



Generic cognitive adaptations to task interference in task switching

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ABSTRACT

The present study investigated how the activation of previous tasks interferes with the execution of future tasks as a result of temporal manipulations. Color and shape matching tasks were organized in runs of two trials each. The tasks were specified by a cue presented before a task run, cueing only the first trials of each run. Response times (RTs) and error rates were measured for task switching and task repetition conditions. Task interference was varied as a function of response-cue interval (RCI of 300 and 900 ms), that is, the interval between the task runs. Keeping the response-stimulus interval within the task runs constant at 300 ms allowed the disentangling of the *direct* effects of RCI manipulation on performance (first trials) from the *general* effects on performance (both trials in the run). The data showed similar performance improvement due to RCI increase on both trials in the task run. Furthermore, increasing RCI improved both switch and repetition performance to a similar extent. Together, our findings provide further evidence for accounts stressing generic effects of proactive task interference in task switching.

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1. Introduction

Optimal task execution in a dynamic environment depends on an efficient interaction between maintaining the current goal and protecting it from distractions on the one hand and changing the focus if needed on the other hand. Recently, the interplay between processes involved in the control of adaptive actions has been explored by using different versions of the task-switching paradigm (e.g., see Monsell (2003) for an overview). This paradigm typically involves two competing tasks, each requiring responding to a stimulus feature according to a specific, arbitrary stimulus-response (S-R) mapping. In the present study, for instance, we used geometrical figures filled with different colors, and the two tasks assigned to these bivalent stimuli were color and shape matching tasks. Since bivalent stimuli as such can call for both tasks, cues are mostly used to specify the required task, which can differ from (task switch) or be the same as (task repetition) the task performed on the previous trial. In such a dynamic context, task execution depends on both intentional (e.g., cue-based preparation of the upcoming task) and unintentional (e.g., proactive interference from the competing task) factors

(e.g., Koch & Allport, 2006). Goal of the present study was to investigate how the activation of previous tasks interferes with the execution of future tasks as a result of temporal manipulations in task switching.

First to point out the involvement of task interference in task switching were Allport, Styles, and Hsieh (1994). They proposed that a performance cost observed when comparing task switches with task repetitions, namely the so-called *switch cost*, was directly linked to involuntary carryover effects from the competing task executed on the previous trial. Once activated, tasks maintain a heightened state of activation for substantial amounts of time. According to this view, proactive interference arises thus due to inertia of task activation. This idea has been supported by different empirical evidence mainly coming from studies manipulating the response-cue interval (RCI). The finding reported is a reduction in switch cost with increasing RCI (e.g., Koch, 2001; Meiran, Chorev, & Sapir, 2000; Sohn & Anderson, 2001). The reasoning is based on the assumption that, after a task is being executed, its activation decays over time. Accordingly, the activation of a task just performed decays more if the interval between the produced response and the instruction for the upcoming task (i.e., RCI) is prolonged. So, when this upcoming task involves a task switch, the decrease in persisting activation of the just abandoned task reduces the existing interference between the two competing tasks resulting in a performance improvement on the switch trial. In contrast to this positive effect, activation decay produces performance deterioration for task repetitions. Namely, the benefit of repeating the

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same task (task-repetition priming) decreases with RCI increase causing performance deterioration on repetition trials.¹

Empirically, these two effects have been observed either in isolation, that is, as performance benefit on switch trials only (e.g., Altmann, 2005, Experiment 1; Koch, 2001) or as performance deterioration on repetition trials only (e.g., Altmann, 2005, Experiment 2), or in combination (e.g., Sohn & Anderson, 2001). Considering the switch cost, decrease in both task interference and in task-repetition benefit has the same eventual outcome, namely, a reduction in switch cost. Some studies, however, failed replicating the positive RCI effect on switch cost in some conditions (e.g., Altmann, 2005; Luria & Meiran, 2003; Meiran, Levine, Meiran, & Henik, 2000). Altmann, for instance, observed reduction in switch cost due to RCI increase only if RCI was manipulated within participants. When manipulating the RCI between participants, Altmann reported a general performance improvement with longer RCI. Specifically, increasing RCI between participants produced an equal performance benefit for both task switch and task repetition performance (but see Koch, 2001). Interestingly, Cepeda, Kramer, and Gonzales de Sather (2001) reported a similar general performance improvement even with a within-subject manipulation of RCI in a condition where cueing of tasks was relatively short. For relatively long task cueing, however, prolonging the RCI had no significant effect on performance in their study. Taken together, the empirically observed positive effects of longer RCI on repetition trials in particular (Altmann, 2005; Cepeda et al., 2001) cannot be explained in terms of decaying task activation (i.e., decay of task interference and of task-repetition benefit). These effects rather suggest a more general influence of task interference and decaying task activation in task switching.

