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Adaptive control of response preparedness in task switching

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ABSTRACT

When rapidly switching between two tasks, bivalent stimuli can accidentally trigger the previously executed and therefore still activated response. Recently, it has been suggested that behavioral response-repetition effects reflect response inhibition that reduces the risk of such erroneous response repetitions. The present study investigated neural correlates of this inhibition process using lateralized readiness potentials (LRP). In three experiments, we demonstrate a response-switch bias emerging during the preparatory interval which is independent of task sequence (Experiment 1), which is linked to task preparation (Experiment 2), and which is present only under task-switching conditions (Experiment 3). These results suggest that the bias reflects a control process that adaptively regulates response preparedness.

Complex human action often consists of a series of elementary tasks. Because these tasks have usually to be executed in a specific order, control processes are necessary which prepare the mental system for every new task. Numerous processes have been identified that support this task preparation, like memory retrieval (Mayr & Kliegl, 2000), attention adjustment (Meiran & Marciano, 2002) or cue processing (Koch, 2003). An essential role in this context is played by the control of response preparedness. When confronted with a new task, only task-relevant responses should be in a prepared state. Moreover, response preparedness should adapt to the risk by which specific responses could cause an error. Responses which are at risk to be accidentally triggered by available stimuli should be in a less prepared or even inhibited state. For instance, before one enters the supermarket to buy some healthy vegetables, it could be appropriate to prepare "take the carrots" and to inhibit "take the chocolate".

A special case is given when a response was executed recently, and thus, is still in an activated state. Because the risk to be accidentally triggered by an upcoming stimulus is particularly high for such a response, there should be a general tendency to inhibit the previously executed response. This idea receives support from behavioral studies on task switching showing that repeating the response on consecutive trials can be costly under certain conditions. This response-repetition cost has been attributed to the inhibition of the previously executed response (Druey & Hübner, 2008a, 2008b; Hübner & Druey, 2008; Steinhauser & Hübner, 2006). Our aim in the present study was to demonstrate this inhibition in a more direct way by measuring physiological correlates of response preparedness using event-related potentials. Before we introduce our method, though, a brief overview over the relevant paradigms and studies is provided.

The task-switching paradigm (Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995) is frequently used to investigate processes underlying task preparation. In one version of this paradigm, participants perform multiple tasks in a randomized order in which a cue indicates the relevant task on each trial (Meiran, 1996). Most studies on task switching focused on the so-called switch costs which refer to increased response times and error rates on task-switch trials relative to task-repetition trials and which are attributed to task preparation (Rogers & Monsell, 1995; Steinhauser, Maier, & Hübner, 2007) as well as to memory effects (Allport et al., 1994; Schuch & Koch, 2003; Steinhauser & Hübner, 2006). Another interesting phenomenon, however, is the complex pattern of response-repetition effects, initially reported by Rogers and Monsell (1995). Numerous studies found a response-repetition cost when the task switched, but a smaller cost or even a response-repetition benefit when the task repeated (e.g., Hübner & Druey, 2006; Kleinsorge, 1999; Lien, Schweickert, & Proctor, 2003; Rogers & Monsell, 1995; Schuch & Koch, 2004; Steinhauser & Hübner, 2006).

A variety of theories has been proposed to account for this pattern. Most relevant in the present context is the idea that response-repetition effects in task switching result from the interplay of two processes (e.g., Druey & Hübner, 2008b; Hübner & Druey, 2006; Rogers & Monsell, 1995; Steinhauser & Hübner, 2006). One process is the inhibition of the previously executed response which should prevent that this response is accidentally triggered by the next stimulus. Because the probability that an accidental response repetition leads to an error is independent of whether the task is repeated or switched, inhibition should be similar for task

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repetitions and task switches. Accordingly, this alone would imply a general response-repetition cost. Usually, however, costs show up only on task-switch trials. This is explained by the assumption that on task-repetition trials, inhibition is compensated by category priming. When the task as well as the response is repeated, priming of the stimulus category has a strong facilitative effect. As a consequence, inhibition produces a response-repetition cost on task-switch trials, whereas category priming reduces this cost or even turns it into a response-repetition benefit on task-repetition trials.

Evidence for this two-process account has been provided, for instance, by Hübner and Druey (2006). In their experiments, stimuli were used which required the same response for each task (congruent stimuli) or a different response for each task (incongruent stimuli). When the previous stimulus was congruent, the response-repetition benefit on task-repetition trials was decreased to the same amount as the response-repetition cost on task-switch trials was increased (see, Fig. 2 in Hübner & Druey, 2006). In other words, the inhibitory component was selectively increased. To explain this, they argued that congruent stimuli imply stronger activation of the executed response. This, in turn, increases the risk that this response is accidentally triggered by the next stimulus. To counteract this risk, more inhibition of this response is required on the next trial (see also, Druey & Hübner, 2008b).

