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Preparatory adjustment of cognitive control in the task switching paradigm

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In this article, the authors investigate the assumption that preparation while switching between cognitive tasks is dynamically adjusted to the current task demands. Performance in high-shift blocks (75% shifts) was compared with performance in high-repetition blocks (75% repetitions). This probability information was given either at the beginning of a block (global condition) or by specific probability cues before every trial (local condition). The authors report strong preparation effects (activation of the probable task and inhibition of the improbable task) in high-shift blocks, especially when specific probability cues were provided. In high-repetition blocks, however, the preparation effects were less pronounced. The results support the assumption that preparation is dynamically adjusted to the expected task requirements.

Whether on a normal working day or during leisure time, people constantly have to switch between different thoughts and actions without losing track of their current and future goals. Imagine that one organizes a dinner for friends: One might switch between chopping vegetables and stirring soup, while simultaneously scheduling an appointment with one's landlady. Whether or not one succeeds in such situations obviously depends on the number of tasks that one tries to coordinate, the difficulty of each task, and whether the tasks can be anticipated or come by surprise. In order to investigate how people deal with these changing task demands from the environment, cognitive psychologists have invented the "task-switching paradigm" (Allport, Styles, & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). Participants are asked to switch between simple cognitive tasks such as judging whether a number is odd or even versus whether the number is smaller or bigger than a reference number. The general finding is that a switch to a new task takes longer than the repetition of the same task. Even though these switch costs (hence, the difference in response time [RT] between task shifts and task repetitions) can be reduced by preparation (see, e.g., Meiran, 1996; Rogers & Monsell, 1995; but see also Altmann, 2004), a residual component generally remains even after extensive practice (e.g., Dreisbach, Haider, & Kluwe, 2002, Experiment 3). Usually, these residual switch costs are taken as evidence that the process of task switching requires cognitive control, as in task set reconfiguration (Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Monsell, 2003; Rogers & Monsell, 1995). However, growing evidence suggests that cognitive control processes are not restricted to task switches. Rather, as some authors assume, it seems that task repetitions necessitate cognitive control as well (e.g., Altmann, 2004; Dreisbach et al., 2002; Koch, 2001, 2005; Ruthruff, Remington, & Johnston, 2001; Sohn & Carlson, 2000). According to this perspective, residual switch costs appear to reflect an automatic carryover effect from the previous task instead of a task set reconfiguration, so that the term *repetition benefit* instead of switch costs would more appropriately describe the phenomenon. The assumption of an automatic carryover effect is mainly based on studies in which task expectancies have been manipulated independently of task type (i.e., shift vs. repetition). The results of these studies have shown the same preparation effects for task shifts and task repetitions. Recently, Altmann (2004) has offered a different account by showing that shift-specific preparation effects, commonly interpreted as evidence for the reconfiguration view, occur only with a within-subjects manipulation of the preparation interval but disappear with a between-subjects manipulation (see also Koch, 2001; Sohn & Anderson, 2003).

Taken together, these findings suggest that the assumption of a specific switching mechanism such as task set reconfiguration is questionable. This does not deny that cognitive control is involved in *preparatory processes* during task switching. Rather, cognitive control appears to be dynamically adjusted to current task demands, be it a switch or a repetition (Dreisbach et al., 2002; Gos-

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chke, 2000; Hübner, Dreisbach, Haider, & Kluwe, 2003; Koch, 2001, 2005; Mayr & Keele, 2000; Meiran, 1996; Meiran et al., 2000; Rogers & Monsell, 1995). One important mechanism in this context is backward inhibition (Dreisbach et al., 2002; Hübner et al., 2003; Mayr & Keele, 2000). Mayr and Keele were the first to show that the preparation of a new task is supported by the inhibition of the previously executed task, resulting in a performance deficit if this inhibited task has to be executed shortly thereafter. Hübner et al. were able to show that this inhibition could result in a performance advantage, in that it reduced the interference from the previously executed task on the current task. And finally, Dreisbach et al. (Experiments 4 and 5) presented evidence that this inhibition process affects not only a previously executed task but also other possibly interfering tasks. In these experiments, participants had to switch among four different tasks. Each task was announced by a probability cue (75% repetition and 25% shift or 75% shift and 25% repetition). Note that within each block, 50% of the tasks were task shifts and 50% were repetitions, so that each probability cue was maximally informative with regard to the upcoming task type. In addition to the probabilities, the cue either contained information about the *specific* probable or improbable shift task (one out of three) or did not. The results of these experiments showed that with *specific* probability cues, latencies for shifts and repetitions increased to the same extent with decreasing probability. In contrast, when the probability cue did not provide specific information about the shift task, probable shift tasks could not be prepared for, and correspondingly RTs for the improbable task repetitions were faster than those in the specific condition. Paradoxically, RTs for improbable shifts were also faster than those in the specific condition, where participants knew in advance which specific task would appear with low probability. This pattern of results suggests that task shifts as well as task repetitions are both prepared for, and that task preparation for the probable task is accompanied by the *inhibition* of the improbable task if and only if foreknowledge about the upcoming task is provided.