Additional empirical evidence for the involvement of task interference in general task execution in task switching has been provided by studies examining performance costs in repetition trials, namely the *restart cost* and the *mixing cost*. Restart cost is observed on the first trials compared to the multiple trials that follow in a task run involving a task repetition (e.g., Allport & Wylie, 2000; Altmann & Gray, 2002; Gopher, Armony, & Greenspan, 2000; Poljac, De Haan, & Van Galen, 2006). In such a run, only the first trials are cued. Mixing cost, on the other hand, is observed as slower responses on repetition trials under mixed-task conditions compared to responses on repetition trials under single-task conditions (e.g., Los, 1996; Rubin & Meiran, 2005). Involvement of task interference was suggested in both restart cost (Poljac, Koch, & Bekkering, 2009) and mixing cost (e.g., Koch, Prinz, & Allport, 2005; Philipp, Kalinich, Koch, & Schubotz, 2008; Rubin & Meiran, 2005). Specifically, in all these studies, increase in task interference harmed the repetition performance. Altogether, task interference seems to affect the performance in task switching in such a way that it generally impairs the execution of tasks rather than just impairing the performance specifically on switch trials.

Recently, Altmann and Gray (2008) (see also Altmann, 2002) proposed a cognitive-control model (CCM), in which task interference has a slightly different role in task switching than originally proposed by Allport et al. (1994). While the basic assumption of proactive interference being the main constraint on performance is quite similar to the one proposed by Allport et al., the model

assumes no direct relation between proactive interference and switching performance. Altmann and Gray propose that proactive interference asks for cognitive adaptations that allow the cognitive system to successfully adapt to the dynamics of conditions involving frequently changing task requirements. According to them, controlled performance depends on maintaining access to the mental representation of the current task (task code) in episodic memory. As proactive interference from old task codes limits this access, other memory processes are organized to overcome the interference. The retrieval of the currently correct task code among other competing codes is realized in the model by a dynamic relation between *activation* and *decay* of tasks codes. The model assumes that when a task cue is presented, cue-encoding processes activate the relevant task code in episodic memory to a level at which it will be more active than any other and thus accessible enough to govern performance to the required number of trials. After the stimulus presentation, the relevant task code is retrieved from episodic memory, if its activation has passed the retrieval threshold. It is assumed that the retrieval threshold is adjustable for each task run and adapts to the current interference level, which is determined by the activation of the most active old task code. While the activation level required for the retrieval of the currently relevant task code is achieved by encoding processes, the extent to which the current task code interferes with its successors is limited by decay of its activation. According to Altmann and Gray, decay plays a functional role in task switching as an automatic process that protects the cognitive system from a catastrophic buildup of proactive interference that might eventually make flexible cognitive control impossible. The dynamic interplay between the two mechanisms generates different behavioral phenomena (e.g., switch cost, restart cost, and preparation effects) demonstrating that cognitive control in task switching is reflected in more behavioral phenomena than in switch cost only. So, this view emphasizes more the generic effects that proactive interference might have on task execution in task switching.

The present study was conducted to test the basic assumption of CCM (Altmann & Gray, 2008) that proactive task interference calls for cognitive adaptations in terms of strategic and automatic processes described above, that is, activation and decay of task codes, respectively, affecting a more general level of task execution when switching between conflicting tasks. Additionally, we made a first attempt in comparing this idea with the one proposed by Allport et al. (1994), who suggested a direct causal relation between proactive task interference and switch cost. While CCM predicts that the cognitive system manages proactive interference through more general memory processes that generate different behavioral effects, account proposed by Allport and colleagues predicts a more local control of interference directly reflected in switch cost.

To compare the assumptions of the CCM (Altmann & Gray, 2008) with the account proposed by Allport et al. (1994), a task-switching paradigm was used, in which the two tasks were color and shape matching. The tasks were organized in runs of two trials, in which only the first trial was cued. The cue was presented for 300 ms and disappeared before the stimulus onset. The amount of interference between the two tasks was varied as a function of RCI duration between task runs. Each participant switched between the two tasks within a relatively high (300 ms of RCI) and a relatively low (900 ms of RCI) interference context. The two levels of RCI were presented in a block-wise manner involving an equal number of task runs (i.e., task cues) each. Based on both accounts, we assumed here that allowing for more decay of activation of tasks in the previous run reduces interference between tasks. The critical feature of our paradigm was that while the RCI between task runs was varied, the response-stimulus interval (RSI) within task runs was kept constant at 300 ms. In this way,

