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OBSERVATION

Context, Not Conflict, Drives Cognitive Control

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Theories of cognitive control generally assume that perceived conflict acts as a signal to engage inhibitory mechanisms that suppress subsequent conflicting information. Crucially, an absence of conflict is not regarded as being a relevant signal for cognitive control. Using a cueing, a priming, and a Simon task, we provide evidence that conflict does not have this unique signal status: Encountering a conflict does not lead to behavioral adjustments on subsequent conflict trials, whereas encountering a nonconflict trial does lead to behavioral adjustments on subsequent nonconflict trials. We propose that this apparent role-reversal can be explained by a mechanism that responds to both the presence and the absence of conflict, down-regulating the visuomotor system following conflict, and up-regulating it following nonconflict.

Keywords: cognitive control, conflict, priming, cueing, Simon task

Everyday situations frequently demand that a habitual behavior, triggered by an environmental stimulus, is suppressed in favor of an alternative response. The faster the prepotent but inappropriate response can be inhibited, the less it will interfere with the desired one, and the faster and more reliably the desired response can be produced. Consequently, potentially conflict-rich situations are likely to call for heightened inhibitory readiness. Empirical evidence for the existence of such context adaptation comes from response conflict paradigms, where participants have to make a speeded response to one stimulus or stimulus feature, while ignoring another, distracting stimulus or feature. On any given trial, the distractor is either associated with the same response as the target (*compatible* trial) or with a different response (*incompatible* trial). Responses are typically slower and more error-prone on incompatible than on compatible trials, as the distractor triggers processes that interfere with the intended behavior. It is important to note that these interference effects are context dependent, that is, they are usually smaller following an incompatible than a compatible trial (“Gratton effect”; e.g., Gratton, Coles, & Donchin, 1992; Stürmer, Redlich, Irlbacher, & Brandt, 2007; Wühr & Ansorge, 2007).

The *conflict monitoring account* (e.g., Botvinick, Cohen, & Carter, 2004; Carter et al., 1998) explains the Gratton effect as resulting from a high-level control system monitoring motor

activity. When this system detects simultaneous activation of competing responses, it generates a top-down signal that focuses processing resources on relevant and away from irrelevant stimuli. Thus, neural patterns triggered by subsequent irrelevant stimuli will be less highly activated and cause less interference. The *associative priming account*, in contrast, assumes that the Gratton effect is due primarily to bottom-up stimulus-response priming. In several studies, reduced interference effects have been observed exclusively for trials where stimuli and responses repeat (e.g., Mayr, Awh, & Laurey, 2003; Nieuwenhuis et al., 2006). However, this finding might be specific to response conflict studies using the Eriksen Flanker task (Eriksen & Schultz, 1979). Studies using various other response conflict paradigms found Gratton effects even when controlling for stimulus/response repetitions (e.g., Akcay & Hazeltine, 2007; Kerns et al., 2004; Kunde & Wühr, 2006; Ullsperger, Bylsma, & Botvinick, 2005). To accommodate these and other diverging results, more recent models of behavioral control and context adaptation favor a hybrid approach, combining associative bottom-up learning mechanisms with conflict-driven top-down control (e.g., Davelaar & Stevens, 2009; Verguts & Notebaert, 2009). An entirely different model has been proposed by Scherbaum, Dshemuchadse, Fischer, and Goschke (2010), who suggest that conflict adaptation reflects not a proactive mechanism, but the conflict-triggered reactivation of previously used conflict resolution processes.

The exact nature of the Gratton effect, though, is a factor that surprisingly is often ignored in this field. Note that this effect depends on the relationship between the four different trial sequences (compatible [C] and incompatible [I] trials preceded by either a compatible [c] or an incompatible [i] trial, hereafter labeled cC, iC, cI, and iI, respectively). Both the conflict monitoring account and the reactivation account place the main emphasis on improved performance on iI relative to cI sequences, as the conflict on the preceding trial leads to improved inhibitory control