The conclusion so far is that the specific preparation of an upcoming task is accompanied by a specific inhibition of the previous task (Mayr & Keele, 2000; Hübner et al., 2003) or other possibly interfering tasks insofar as specific information about these interfering tasks is provided (Dreisbach et al., 2002). Note that, in these studies, the common constraint for inhibition to occur is that the upcoming task, shift or repetition, can specifically be prepared for.

The goal of the present experiment was to further investigate preparatory control processes during task switching. More precisely, we examined the effect of a blockwise (i.e., between blocks) manipulation of task frequencies (repetition vs. shift): Two blocks contained 75% shifts and 25% repetitions and two blocks contained 25% shifts and 75% repetitions. In one block from each frequency condition, participants were informed about these global task frequencies at the beginning of a given block (global expectancy condition hereafter), and in the other block from each frequency condition, a specific probability cue was presented. This probability cue either always announced a task shift with 75% and a task repetition with 25% probability (in the 75% shift block) or always announced a repetition with 75% and a shift with 25%, respectively. Thus, in contrast to Dreisbach et al.'s original experiments in which repetitions and shifts occurred with equal frequencies in a given block (only the local probabilities from trial to trial changed), the local information about the probability cues corresponded to the global task frequency. The probability cues in the present experiment thus simply reflected the global frequencies and therefore were only useful but not necessary cues (see Sudevan & Taylor, 1987). Thus, the only difference between the local and global conditions was that in the local expectancy condition, the cue explicitly informed participants in advance of task presentation which task to prepare for and which task to inhibit, whereas in the global expectancy condition, participants had to generate this knowledge by themselves.

If cognitive control is dynamically adjusted to the task requirements (Goschke, 2000; MacDonald, Cohen, Stenger, & Carter, 2000; Tornay & Milán, 2001), then preparation effects should be more pronounced in high-shift blocks than in high-repetition blocks. We therefore expected strong preparation effects in the 75% shift blocks, but only small preparation effects in the 75% repetition blocks. Statistically, we expected an interaction between task type (repetition vs. shift) and task frequency (75% shift blocks vs. 75% repetition blocks) if participants were able to adjust their cognitive control dynamically to task demands. Furthermore, we expected that these stronger preparation effects would materialize not only in faster RTs on the probable task but also in slower RTs on the improbable task. As mentioned above, previous studies with probability cues have suggested that the preparation of the probable task goes along with the inhibition of the improbable task (Dreisbach et al., 2002, Experiment 4). Thus, finding slower RTs for the improbable task would be in line with the assumption of inhibitory processes.

Moreover, the comparison of preparation effects from the global expectancy blocks and from the local expectancy blocks should reveal the roles of exogenous versus endogenous cues for the preparatory adjustment of cognitive control. If the exogenous cues in the local expectancy blocks support the preparatory adjustment of cognitive control, one should find more pronounced differences in switch costs between the 75% shift blocks and the 75% repetition blocks than in the global expectancy blocks. In contrast, if only task frequency and not specific cue information affects the preparatory adjustment of cognitive control, then we should not find any difference between the local and the global expectancy blocks.

Taken together, we assume that preparatory processes reflect the adjustment to the present task requirements. A 75% shift block requires more preparatory processes and thus should go along with the inhibition of potentially interfering tasks. A 75% repetition block, by contrast, requires less preparatory processes and thus may not require inhibiting interfering tasks. Whether or not this assumed adjustment of preparatory processes to current task requirements is modulated by the availability of explicit cues will be revealed by the comparison of the local and the global condition.

METHOD

Participants

Twenty-four students (14 female; mean age = 21.08, $SD = 2.63$; range, 18–28) from the Dresden University of Technology participated for partial course credit or €2. Participants signed informed consent and were debriefed after the session.