¹ In addition to this, Wylie and Allport (2000) (see also Allport & Wylie, 1999; Allport & Wylie, 2000) reported another type of task interference in task switching. They observed negative priming effects arising from individual task-stimuli that, after being associated with one of the tasks, were presented in the context of the competing task. They proposed that these stimuli functioned as a cue automatically triggering retrieval of the task with which they have implicitly been associated in the previous trials. These specific stimulus-based priming effects seem to be long lasting (e.g., Waszak, Hommel, & Allport, 2003) and not directly related to task decay (i.e., RCI) effects (Koch & Allport, 2006).

we could examine and compare the possible direct contribution of task interference to switch cost, measured as difference in switch and repetition performance on cued trials (performance on Trial 1) and the possible effect of task interference on the general task execution (performance on Trials 1 and 2). If proactive interference from the previous trial directly causes switch cost, then allowing for more decay of the competing task just executed should affect the performance on the first trials but not on the second trials in a task run. If, however, task interference is managed by more general cognitive adaptations as suggested by CCM, then increasing task interference should affect both the first and second trials in the run even though the interval just before the second trial (i.e., RSI) was held constant. Finally, finding evidence for the latter view would make it interesting to further examine the time course over which the cognitive system adapts to the different levels of RCI used in our study, as CCM predicts that the system adjusts the retrieval threshold in response to different interference levels.

2. Method

2.1. Participants

Forty participants, 30 women and 10 men, were all undergraduate students from Radboud University Nijmegen. Their ages ranged between 18 and 43 years, with a mean age of 21.9 years. Three participants were left-handed, and the remaining 37 were right-handed. All participants had normal or corrected-to-normal vision. Four additional participants were excluded because their accuracy was below 90%.

2.2. Stimuli and tasks

The stimuli were four different geometric figures (a square, a triangle, a circle, and a hexagon) displayed in one of four different colors (red, blue, yellow, or green). On each trial, a reference figure and four match figures were presented. The reference figure was displayed in the upper half of the screen, while the four match figures were displayed simultaneously in the lower half of the screen. The color-shape combination of the stimuli was randomly chosen on each trial with two restrictions. First, no simultaneous occurrence of the same shape or color was allowed among the four match figures within a trial. Second, the exact match (in both shape and color) was not allowed between the reference and the match figures. The two tasks were to match either the color or the shape of the reference figure to one of the four match figures. Written cues (words 'color' and 'shape'), printed in uppercase 32-point Times New Roman font, were used to announce the upcoming task.

2.3. Procedure

The experiment consisted of a single session with one participant at a time. The participant received written instructions displayed on a Pentium 650 MHz (17 in. effective screen), which was placed at a distance of approximately 60 cm. Verbal explanation of the experiment was also given. The participant was asked to respond as quickly and accurately as possible by pressing one of the four buttons on a button box with either the index or middle finger of either the right or left hand. The four buttons corresponded to the location of the four match figures that were presented on the screen. Both the reference and the match figures remained on the screen until the participant gave a response or until the maximum response time of 3 s had elapsed (no-response). In the latter case, the participant received feedback to respond more quickly.

After reading the instructions, the participant started practicing the tasks. The actual tasks were organized in pairs of two trials we called task runs. The difference between the two tasks lay in the relevant stimulus information, which means that either the color or the shape of the reference figure needed to be matched. The cue, which specified the nature of the upcoming task, appeared at the center of the computer screen at the beginning of a task run and disappeared after 300 ms of CSI. Immediately after the cue disappeared, the first stimulus appeared on the screen until a response (or feedback if too slow) was given. The interval between the response to the first stimulus and the presentation of the second stimulus, the RSI, was fixed at 300 ms within task runs. The response to the second stimulus was followed by either 300 or 900 ms of RCI, after which period a new run started, again preceded by a task cue. No switching between the two tasks occurred within runs, which means that all the second trials were task-repetition trials. Participants first completed 24 practice runs and then a total of 376 experimental runs divided into four consecutive blocks. The four blocks were separated by a pause that was self-paced. The first four task runs of each experimental block were considered as warming up runs.

2.4. Design

Half of all 376 experimental runs were the so-called *switch* runs, in which the task differed from the task in the previous run. The other half were the *task-repetition* runs, in which the task to be performed was identical to the task in the preceding run. The two tasks were equally represented in both types of task runs and both RCIs. This constraint of equal task occurrence made the task sequence pseudo-random. The four experimental blocks contained just one of the two levels of the RCI, the occurrence of which was counterbalanced among the participants. In other words, around one half of the participants ($n = 22$) were presented with the shorter RCI (300 ms) in Blocks 1 and 4 and with the longer RCI (900 ms) in Blocks 2 and 3 of the experiment, and vice versa for the rest of the participants ($n = 18$). This means that RCI was manipulated within participants in a block-wise manner.

