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Shielding and relaxation in multitasking: Prospect of reward counteracts relaxation of task shielding in multitasking☆

Rico Fischer[a,⁎], Kerstin Fröber[b], Gesine Dreisbach[b]

[a] Department of Psychology, University of Greifswald, Greifswald, Germany
[b] Department of Experimental Psychology, University of Regensburg, Regensburg, Germany

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ABSTRACT

Performing two similar tasks at the same time requires the shielding of the prioritized Task 1 from interference of additional Task 2 processing (between-task interference). In the present study we tested how motivational factors such as prospect of reward might drive shifts between increased proactive control, enabling task shielding, and reduced proactive control resulting in relaxed task shielding. In Experiment 1 an instruction-induced prioritization of Task 1 over Task 2 resulted in initially reduced between-task interference. With increasing time on task, however, between-task interference continuously increased, presumably because participants engaged less in proactive control resulting in reduced task shielding. In Experiment 2 the prospect of reward activated proactive control as indicated by reduced between-task interference in the Reward than in the No reward condition. In Experiment 3, we directly compared the performance of a Reward and a No reward group in a between-subject design. Whereas between-task interference again continuously increased over time in the No reward group, indicating a relaxed mode of task shielding, the Reward group displayed constant small between-task interference over time, suggesting maintained high levels of task shielding. Together these findings speak in favor of an impressive flexibility in regulating cognitive control engagement in multitasking situations. This not only shows the capacity for optimization of multitasking performance by motivational incentives but also further supports assumptions of the strategic nature of assumed processing limitations (bottlenecks) in dual-task performance.

1. Introduction

Increased levels of multimedia interactions and complex human-technological interactions emphasize the need for higher multitasking efficiency. At the same time, multitasking is often characterized as costly. Indeed, the subjective feeling of efficiency of "getting several things done at the same time" repeatedly tricks us into engaging in complex multitasking situations that often incur costs rather than benefits compared to sequential single task execution. It is thus not surprising that an important endeavor in basic and applied cognitive research is the quantification of multitasking costs and the determination of measures for its potential reduction and/or circumvention. In this context, the starting point of the present study is based on increasing evidence suggesting that prioritization of one task over the other in multi-tasking can reduce such dual-task costs (Fischer & Plessow, 2015). Here, we aim at showing that such a strategic prioritization is relaxed with increasing time on task, but that this relaxation can be prevented by the prospect of performance-contingent reward.

The cost of multitasking is evident even when simultaneously engaging in putatively simple cognitive tasks, which has contributed to the assumption of a structural processing limitation underlying the performance decrement in dual task processing (Pashler, 1994; Welford, 1952). The influential response selection bottleneck (RSB) model assumed that two cognitive tasks are processed independent of each other and that scheduling is realized by a first come – first serve mechanism. In particular, the RSB model proposes that peripheral processing stages (e.g., perception, motor stage) of two tasks can occur in parallel whereas central stages (e.g., response selection) require access to a single processing channel that is limited in resources and thus can process response selection from only one task at a time. When both

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⁎ Corresponding author at: Department of Psychology, University of Greifswald, D-17489 Greifswald, Germany.
E-mail address: rico.fischer@uni-greifswald.de (R. Fischer).

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tasks overlap strongly in time the response selection of Task 2 (T2) has to wait until central processing of Task 1 (T1) is finished. This cognitive slack reflects an interruption of T2 processing, a so-called bottleneck or psychological refractory period (PRP).

Although extremely powerful in its explanatory value for an abundant amount of empirical research data, this model of dual-task performance is at the same time severely limited in explaining dynamic adjustments of multitasking performance to changing environments. In fact, alternative theoretical models propose a functional rather than a structural processing limitation (Feng, Schwemmer, Gershman, & Cohen, 2014; Logan & Gordon, 2001; Tombu & Jolicoeur, 2003) that allows for a strategic regulation of cognitive control in dual-task performance (e.g., Meyer & Kieras, 1997). Moreover, the idea of functional limitations (e.g., computational limitations when cognitive control schedules multiple processes that require the same representation, cf. Feng et al., 2014) offers potential explanations for intra-individual performance variability in multitasking and allows for the identification of measures to increase multitasking efficiency.

Recent studies have shown that individuals can flexibly adopt different processing strategies that are associated with different levels of cognitive control engagement and resource investment, which might be labeled as relaxation on the one side and shielding on the other (see Fischer & Plessow, 2015 for an overview). For example, oftentimes two tasks are not processed independent of each other as originally proposed in RSB. In fact, the desire of engaging into multiple tasks clashes with the demand of interference-free processing of the prioritized task. When both tasks are highly similar, task shielding is required to avoid confusions in the simultaneously running stimulus-response translation processes in each task (e.g., assigning the correct stimulus to the correct response). As a consequence, cognitive control is required to keep stimulus processing and task representations separate (Logan & Gordon, 2001). In most situations, a strict avoidance of simultaneous task processing by shielding (i.e., adopting serial instead of parallel processing) seems to represent the most effective processing strategy (but see Reissland & Manzey, 2016). However, the continuous shielding of prioritized task processing comes with increased cognitive labor and mental effort (Lehle, Steinhauser, & Hübner, 2009) and is avoided when resources need to be saved (Plessow, Schade, Kirschbaum, & Fischer, 2012). The strategy of cognitive leisure and thus relaxation of control, on the other side, comes at the cost of increased between-task interference. Interestingly, the adoption of either processing strategy – relaxation vs. shielding – has been shown to depend on given instructions (Lehle & Hübner, 2009; Plessow, Schade, Kirschbaum, & Fischer, 2017), task demands (Fischer, Miller, & Schubert, 2007), contextual regularities (Fischer, Gottschalk, & Dreisbach, 2014; Miller, Ulrich, & Rolke, 2009), recent experience of between-task interference (Janczyk, 2016; Scherbaum, Gottschalk, Dshemuchadse, & Fischer, 2015), or on a priori induced control states (Fischer & Hommel, 2012).