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and correspondingly reduced interference on the current trial (see Kerns et al., 2004, for an example). Associative priming accounts assign the major effect to improved performance on identical repetition trials (e.g., compatible-left response followed by compatible-left response, or incompatible-left response followed by incompatible-left response; e.g., Mayr et al., 2003; Nieuwenhuis et al., 2006). Neither of these accounts, nor any of the hybrid models, predicts selective performance benefits for cC relative to iC sequences without a corresponding performance benefit for iI relative to cI sequences. Yet this pattern—a trial-type repetition benefit for compatible, but not for incompatible trials—has been observed repeatedly (e.g., Akcay & Hazeltine, 2007; Kunde & Wühr, 2006; Ullsperger et al., 2005). Because of its potential significance for theories of cognitive control, the present study aims to investigate (i) whether selective performance benefits for cC sequences manifest reliably in different response conflict paradigms, and (ii) the dependence of such benefits on stimulus/response repetition. In a series of follow-up experiments, we varied overall levels of response conflict in order to investigate (iii) the extent to which sequential effects are modulated by strategic (expectancy-based) control.

Method

General Design

A cueing, a priming, and a Simon task were employed. These paradigms are similar in general stimulus characteristics and task demands (see Figure 1), yet differ substantially in their (combinations of) task-relevant and -irrelevant information. In the main experiment, 50% of all trials were compatible, 50% were incompatible. In the follow-up experiments, we employed lower (20%) and higher (80%) overall levels of conflict.

Participants

Fifty young healthy undergraduates at the Department of Psychology, University of Warwick, participated for course credit. Each participant completed two tasks: either 50%-Cueing and

50%-Simon ($n = 30$), or 50%-Priming and a task unrelated to the current study ($n = 20$). Task order was counterbalanced between participants.

Stimuli and Procedure

Participants sat in a dimly lit, sound attenuated room, giving responses by pressing buttons with their left and right index fingers. Stimuli were presented on a 17-inch, 60 Hz CRT monitor at a viewing distance of 1 m. In all tasks, two stimuli—separated by a 150-ms interval containing a blank screen or a “frame”—appeared in quick succession, in black on a white background (see Figure 1). The first stimulus was response irrelevant and appeared for 33 ms at the screen center. The second stimulus (target) was response relevant and appeared for 100 ms. The first stimulus was either a left- or right-pointing double-arrow (‘<<’ or ‘>>’, subtending a visual angle of $0.9^\circ \times 0.5^\circ$) or a fixation cross ($0.2^\circ \times 0.2^\circ$). Targets were double-arrows or the letter ‘X’ ($0.4^\circ \times 1.2^\circ$), and appeared either centrally, or 8° from the center on the left or right side of the screen.

Participants gave speeded left- or right-hand responses corresponding to the target location (cueing task) or the target pointing direction (priming and Simon task). Distractor information (i.e., cue direction, prime direction, or target location) corresponded to either the correct or the incorrect response (compatible or incompatible trials, respectively). Left- and right-hand responses were equiprobable. Each participant completed 500 fully randomized trials per task.

Data Analysis

Only trials following a correct-response trial were analyzed. For reaction times (RTs) analyses on correct-response trials, eight trial types (containing 54 trials on average) were extracted for each experiment (2 current-trial conflict [compatible, incompatible] \times 2 conflict sequence [conflict-type repetition, conflict-type alternation] \times 2 response sequence [response repetition, response alternation]) and analyzed using a repeated-measure ANOVA with these factors. Subsequently, we calculated sequential effects as

