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Evidence for capacity sharing when stopping

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ABSTRACT

Research on multitasking indicates that central processing capacity is limited, resulting in a performance decrement when central processes overlap in time. A notable exception seems to be stopping responses. The main theoretical and computational accounts of stop performance assume that going and stopping do not share processing capacity. This independence assumption has been supported by many behavioral studies and by studies modeling the processes underlying going and stopping. However, almost all previous investigations of capacity sharing between stopping and going have manipulated the difficulty of the go task while keeping the stop task simple. In the present study, we held the difficulty of the go task constant and manipulated the difficulty of the stop task. We report the results of four experiments in which subjects performed a selective stop–change task, which required them to stop and change a go response if a valid signal occurred, but to execute the go response if invalid signals occurred. In the consistent-mapping condition, the valid signal stayed the same throughout the whole experiment; in the varied-mapping condition, the valid signal changed regularly, so the demands on the rule-based system remained high. We found strong dependence between stopping and going, especially in the varied-mapping condition. We propose that in selective stop tasks, the decision to stop or not will share processing capacity with the go task. This idea can account for performance differences between groups, subjects, and conditions. We discuss implications for the wider stop-signal and dual-task literature.

1. Introduction

Stopping prepared but no longer relevant responses is a simple act of executive control that supports flexible and goal-directed behavior (Aron, Robbins, & Poldrack, 2014; Logan, 1994; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004; Verbruggen & Logan, 2008c). In the last two decades, response inhibition has received much attention across research domains. Cognitive psychologists and neuroscientists have explored the cognitive and neural mechanisms of response inhibition, developmental scientists have studied the 'rise and fall' of inhibitory control capacities across the life span, and clinical psychologists, neuropsychologists, and psychiatrists have examined correlations between individual differences in response inhibition and behaviors such as substance abuse, overeating, pathological gambling, and risk taking (for reviews, see Aron et al., 2014; Bari & Robbins, 2013; Chambers, Garavan, & Bellgrove, 2009; Logan, 1994; Verbruggen & Logan, 2008c). Research on response inhibition has thus become a central component of the study of self-regulation and behavioral change (see e.g. Hofmann, Schmeichel, & Baddeley, 2012).

Most response inhibition studies implicitly or explicitly assume that stop processing occurs independently from go processing for most of the time. By making this

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assumption, the covert latency of the stop process can be estimated. Here we report the results of four experiments that used a selective stop–change task in which different signals could be presented; subjects were instructed to stop and change the planned go response if one of the signals occurred (valid signal), but to execute the planned go response if the other signals occurred (invalid signals). Our experiments challenge the dominant independent race model of response inhibition because they indicate that the processes underlying going and stopping can interact substantially, especially when the stop-signal rules change frequently. Our results also shed a new light on strategy selection in selective stop tasks.

1.1. A brief introduction to independent race models of inhibitory control

Reactive inhibitory control in response to changes in the environment or internal state is often studied in tasks such as the go/no-go task (Donders, 1868/1969) and the stop-signal task (Lappin & Eriksen, 1966; Logan & Cowan, 1984; Vince, 1948). In the go/no-go task, subjects are instructed to respond when a go stimulus appears (e.g. an 'O'), but to withhold their response when a no-go stimulus appears (e.g. an 'X'). In the stop-signal task, subjects perform a primary go task, such as responding to the identity of a stimulus (e.g. press left when an 'O' appears, and right when an 'X' appears). On a minority of the trials, an extra visual or auditory signal appears after a variable delay, instructing subjects to withhold the planned go response.