Within-subject variables were Run type (switch and repetition), Trial (1 and 2), and RCI (300 and 900 ms). Since the variable Task (color and shape) did not produce any reliable interactions that would change any of our theoretical conclusions, we decided to collapse the data across the Task variable. As dependent variables, reaction times (RTs) were measured for each button press, and incorrect responses as well as no responses were recorded.

2.5. Data analysis

Apart from the 24 practice runs, the first four task runs of each experimental block were excluded from the ANOVA. These warming up runs were only included in the additional analysis focusing on the time course of retrieval-threshold adjustments to varying interference levels. Furthermore, error trials and no-response trials were excluded from the RT analysis as well as the trials that immediately followed. Next, if within a certain task run the second trial was an error trial, then the whole task run that immediately followed was also not included in the analysis. The task runs included in the analysis contained on average a low error rate of 4.74%. These error rates were first transformed using the arcsine transformation (Bishop, Fienberg, & Holland, 1975) to achieve approximate variance equality. Finally, an alpha level of .05 was used for all statistical tests in this study.

3. Results

3.1. RTs and errors

A 2 × 2 × 2 (Run type × Trial × RCI) repeated measures ANOVA applied on median RTs yielded significant main effects of run type, $F(1, 39) = 29.16, p < .001$; trial, $F(1, 39) = 11.06, p < .005$; and RCI,

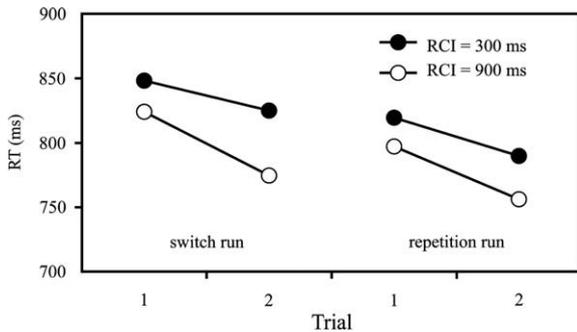


Fig. 1. Means of median response time (in ms) as a function of trial positions (1 and 2) over two run types (switch and repetition) for the two levels of the response-cue interval (RCI, 300 and 900 ms).

Table 1

Means of median response time (in ms) and error rates (in %) as a function of response-cue interval (RCI) for task switch and task repetition on the first and second trials in a task run.

RCI		Switch run		Repetition run	
		Trial 1	Trial 2	Trial 1	Trial 2
300 ms	RT	848 (21)	825 (21)	820 (20)	790 (19)
	Errors	5.36 (.62)	7.11 (.66)	3.75 (.43)	3.97 (.48)
900 ms	RT	824 (22)	775 (21)	797 (21)	756 (19)
	Errors	5.42 (.66)	5.94 (.64)	3.00 (.31)	3.39 (.40)
Effect	RT	24**	50***	22*	34***
	Errors	-.06	1.17*	.75	.58

Note. Standard Errors (SE) are given in parentheses.

- * $p < .05$.
- ** $p < .005$.
- *** $p < .001$.

$F(1, 39) = 29.61, p < .001$. On average, participants responded significantly slower in a task run involving a task switch (818 ms) than involving a task repetition (791 ms). Furthermore, responses on Trial 1 (822 ms) were on average slower than those on Trial 2 (786) in a task run. Importantly, responding after the RCI of 300 ms was generally slower than after the RCI of 900 ms, with 821 and 788 ms, respectively. Fig. 1 shows that RCI effect was present on both trials, with a tendency of being stronger on Trial 2, with $F(1, 39) = 3.28, p = .08$, for RCI × trial. Specifically focusing on performance in Trial 1, performance improvement observed for longer RCI ($F(1, 39) = 9.16, p = .004$) was similar for both task switches and task repetitions ($F < 1$, for RCI × run type), showing no reduction in switch cost, which was 29 and 27 ms for 300 and 900 ms of RCI, respectively. Finally, no other significant interactions were observed.

Error data presented in Table 1 yielded main effects of run type, $F(1, 39) = 40.79, p < .001$; trial, $F(1, 39) = 6.75, p < .005$; and RCI, $F(1, 39) = 4.20, p < .05$. Participants made more errors in a task-switch run (6.0%) than in a task-repetition run (3.5%). On average, more errors were made on Trial 2 (5.1%) than on Trial 1 (4.4%) in a task run. Importantly, participants performed better after the RCI of 900 ms (4.4%) than after the RCI of 300 ms (5.1%). Specifically focusing on performance in Trial 1, no significant RCI effect was observed ($F(1, 39) = 1.25, p = .27$). Finally, no significant interactions were observed.