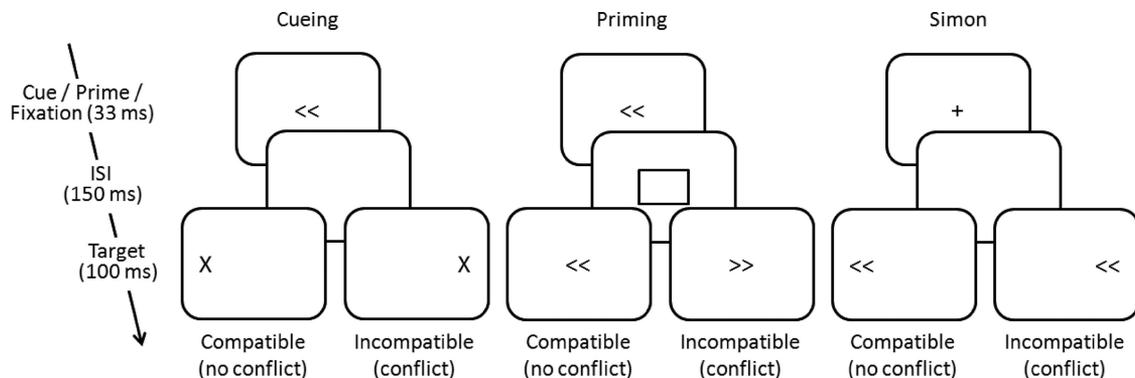


Figure 1. Basic trial structure of the three tasks, with compatible (C) and incompatible (I) trials depicted for each. Note that in the cueing and the Simon task, response-relevant and response-irrelevant information could be readily distinguished by their location, whereas in the priming task, this was not the case. To reduce this additional difficulty, an empty “frame”-like stimulus was inserted between prime and target in this task in a procedure identical to the one Schlaghecken and Eimer (2002) employed.

Table 1
Error Rates (in %) in the 50%-Conditions of the Three Tasks

	Compatible trials		Incompatible trials	
	Conflict type repetition	Conflict type alternation	Conflict type repetition	Conflict type alternation
Cueing Task	0.7 (0.2)	0.9 (0.2)	2.3 (0.5)	5.4 (1.0)
Priming Task	0.5 (0.3)	0.9 (0.4)	3.9 (1.0)	10.3 (2.4)
Simon Task	0.9 (0.2)	3.5 (0.6)	4.0 (0.6)	15.4 (2.1)

Note. Numbers in brackets indicate one standard error.

trial-type repetition benefits (RT on trials preceded by an opposite-conflict-type trial minus RT on trials preceded by a same-conflict-type trial, that is, conflict-type alternation minus conflict-type repetition]). We examined trial-type repetition benefits as a function of current conflict (compatible, incompatible) and response sequence (response repetition, response alternation). Error rates were extremely low, specifically on compatible trials (approx. 1% on average), and thus were descriptively, but not statistically analyzed.

Results

In all three tasks, responses were slower on incompatible than on compatible trials (mean conflict effect: 42 ms), and slower on conflict-type alternation than on conflict-type repetition trials (mean conflict-type repetition benefit: 27 ms), all $F_s > 34.30$, all $ps < .001$. We observed a corresponding pattern for error rates (see Table 1). Importantly, trial-type repetition benefits were larger overall for compatible than for incompatible responses (37 vs. 18 ms; Figure 2, bottom). This asymmetry was nonsignificant in the cueing task, $F < 1.63$, $p > .20$, but highly significant in the priming and the Simon task, both $F_s > 31.40$, both $ps < .001$. Finally, in all three tasks the asymmetry was present only for response alternations (mean compatible trial-type repetition benefits: 40 ms, mean incompatible trial-type repetition benefits: 1 ms), but not for response repetitions (mean values of 33 and 34 ms, respectively), all $F_s > 6.79$, all $ps < .018$.

In a follow-up study, we extended the investigation to conditions where conflict trials appeared with an overall probability of either 20% or 80%. Eighty new participants completed two of the six tasks each (only datasets with more than 5 trials in each condition were included in the analysis, reducing the number of datasets from 160 to 136). Figure 3 shows that the overall pattern of results remained stable: in all tasks, trial-type repetition benefits were larger on compatible than on incompatible trials for response alternations, all $t_s > 1.75$, all $ps < .048$, one-tailed, but were of similar size for response repetitions, all $t_s < 1.30$, all $ps > .22$.

Discussion

Interference effects in response conflict tasks are typically smaller following incompatible (conflict-rich) trials than following compatible (conflict-free) trials. In contrast to predictions derived from conflict monitoring accounts, the present study found that this sequential effect is driven mostly by faster responses on cC (compatible-preceded-by-compatible) trials relative to iC

(compatible-preceded-by-incompatible) trials, and less by faster responses on iI (incompatible-preceded-by-incompatible) trials relative to cI (incompatible-preceded-by-compatible) trials. In particular, and in contrast to predictions derived from associative priming accounts, we found that these trial-type repetition benefits on compatible trials were of similar magnitude for response repetition and response alternation trials (whereas on incompatible trials, they were evident only with response repetitions). This pattern occurred in all experiments despite differences in task characteristics and in overall probability of conflict,¹ suggesting that it reflects fundamental characteristics of the visuomotor system, not a task-specific phenomenon or strategic adjustments. Furthermore, similar patterns of results have recently been obtained in the Eriksen and the Stroop task (Lamers & Roelofs, 2011).