In the present study we followed the idea of a strategic performance optimization in dual-task performance by addressing the question of how motivational factors drive cognitive control engagement. On the basis of the dual-mechanisms framework of cognitive control (Braver, 2012) we investigated the strategic involvement and shifts between deliberate engagement in proactive control and task shielding on the one hand and a less proactive and/or more reactive control and relaxation on the other. In dual tasking, we would assume that proactive control can be recruited to reduce the impact of expected interference by task-irrelevant information. More precisely, proactive control supports the maintenance of task instructions, namely the prioritization of T1 processing while maintaining fast and accurate performance in both tasks. However, since the engagement in proactive control is effortful and resource demanding, it will only be maintained when experienced as utilitarian and rewarding. In contrast, reactive control is considered a late correction mechanism that is not triggered in advance but only after stimulus onset and thus requires much less resources and effort. We argue that in dual tasks, the instruction of how to perform two tasks simultaneously promotes a proactive control set with high levels of shielding the prioritized task (Lehle & Hübner, 2009; Plessow et al., 2017) that is pursued at the start of an experiment. This enhanced level of proactive control, however, might eventually vanish and might be substituted by the adoption of a less demanding reactive control mode (Plessow et al., 2012). This relaxation of shielding would thus result in increased between-task interference in the course of the experiment. Therefore, in a first step we tested the stability of proactive processing in dual tasks and its potential shift to a less proactive and/or more reactive control mode with increasing time on task (Experiment 1). We then investigated the ability to flexibly shift between different modes of control by means of motivational incentives such as prospect of reward (Experiment 2). This reasoning is based on the well-documented evidence that the prospect of reward increases proactive control in terms of increased task shielding and context maintenance (e.g., Chiew & Braver, 2014; Fröber & Dreisbach, 2014; Hefer & Dreisbach, 2017). In a final Experiment 3 we implemented a between-subjects design to directly compare dual-task performance in a No reward group and in a Reward group over the course of the experiment.

The cognitive control demand under investigation in the present study is the ability to minimize between-task interference by means of protecting T1 processing from influences of simultaneous additional T2 processing. The functioning of this shielding process can be inferred by the extent of observed processing interference between tasks. Small between-task interference reflects strong T1 shielding and large between-task interference reflects relaxed T1 shielding (Fischer & Hommel, 2012). Note, that there are currently separate (not mutually exclusive) mechanisms discussed how shielding can be realized, e.g., by increasing prioritized task processing (Stelzel, Brandt, & Schubert, 2009) or by temporarily inhibiting non-prioritized task processing (Koch, Gade, Schuch, & Philipp, 2010). T1 shielding has typically been studied in dual-task paradigms that include two similar tasks that share considerable dimensional overlap to ensure the observation of between-task interference. In its most extreme form, two tasks may be identical, i.e., they require the same categorization rule (e.g., Fischer et al., 2007; Logan & Schulkind, 2000). For example, participants perform a parity judgment task (i.e., odd versus even) on two stimuli. A first digit (S1) is presented in an upper position of the screen (T1) and a second digit (S2) is presented in various temporal intervals in a lower position of the screen (T2). Interactions between simultaneous processing of these tasks are captured in the so-called response-category (RC) compatibility effect in T1 (i.e., crosstalk).[1] RC compatibility is found when S1 and S2 require the same categorization (e.g., both odd) and RC incompatibility occurs when S1 and S2 require different categorizations (e.g., S1-odd and S2-even or vice versa). The influence of S2 categorization on processing S1 has been termed "backward crosstalk" and can be taken as a marker for T1 shielding (Janczyk, 2016; Plessow et al., 2012; Zwosta, Hommel, Goschke, & Fischer, 2013).[2] The stronger the shielding of the prioritized T1 the smaller is the expected RC compatibility effect.

[1] On a theoretical level, RC compatibility effects are often explained by means of automatic response activation processes in both tasks that interact irrespective of assumed processing limitations in dual tasks or by means of shared capacity between simultaneous task component processing (for an overview see Fischer & Plessow, 2015; Janczyk, Pfister, Hommel, & Kunde, 2014; Lien & Proctor, 2002; Logan & Gordon, 2001). This crosstalk between tasks is thus incompatible with traditional conceptions of the RSB model, but effort has been made for reconciliation (Hommel, 1998; Lien & Proctor, 2002; Schubert, Fischer, & Stelzel, 2008).

[2] The influence of S2 categorization onto T1 propagates back onto T2 at the central bottleneck stage (for the propagation logic, see Fischer & Plessow, 2015; Janczyk, Renas, & Durst, 2017; Schubert et al., 2008). In addition to this propagation effect, S1 categorization also influences S2 processing, which is also termed "forward crosstalk". Therefore, an often-observed finding is larger crosstalk in T2 than in T1. Because of the often-emphasized T1 prioritization, crosstalk effects in T2 are of lesser theoretical importance.