A similar increase of the response-repetition cost was shown under conditions of strong time pressure (Steinhauser & Hübner, 2006). From a theoretical view, this is plausible given that time pressure induces a lower response criterion. Under these conditions, more inhibition of the previously executed response is beneficial because a low criterion increases the risk that an accidentally triggered response exceeds this criterion. Finally, when stimuli were used that were linked to one task only, inhibition seemed to be largely absent (Hübner & Druey, 2006). This supports the idea that inhibition is linked to the risk that an error occurs when the stimulus triggers the previously executed response. When stimuli are linked to only one task, then the stimulus is associated only with the correct response and thus cannot trigger the wrong response.

Despite these findings, the behavioral response-repetition effect is rather limited as an indicator of response preparedness. As mentioned above, only a portion of the response-repetition effect can be due to inhibition because the effect of inhibition is blurred by category priming when the task is repeated (e.g., Hübner & Druey, 2006). Moreover, other authors have proposed mechanisms which might further contribute to the complex response-repetition effects, and which would affect task-repetition trials as well as task switch-trials. For instance, Kleinsorge (1999) suggested that preparing a task-switch generally implies preparation of a response switch and vice versa. Finally, other authors assumed a process called response recoding which alone would imply response-repetition benefits on task-repetition trials but response-repetition costs on task-switch trials (Meiran, 2000; Schuch & Koch, 2004). Taken together, without precise knowledge of how these mechanisms contribute to the overall pattern, a valid estimation of the inhibitory component of the response-repetition effect is difficult. Because of this, it would be desirable to have a more direct measure of response inhibition.

We assumed that response inhibition can be measured more directly by considering an event-related potential called the lateralized readiness potential (LRP, de Jong, Wierda, Mulder, & Mulder, 1988; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). The LRP corresponds to the relative increase of scalp potentials over motor areas contralateral to the response hand, and is regarded as a correlate of the preparedness for a specific hand response. In the context of task switching, LRPs were used to investigate the source of the switch cost and the mechanisms underlying task preparation (de Jong, Gladwin, & t Hart, 2006; Gladwin, Lindsen, & de Jong, 2006; Hsieh & Liu, 2005; Hsieh & Yu, 2003a, 2003b).

In the present study, we investigated response inhibition using the LRP as a measure of response preparedness. To this end, a simple task-switching paradigm was applied in which the participants classified digits as odd/even or as less/greater than 5 by responding with their left or right hand, respectively. Task order was randomized and the relevant task on each trial was indicated by a cue preceding the stimulus. The participants were instructed to respond very quickly because time pressure seems to promote the observation of response inhibition (Steinhauser & Hübner, 2006). Based on the previous considerations, a simple prediction could be derived. If response inhibition influences response preparedness, the LRP should show a bias toward the previously not executed response emerging during the preparatory interval. In the following, we not only demonstrate the existence of such a response-switch bias, but also provide evidence that this bias is linked to response inhibition as postulated by Hübner and Druey (2006): We show that the response-switch bias is similar for task-switch trials and task-repetition trials (Experiment 1). Moreover, we provide evidence that the bias is related to task preparation (Experiment 2), and occurs only under conditions where the stimuli can accidentally trigger the wrong response (Experiment 3).

1. Experiment 1

The first experiment tested the crucial predictions of the response-inhibition account. To this end, we examined LRP epochs comprising the response on trial $n-1$ as well as the response on trial n. Specifically, we focused on the cue-stimulus interval (CSI) in which participants prepare the upcoming task. According to our hypothesis, a response-switch bias should emerge during this interval reflecting the inhibition of the previously executed response. At stimulus onset on trial n, the LRP should be biased toward the correct response if a response switch is required, whereas it should be biased toward the incorrect response if a response repetition is required. Moreover, this bias should be similar for task-repetition trials and task-switch trials. Any LRP effects related to task sequence should emerge not before stimulus onset.

If we observe a response-switch bias emerging during the CSI, then the question arises whether this bias can be attributed to task preparation. To allow for such an interpretation, one has to show that the participants really prepare the task during the CSI, which is not self-evident in a procedure like the present one (cf., Altmann, 2004; Koch, 2001; Steinhauser et al., 2007). To test this, we additionally examined electrophysiological correlates of task preparation. Indeed, a number of studies showed a positivity on parietal channels for task-switch trials relative to task-repetition trials, which has been interpreted as a correlate of endogenous task preparation (Barcelo, Escera, Corral, & Perianez, 2006; Barcelo, Perianez, & Knight, 2002; Karayanidis, Coltheart, Michie, & Murphy, 2003; Miniussi, Marzi, & Nobre, 2005; Nicholoson, Karayanidis, Poboka, Heathcote, & Michie, 2005; Nicholson, Karayanidis, Bumak, Poboka, & Michie, 2006; Nicholson, Karayanidis, Davies, & Michie, 2006). If we find a similar effect, this would support the assumption that task preparation took place during the CSI.

1.1. Method

1.1.1. Participants

Sixteen participants (12 female, 4 male) between 19 and 27 years of age (mean 22.2) with normal or corrected-to-normal vision participated in the study. Participants were recruited at the Universität Konstanz and were paid 5€/h. The study was conducted in