We propose that these effects reflect the operation of a general context adaptation mechanism rather than a mechanism specifically responding to conflict. According to this account, context adaptation occurs continuously as an increase or decrease in the visuomotor system's responsiveness, which comprises two components: activation gain and output threshold. When adjusted in conjunction, these might enhance or cancel overt behavioral effects. This is illustrated in Figure 4. Here, interference effects—RT differences between conflict and nonconflict trials—result from distractor-related visuomotor activation, which directly affects target-related activity levels.² Following compatible (nonconflict) trials, the system “relaxes” its responsiveness (faster increase in distractor-related activation and lower output thresholds), resulting in shortened RTs on compatible (blue open circle) relative to incompatible responses (blue filled circle). Following incompatible (conflict) trials, the system “tightens” its responsiveness (slower increase in distractor-related activation and higher output thresholds). Together, these adjustments prolong RTs on compatible trials (red open circle), whereas for incompatible trials, their combined effect mimics the combined effect of relaxation, result-

¹ Note that these factors modulated sequential effects (smallest in the cueing and largest in the Simon task regardless of overall conflict level, smaller with high than with low levels of conflict regardless of task), but did not substantially alter them.

² In this idealized version, accumulation of target-related activity is assumed to be always at maximum, that is, the system is always maximally susceptible to relevant input (note that an equivalent model could be constructed where distractor-related activity affects the rate rather than the onset level of target-activity accumulation).