Stimuli and Tasks

The stimuli were the digits 1, 2, 3, 4, 6, 7, 8, and 9, printed in blue or red. The participants had to decide either whether the digit was odd or even (blue digits) or whether the digit was smaller or bigger than five (red digits). Half of the participants had to press a left key on a computer keyboard if the digit was odd or smaller than five, and they had to press a right key if the digit was even or bigger than five. Mapping was reversed for the other half of the participants.

The probability cues in the local expectancy condition consisted of four small blue or red squares, with each square indicating the corresponding task with 25% probability. Thus three small red squares and one blue square indicated the occurrence of a red digit with 75% probability and the occurrence of a blue digit with the remaining 25% probability. Correspondingly, three blue squares and one red square indicated a blue digit with 75% probability and a red digit with 25% probability.

Procedure

The experiment started with a practice block of 84 tasks. Each trial began with the presentation of a fixation cross for 400 msec, followed by a blank screen of 500 msec. Then the target digit appeared and remained on the screen until a response was given. After another 500 msec, the next trial began with the presentation of the fixation cross. Red and blue digits appeared in randomized order with equal probability. In this block, 50% of the trials were switch trials and 50% were repetition trials. Participants were encouraged to answer as quickly as possible while avoiding errors. If a participant answered erroneously, feedback was given and the response–stimulus interval (RSI) was extended to 2,000 msec.

The main experiment consisted of 4 blocks of 100 tasks each. There were two blocks with 75% shifts (and 25% repetitions) and two blocks with 75% repetitions (and 25% shifts). In the global condition, the participants were informed at the beginning of each of the two blocks about the actual task frequencies (75% shifts and 75% repetitions). In the local condition, the participants did not get this global information but instead learned about the meaning of the specific probability cues at the beginning of the block. Each trial was announced by a specific probability cue. In the local 75% shift block, for example, the cue always contained only one small colored square from the just-executed task and three small colored squares from the other task. That is, the cue in this condition always announced a task shift with 75% probability. Accordingly, in the local 75% repetition block, the cue always contained three small colored squares from the just-executed task and only one small colored square from the other task.

Participants were encouraged to use the probability information (global or local) for preparation. In the local probability condition, each trial began with presentation of one of the two specific probability cues for 400 msec followed by a blank screen for 500 msec. Then the target was presented; it remained on the screen until a response was given. After an interval of 500 msec, the next cue was presented. In the global expectancy blocks, the cue was replaced by a fixation cross, and timing characteristics were the same. The experiment started either with the local expectancy condition or with the global expectancy condition. A given expectancy condition began either with a block of 75% task repetitions or with a block of 75% task switches. Block order was counterbalanced across participants. The whole experiment lasted 25 min.

Design

A 2 (expectancy: local vs. global) × 2 (task frequency: 75% repetition vs. 75% shift) × 2 (task type: repetition vs. shift) complete block design was used. All factors were manipulated within participants.

RESULTS

Incorrect responses and those following an error were excluded from the analysis (9.2%). In addition, we excluded RTs that differed more than 2 *SD*s from the individual mean of each factor combination (an additional 2.17% of the data). For each participant, we then computed mean RTs and error rates separately for shifts and repetitions for the different expectancy and probability conditions.

Latencies

Figure 1 depicts mean RTs as a function of task type, task frequency, and expectancy condition. On first glance, it is obvious that large shift costs occurred in the 75% repetition blocks, and that they were about the same in the global and local condition. In the 75% shift blocks, however, shift costs were generally smaller and they were completely absent in the local condition. Consequently, the 2 (expectancy condition) × 2 (task frequency) × 2 (task type) ANOVA for repeated measures yielded a significant triple task type × task frequency × expectancy condition interaction [$F(1,23) = 11.38$, $MS_e = 9{,}410.72$, $p < .01$]. Furthermore, we found significant main effects of task frequency [$F(1,23) = 20.96$, $MS_e = 16{,}381.80$, $p < .001$] and of task type [$F(1,23) = 37.57$, $MS_e = 38{,}873.25$, $p < .001$], reflecting an overall RT advantage for task repetitions and for the 75% repetition blocks. The latter effect—namely, the slower overall performance in high-shift blocks than in high-repetition blocks—shows that the high-shift blocks were, as hypothesized, more demanding. However, this effect was not due solely to switch trials' being harder than repeat trials, as will be shown below. In addition, and also in accordance with our hypotheses, there was a significant task type × task frequency interaction [$F(1,23) = 53.01$, $MS_e = 15{,}867.95$]. No other effect was significant (all ps $> .1$).