3.2. Time course of performance adjustments to RCI variations

An additional analysis was applied on median RTs and errors to test the time course of the observed effects that RCI manipulation had on general performance. This analysis aimed at gaining more information on how the cognitive system adjusted to a certain level of RCI in the present study. All 94 task runs in each of the four experimental blocks were included in this analysis. In order to reduce the noise, task runs were clustered in six approximately equal data bins (see Fig. 2). Accordingly, two within-subject variables were Block (I, II, III, and IV) and Run cluster (1, 2, 3, 4, 5, and 6, containing the task runs 1–15, 16–31, 32–47, 48–63, 64–79, and 80–94, respectively). Since the presentation of the two RCI levels was counterbalanced between participants (ABBA and BAAB, for

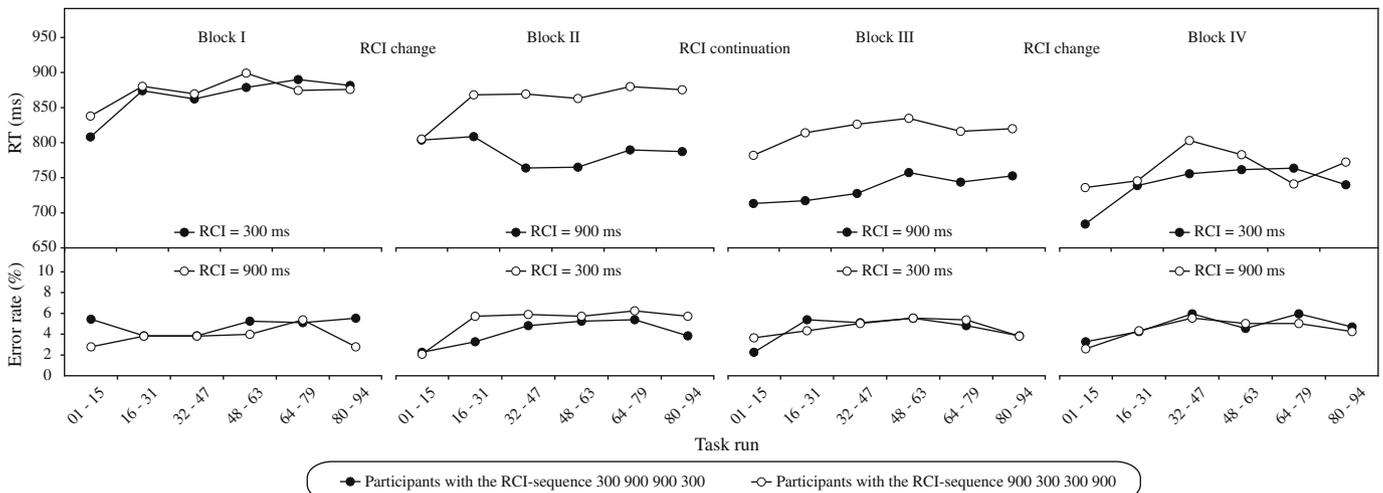


Fig. 2. Time course of cognitive adjustments to the different levels of the response-cue interval (RCI) in the present study. Means of median response time (in ms) and error rates (in%) are presented as a function of task runs clustered in six groups of a similar size (from left to right: 1–15, 16–31, 32–47, 48–63, 64–79, and 80–94) for two participant groups who followed different RCI-sequence presentations during the experiment. While one group of the participants followed the RCI-sequence of 300–900–900–300 (filled dots), the other group followed the reversed RCI sequence, namely 900–300–300–900 (open dots) across the four blocks (I, II, III, and IV) that the experiment consisted of. The moves from Block I to II and from Block III to IV were accompanied with a change in RCI level, while the RCI level continued into Block III. Which of the two RCI levels (300 or 900 ms) was presented to each participant group is indicated for each experimental block separately in the figure.

$A = 300$ and $B = 900$ ms of RCI), the between-subject variable was Participant group (1 and 2, for 300–900–900–300 and 900–300–300–900 RCI experimental sequence, respectively). Therefore, a $4 \times 6 \times 2$ (Block \times Run cluster \times Participant group) repeated measures ANOVA analysis was applied on median RTs and errors.