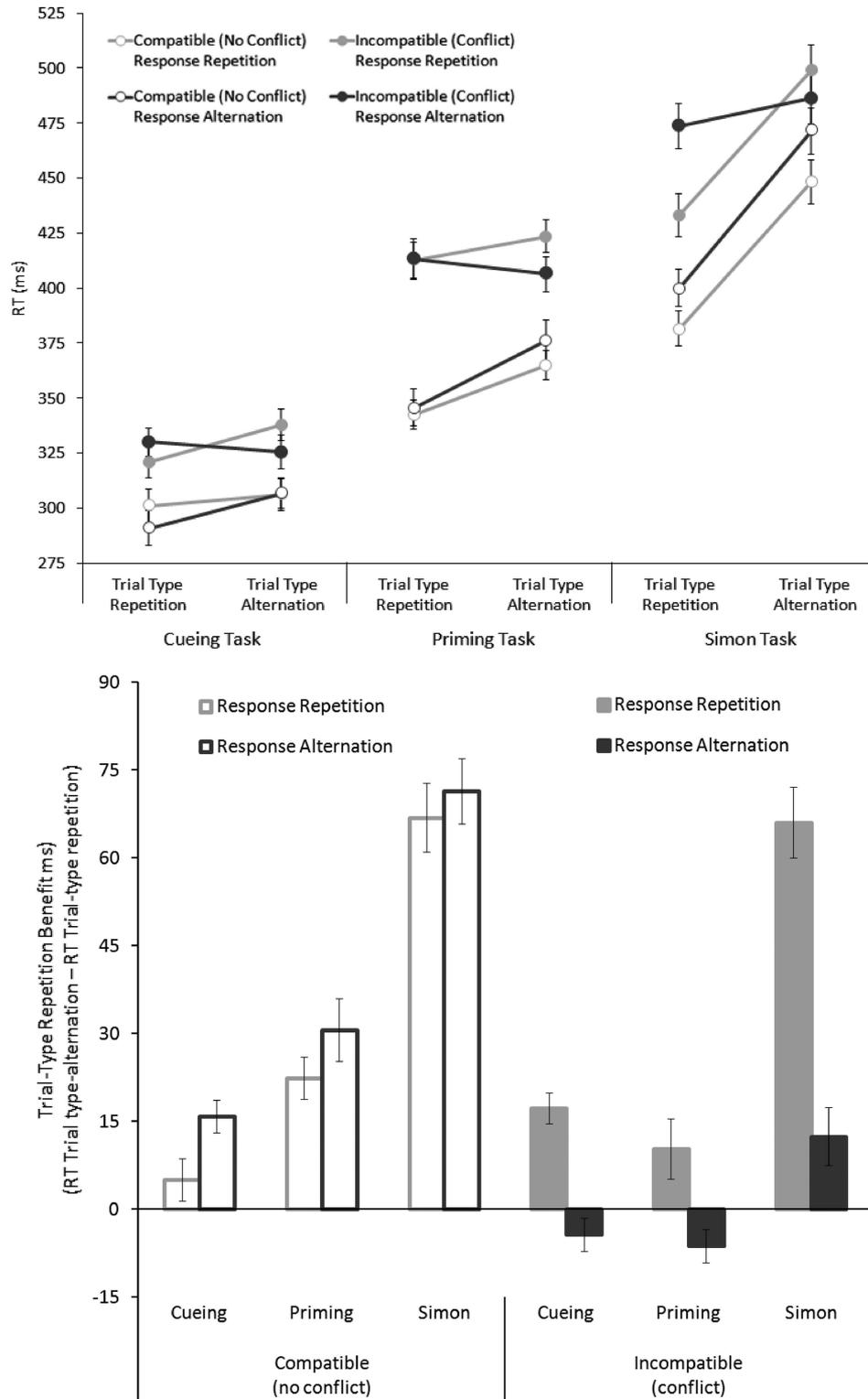


Figure 2. **Top:** Mean RTs (ms) for compatible (open circles) and incompatible (filled circles) trials, plotted separately for trial pairs involving response repetitions (light gray) or response alternations (dark gray), in the Cueing, Priming, and Simon task as a function of previous trial type (same as current trial, opposite to current trial). **Bottom:** Trial-type repetition benefits: RT difference (ms) between trial-type alternation (iC, cI) and trial-type repetition (cC, iI), plotted separately for compatible (open bars) and incompatible (filled bars) trials, and for response repetition (light gray) and response alternation (dark gray). Error bars indicate one standard error of mean.

