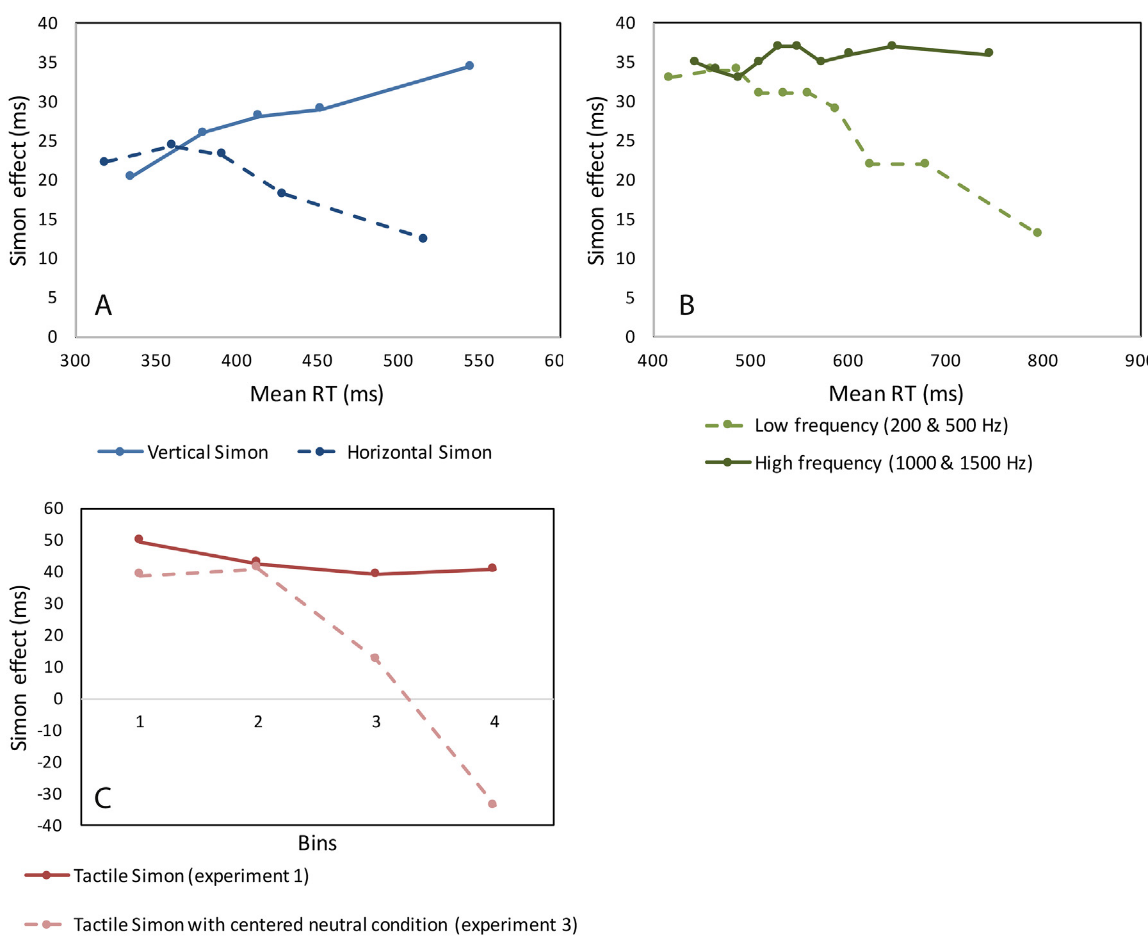

Fig. 1. Distribution of mean Simon effect, also known as delta plots, for (A) horizontal and vertical visual Simon task (data adapted with permission from Töbel et al., 2014), (B) high- and low-frequency auditory Simon task (data adapted with permission from Xiong and Proctor, 2016), and (C) tactile Simon task with- and without-central neutral condition (data adapted with permission from Salzer et al., 2014).