Following the time course of the experiment, Fig. 2 shows three interesting effects in RTs regarding the performance adjustments to RCI changes. First effect concerns the relation in performance between Blocks I and II. While the performance between the two participant groups was similar in Block I ($F < 1$), in which each participant was exposed to only one of the two RCI levels so far, the change in RCI that occurred between Blocks I and II generated a significant difference in RTs for the two participant groups (789 ms for the participants moving from 300 ms of RCI in Block I to 900 in Block II vs. 881 ms for the participants moving from 900 ms of RCI in Block I to 300 in Block II). This difference ($F(1, 38) = 4.37, p = .04$) emerged after the first 15 task runs of Block II. During the first run cluster of this block, both participant groups had on average similar response speed ($F < 1$). Fig. 2 shows that the performance adjustment to the RCI change in Block II was such that while the participants moving to 300 ms of RCI responded with a similar speed ($F < 1$) in Block I (873 ms) and Block II (869 ms), participants moving to 900 ms of RCI in Block II were significantly faster in Block II (792 ms) than in Block I (866 ms), with $F(1, 21) = 39.08, p < .001$. Second effect concerns the comparison in performance between Blocks II and III, which involved no change in RCI. As Fig. 2 shows, difference in RTs between the two groups of participants observed in Block II after the first run cluster persisted to Block III. During the whole Block III, the participants with the relatively longer RCI were significantly faster (735 ms) than participants with the relatively shorter RCI (816 ms), with $F(1, 38) = 4.70, p = .036$. Third effect observed in RTs concerns the second change in RCI, which occurred between Blocks III and IV. In Block IV, no significant difference was observed in RTs between the two participant groups (741 vs. 764 ms, for RCI changing back to 300 ms and to 900 ms in Block IV, respectively, with $F < 1$). Furthermore, the participants moving back to 900 ms of RCI were significantly faster in Block IV than in Block III, with $F(1, 17) = 12.15, p < .001$, while RTs of the participants moving back to 300 ms of RCI in Block IV responded with a similar speed in Block IV as in Block III, with $F < 1$. In addition, performance of the latter group of participants significantly differed between run clusters in Block IV ($F(5, 17) = 6.03, p = .002$). Specifically, RTs increased for these participants moving back to 300 ms of RCI in all run clusters following the first cluster in Block IV, with $F(1, 21) = 6.97, p = .015$; $F(1, 21) = 11.79, p = .002$; $F(1, 21) = 12.76, p = .002$; $F(1, 21) = 34.79, p < .001$; and $F(1, 21) = 4.86, p = .039$, for run cluster 1 vs. run clusters 2–6, respectively.

Next to these performance effects observed in RTs specifically regarding relations between different blocks, two other interesting performance effects were observed. First, participants improved their RTs during the experiment from 869 ms in Block I to 831 ms in Block II, and further to 775 and 752 ms in Blocks III and IV, respectively. A significant linear effect ($F(1, 38) = 76.79, p < .001$) accounted for 98% of the variance due to Block. This improvement in performance across the four blocks differed between the two participant groups ($F(3, 36) = 7.17, p = .001$) in such a way that the participants starting the experiment with 300 ms of RCI showed an improvement for the transition from Block I to II, involving a change from 300 to 900 ms of RCI, and from Block II to III, involving no change in RCI ($F(1, 21) = 21.42, p < .001$), but showed no improvement in performance for the transition from Block III to IV, where the RCI went back to 300 ms, while the participants starting the experiment with 900 ms of RCI showed no improvement for the transition from Block I to II, involving a change from 900 to 300 ms of RCI, but showed a significant

improvement for both the transition from Block II to III, involving no change in RCI ($F(1, 17) = 19.02, p < .001$), and for the transition from Block III to IV, where the RCI went back again to 900 ms. Second, a significant difference in performance between run clusters was observed in both RTs ($F(5, 34) = 7.35, p < .001$) and errors ($F(5, 34) = 6.30, p < .001$) in all the four blocks. Performance was most optimal during the first run cluster, both in RTs (773 ms) and in errors (3.05%), after which it declined over the subsequent run clusters. Specifically, RTs increased in all run clusters (808, 812, 820, 814, and 815 ms, for run clusters 2–6, respectively) for a similar amount relative to the first run cluster ($F(1, 38) = 17.92, p < .001$; $F(1, 38) = 25.42, p < .001$; $F(1, 38) = 27.34, p < .001$; $F(1, 38) = 23.15, p < .001$; and $F(1, 38) = 19.91, p < .001$ for run cluster 1 vs. run clusters 2–6, respectively; and with $F < 1$, for RT differences between run clusters 2–6). As to error rates, participants made more errors in all run clusters (4.38%, 5.01%, 5.11%, 5.42%, and 4.31% for clusters 2–6, respectively) following the first run cluster in a block ($F(1, 38) = 6.52, p = .015$; $F(1, 38) = 16.12, p < .001$; $F(1, 38) = 18.20, p < .001$; $F(1, 38) = 25.27, p < .001$; and $F(1, 38) = 4.34, p = .044$ for run cluster 1 vs. run clusters 2–6, respectively). In addition to this, accuracy significantly improved again in the last cluster of a block relative to the two preceding run clusters, that is, relative to run cluster 4 ($F(1, 38) = 5.41, p = .025$) and run cluster 5 ($F(1, 38) = 5.66, p = .023$). Finally, no other significant effects or interactions were observed in RTs and errors.