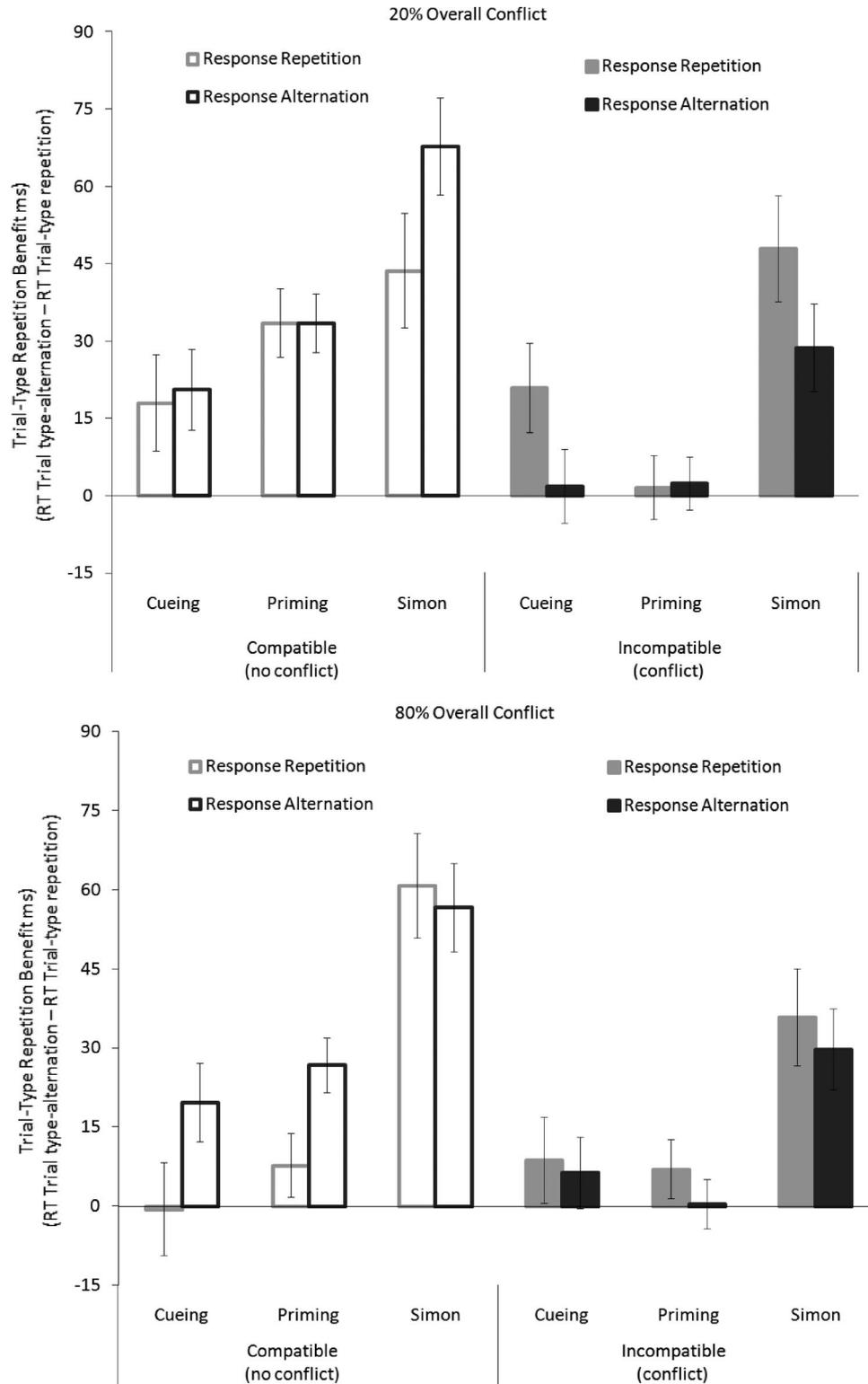


Figure 3. Trial-type repetition benefits: RT difference (ms) between trial-type alternation (iC, iI) and trial-type repetition (cC, iI), plotted separately for compatible (open bars) and incompatible (filled bars) trials, and for response repetition (light gray) and response alternation (dark gray). **Top:** 20% conflict conditions, **Bottom:** 80% conflict conditions. Error bars indicate one standard error of mean.