Performance in these tasks and their many variants can be modeled as an independent race between a go process, triggered by the presentation of a go stimulus, and a stop process, triggered by the presentation of the no-go stimulus or the stop signal (Logan & Cowan, 1984; Logan, Cowan, & Davis, 1984; Logan, Van Zandt, Verbruggen, & Wagenmakers, 2014; for a review, see Verbruggen & Logan, 2009a). When the stop process finishes before the go process, response inhibition is successful and no response is emitted (signal-inhibit); when the go process finishes before the stop process, response inhibition is unsuccessful and the response is incorrectly emitted (signal–respond). In the go/no-go task, the main dependent variable is the probability of responding on no-go trials. In the stop-signal task, the covert latency of the stop process (stop-signal reaction time or SSRT) can also be estimated from the independent race model (Logan, 1981; Logan & Cowan, 1984; Logan et al., 2014); this has made it a very popular paradigm for the study of response inhibition in cognitive psychology, cognitive neuroscience, developmental psychology, and psychopathology (Verbruggen, Chambers, & Logan, 2013; Verbruggen & Logan, 2008c).

The independent race model assumes independence between the finishing times of the go process and the stop process (Logan & Cowan, 1984). The independence assumption takes two forms: context independence (also referred to as signal independence) and stochastic independence. Context independence means that the go reaction time (RT) distribution is not affected by the presentation of stop signals. Stochastic independence means that trial-by-trial variability in go RT is unrelated to trial-by-trial variability in SSRT (in other words, the durations of the go processes and the stop processes are not correlated). These assumptions should not be taken lightly because SSRT cannot be reliably estimated when they are violated (Band, van der Molen, & Logan, 2003; Colonius, 1990; De Jong, Coles, Logan, & Gratton, 1990).

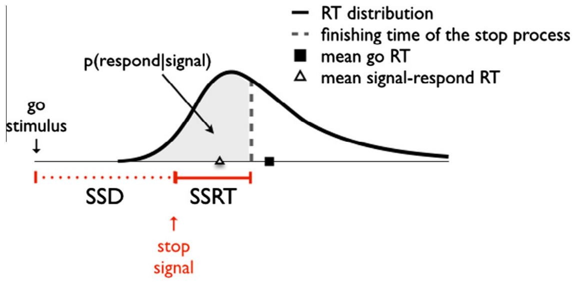

Fig. 1. A graphic representation of the assumptions of the independent horse-race model of Logan and Cowan (1984). On signal–respond trials, the go process finishes before the stop process. The gray area under the curve indicates the probability of a signal–respond trial. This figure shows why mean reaction time on signal–respond trials is shorter than mean RT on no-signal trials: the former is calculated based on the fastest RTs that escaped inhibition (i.e. the RTs on the left of the vertical dashed line), whereas the latter is calculated based on the whole RT distribution (i.e. the RTs on the left and right of the vertical dashed line). SSD = stop-signal delay; SSRT = stop-signal reaction time.

The independence assumptions can be tested by comparing the mean RT for signal–respond trials with the mean RT for no-signal trials, and by comparing RT distributions for signal–respond and no-signal trials (Verbruggen & Logan, 2009a). First, the independent horse-race model predicts that mean no-signal RT should be longer than mean signal–respond RT: mean signal–respond RT only represents the mean of those responses that were fast enough to finish before the stop signal, whereas mean no-signal RT represents the mean of all go responses (Fig. 1). Second, the independent race model predicts that signal–respond and no-signal distributions have a common minimum, but later diverge (Osman, Kornblum, & Meyer, 1986). A review of the literature revealed that the independence assumptions are met in most stop-signal studies (Verbruggen & Logan, 2009a). This conclusion is further supported by behavioral studies that directly tested dependence between going and stopping (e.g. Logan & Burkell, 1986; Logan et al., 2014; Yamaguchi, Logan, & Bissett, 2012), and by studies that modeled the processes underlying going and stopping (e.g. Boucher, Palmeri, Logan, & Schall, 2007; Logan, Yamaguchi, Schall, & Palmeri, 2015; Logan et al., 2014).

1.2. The interaction between going and stopping in stop–change and selective stop tasks

The independent race model provides a simple and elegant description of stop performance in go/no-go and simple stop-signal tasks, and it allows the estimation of the stopping latencies. It has also been applied to the stop–change task and the selective stop task to study cognitive flexibility and selectivity of action control in healthy and