4. Discussion

The data of the present study showed two important findings. First, we observed that a relatively long RCI was generally beneficial for task execution. Specifically, prolonging the RCI improved the performance on first trials, which directly followed this interval, as well as the performance on the second trials, which were preceded by a fixed RSI. This observation offers no support to the idea of proactive task interference causing *directly* the switch costs (e.g., Wylie & Allport, 2000), since this idea would predict the RCI effect to be absent, or at least smaller, on the second trials than on the first trials. Instead, the effect was present on both trials, with a tendency of being stronger on second trials. It seems that providing more time for activation of previous tasks to decay decreased the amount of task interference positively affecting the processes involved in general task execution. This finding implies *generic* (i.e., not switch or cue-encoding specific) effects of proactive task interference and provides evidence supporting the main idea of the CCM model recently proposed by Altmann and Gray (2008). CCM is based on the assumption that the execution of the current task depends on the access the cognitive system has to the mental representation of the specific task. The access to this representation is modulated by the amount of interference from old task representations. The cognitive system manages this interference through memory-related cognitive adaptations, for instance, by adjusting the retrieval threshold for task runs and by task-activation decay. The functional role of this automatic decay process is allowing flexible cognitive control by preventing a catastrophic build up of proactive interference. According to CCM, the adjustments to different levels of interference should affect both cued and non-cued trials in the task run, which is precisely what has been observed in this study.

In an attempt to investigate further the nature of the observed performance adjustments to different interference levels in the present study, we focused on their time course and observed a couple of interesting effects. Importantly, each change in RCI between two consecutive blocks of task runs generated performance adjustments. Specifically, the first RCI change (i.e., from Block I to II)

showed that the cognitive system recognized the change in RCI after about 15 task runs in our study. Performance adaptation that occurred here was dependent on the type of RCI transition, that is, when moving from the relatively short to the relatively long RCI, participants became significantly faster relative to the preceding block, while moving from the relatively long to the relatively short RCI generated a significant slowing down throughout the block relative to the first 15 task runs after the RCI change.

It is interesting to note here that, since the adjustment to this RCI change was not achieved immediately after a few runs, it is most probable that this type of cognitive adaptation to RCI variation would not be observed in designs using randomized RCI manipulation. Randomizing the RCI could possibly force the cognitive system to choose the most optimal retrieval threshold that would fit both levels of RCI to a certain extent (cf. Poljac et al., 2006, for a similar finding for preparation effects in task switching). After the adjustment was complete, the chosen retrieval threshold stayed stable for the whole experimental block and persisted throughout the subsequent block and until the RCI changed again. This second change in RCI (i.e., from Block III to IV) generated a performance pattern similar to Block I, although the performance was generally faster in the last block, which is in line with the practice effects observed across the whole experiment. It seems that the cognitive system responded to this return to the starting RCI value by possibly restoring the original settings constructed in Block I. Interestingly, observing similar performance for the two different interference levels (i.e., in Blocks I and IV) implies that the cognitive system does not simply apply a single optimal retrieval threshold for a given interference level, but that it dynamically adapts its settings opting for an objectively optimal performance regulation at a given moment.

Next to these adjustments specific to RCI changes, the analysis on the time course of performance adjustments showed that each start of a new block was generally beneficial for performance. At least two different explanations are possible for this effect observed both in RTs and in errors. It is possible that the breaks, which were self-paced and implemented between the blocks, allowed for decay of task activations from the preceding block and thus reduced the level of proactive interference arising from these previous tasks. It is, however, also possible that participants used the breaks to motivate themselves to the best possible performance, as they were instructed to do so. Increased motivation might have resulted in a relatively higher commitment to tasks at the beginning of each block causing better performance. Altogether regarding the time course analysis of performance adjustments to task interference, we demonstrate that the cognitive system dynamically adjusts to changes in interference level independently of general practice effects and without converging to a single optimal setting for a given interference level. We need to note here that our analysis on time course is limited in its power regarding any firm conclusions. This analysis provides preliminary data on the nature of the dynamics of performance adjustments to interference in task switching, and all further specifications on this matter will need to be addressed in future studies specifically designed for tackling the dynamics of cognitive adjustments to interference.