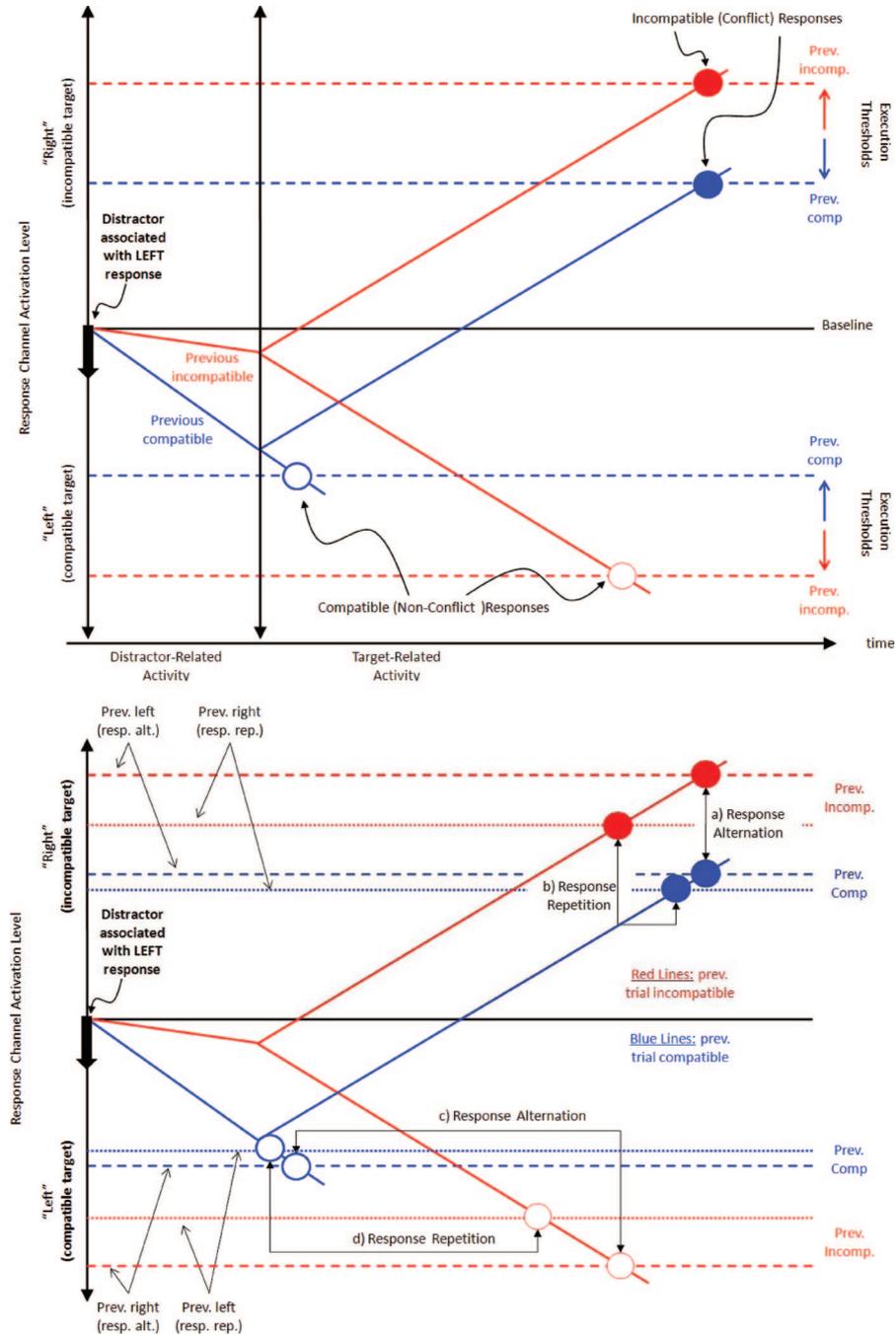


Figure 4. **Top:** A possible mechanism of context adaptation for a 2-alternative response situation (e.g., left and right hand). Blue lines represent the system's behavior following a compatible trial, red lines represent behavior following an incompatible trial. Solid diagonal lines represent changes in a response channel's activation level. Dashed horizontal lines represent response thresholds. Open circles represent compatible-trial responses, filled circles represent incompatible-trial responses. See text for details. [In this example, the distractor is associated with a left-hand response, and the target requires either a left-hand (compatible) or a right-hand (incompatible) response.] **Bottom:** A possible mechanism underlying response repetition effects. Because response repetition benefits are a widely observed phenomenon not restricted to response conflict paradigms (Hale, 1969), we assume that they reflect a general mechanism. Here, this is instantiated by a decrease in response threshold for a just-executed response. Such a decrease is likely to affect high thresholds more than already lowered ones (cf. adaptive gain control mechanisms proposed for the visual [Reynolds & Heeger, 2009] and parietal [Louie, Gratton, & Glimcher, 2011] cortex), producing the type of asymmetry observed in the present data.

ing in unaltered conflict-trial RTs (red filled circle). This system produces a) interference effects (longer RTs on incompatible than on compatible trials), b) Gratton effects (smaller interference effects following incompatible than compatible trials), c) a disproportionately increased error rate on cI trials, where distractor-related activation approaches the execution threshold of the incorrect response (cf. Figure 4, top; Table 1), and d) *observable* trial-type repetition benefits for compatible, but not incompatible, trials (see Figure 4, bottom). Importantly, though, this apparent asymmetry arises from (mirror-)symmetrical adaptations to both preceding compatible and preceding incompatible trials, affecting the visuomotor system on both compatible and incompatible trials. Furthermore, the model is consistent with the finding that context adaptation affects motor performance during, not prior to, response execution (Scherbaum et al., 2010).

Recent developments in the understanding of prefrontal function, particularly of the anterior cingulate cortex (ACC), seem to fit better with such a general context adaptation model than with a conflict monitoring account. Although it traditionally is seen as a ‘conflict control center,’ the ACC (together with subcortical structures, especially the basal ganglia, e.g., Humphries & Prescott, 2010) now often is regarded as serving the more general function of tracking the history of events and their outcomes (e.g., Kennerley, Walton, Behrens, Buckley, & Rushworth, 2006; Nachev, 2006). Accordingly, monitoring and decision-making views of ACC function (see Botvinick, 2007) might be reconciled within a common framework of online context adaptation, without the need to ascribe a specifically significant signal function to conflict.

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