Second finding of the present study regards the observed positive RCI effect that was similar for both task switch and task repetition performance. In other words, we observed no reduction of switch cost with increasing RCI (see also Cepeda et al., 2001). Also this finding implies generic effects of proactive task interference in task switching. Furthermore, it offers no support for the idea proposed by priming accounts of task switching (e.g., Gade & Koch, 2005; Meiran, Chorev, & Sapir, 2000a; Sohn & Anderson, 2001). According to them, the benefit of repetition priming dissipates with time such that a relatively longer task decay interval should

at least be more beneficial for the performance after a task switch than after a task repetition. A possible explanation for the absence of repetition priming effect in our study could be given in terms of overlapping response sets. A response set represents the task-specific S–R mapping, which constitutes the cognitive meaning of responses (e.g., Meiran, 2000). Koch and Allport (2006) suggested that decay of task activation influences the response-related components of task sets. So, the interference coming from the overlapping response sets between the competing tasks is suggested to be the component contributing to switch cost that is prone to decay. While overlap in response sets is common in studies on task switching, in our study, however, the four response buttons were not associated with a specific response for the two tasks. Accordingly, no conflict on the level of response sets was present in our study. Interestingly, Meiran, Levine, Meiran, and Henik (2000b), Experiment 3 (see also Luria & Meiran, 2003) showed that switch cost reduced with RCI increase only when using overlapping response sets. Therefore, absence of explicit overlap in response sets in our study might offer an explanation of why we observed no repetition priming effects.

An alternative explanation, however, could be given in terms of RCI manipulation. Altmann (2005) showed in his study that repetition priming effects are dependent of the way the RCI levels are being manipulated. We manipulated RCI within participants in a block-wise manner and observed no positive effects for switch cost. So far, the results on repetition priming reported in the literature are contradictory. Both within-subjects (mostly random) and between-subjects manipulations of RCI either showed (see e.g., Koch, 2001; Sohn & Anderson, 2001 for within- and between-subjects manipulation, respectively) or did not show a reduction in switch cost (see e.g., Cepeda et al., 2001 and Altmann, 2005 for within- and between-subjects manipulation, respectively). Possibly, the way of presenting the RCI levels might have influenced our finding of no reduction in switch cost with RCI increase. Any comprehensive theoretical explanations, however, need further investigation of the reported design dependency of the RCI effect (for further discussion, see also Horoufchin, Philipp & Koch, submitted for publication).

Both findings just discussed, namely, similar RCI effect on both trials in a task run and no specific reduction of switch cost with RCI increase, imply generic interference effects in task switching. As stated before, the general nature of the effects observed in our study fit nicely with the CCM proposed by Altmann and Gray (2008). We assumed here that task activation of the just executed task decays during RCI reducing the proactive task interference (e.g., Allport et al., 1994). Accordingly, by manipulating the RCI, we assumed to vary the amount of proactive task interference. At least two additional processes, however, that might take place during the RCI need to be discussed in this context. First, it is possible that some kind of task-independent preparation takes place during the RCI (e.g., Meiran & Chorev, 2005). This non-specific preparation might profit from longer RCIs and improve the processes taking place after the relevant task is identified. For instance, non-specific preparation that is related to the fluctuations of general preparedness for an anticipated event (e.g., Los & Heslenfeld, 2005; Los & Van den Heuvel, 2001) might play a role. It has been shown that, if a warning stimulus is separated from an imperative stimulus by an interval referred to as the foreperiod (FP), the responses on imperative stimulus are dependent on FP. The classical finding is that as FP lengthens up to an optimum, RT decreases according to a negatively accelerating function. After FP exceeds an optimal duration, RTs start increasing again (e.g., Posner & Boies, 1971). Based on this positive effect that FP not exceeding the optimum has on performance, one could say that our finding of performance benefit with longer RCI is due to a better general preparedness of the cognitive sys-

tem for the upcoming task rather than to larger decay of the previous task activation. There are, however, at least two arguments that speak against this alternative account. First, the reported FP effects are mainly sequential effects, that is, they are being observed only if FP varies from trial to trial. In the present study, on the contrary, the RCI was varied blocked-wise. Secondly, Los, Knol, and Boers (2001) showed that when varying FP in pure blocks (with the three levels of FP being 0.5, 1.0, and 1.5 s), the RT was slower for longer FPs, which is a reversed pattern from what we observed in our study. Next to this prospective alternative, it is also possible that longer RCIs retrospectively facilitate the ongoing task, by, for instance, providing more time for processes of performance monitoring that might take place after a response is given (cf. Botvinick, Braver, Carter, Barch, & Cohen, 2001). This explanation, however, could only account for the observed RCI effects on first trials (directly preceded by a variable interval) but not for the effects observed on the second trials (directly preceded by a fixed interval) in our study. If a longer RCI interval is beneficial for monitoring of a just executed action, then the constant RSI interval we used in our study should be similarly beneficial for second trials in all task runs. In other words, the alternative in terms of performance monitoring would not predict any RCI effects on the second trials that were preceded by constant interval duration.

In sum, the present study suggests generic effects of proactive task interference in task switching. Our findings are in line with the CCM (Altmann & Gray, 2008), which suggests that the cognitive system manages proactive task interference through memory-related cognitive-adaptations (activation and decay of task codes) causing different behavioral phenomena observed in task switching literature.

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