To gain further insight into the preparatory processes within the local and the global expectancy conditions, we separately analyzed these conditions in two 2 (task type) × 2 (task frequency) ANOVAs. For the local expectancy condition, we found significant effects of task type [$F(1,23) = 31.29$, $MS_e = 18{,}436.67$, $p < .01$] and task frequency [$F(1,23) = 11.41$, $MS_e = 16{,}772.64$, $p < .01$], and a significant interaction of task type × frequency [$F(1,23) = 48.84$, $MS_e = 15{,}852.01$, $p < .01$]. Planned comparisons confirmed that RTs for (improbable) repetitions in the 75% shift block increased dramatically in comparison with RTs for repetitions in the 75% repetition block [$F(1,23) = 40.15$, $MS_e = 21{,}619.2$, $p < .001$]. Like-

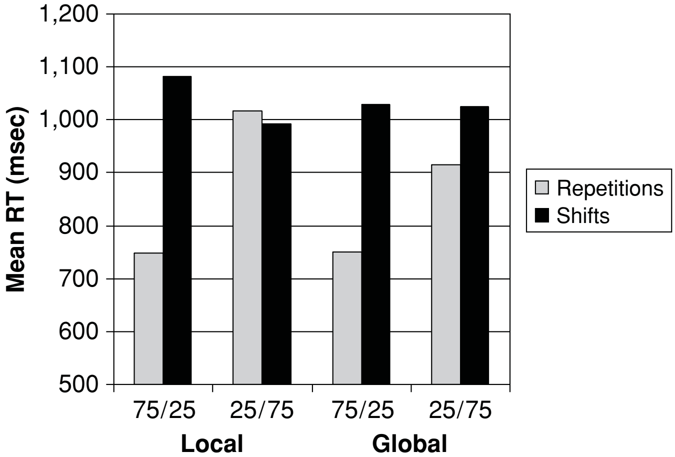

Figure 1. Mean response time (RT, in milliseconds) as a function of task type and task frequency in the local and global expectancy conditions. 75/25 denotes blocks with 75% repetitions and 25% shifts. 25/75 denotes blocks with 75% shifts and 25% repetitions.

wise, RTs for improbable task shifts were slower than RTs for probable task shifts in the local condition [$F(1,23) = 8.88$, $MS_e = 11{,}005.4$, $p < .01$]. However, as was supported by the significant interaction of task type × task frequency, the adjustment to task frequency was much more pronounced for task repetitions. In the global expectancy condition, main effects of task type [$F(1,23) = 32.62$, $MS_e = 27{,}648.23$, $p < .01$] and task frequency [$F(1,23) = 11.56$, $MS_e = 13{,}227.27$, $p < .01$] were significant, as was the interaction of task type × frequency [$F(1,23) = 18.45$, $MS_e = 9{,}426.66$, $p < .01$]. Planned comparisons showed that RTs for probable task repetitions were again significantly faster than RTs for improbable repetitions [$F(1,23) = 29.37$, $MS_e = 11{,}121.6$, $p < .001$]. In the global condition, however, RTs for task shifts were unaffected by task frequency ($p = .86$).

Furthermore, the direct comparison of preparation effects between expectancy conditions computed for the high-demanding 75% shift blocks revealed a significant interaction of expectancy × task type [$F(1,23) = 12.29$, $MS_e = 8{,}667.9$, $p < .01$]. This interaction resulted from the fact that the two expectancy conditions differed significantly with respect to improbable repetitions [$F(1,23) = 4.29$, $MS_e = 28{,}426.9$, $p < .05$], while they did not differ with respect to probable shifts ($p = .4$).

Accuracy

Mean error rates (see Table 1) for each participant for each factor combination were entered into a 2 (expectancy) × 2 (frequency) × 2 (task type) repeated measures ANOVA. No main effect and no interaction proved significant (all ps $> .1$).

DISCUSSION

The results presented in this article are straightforward. The significant triple interaction of task frequency, task type, and expectancy condition supports our assumption of a dynamic adjustment of cognitive control that is modulated not only by the current task demands but also by the availability of specific cues. Two critical differences between local and global expectancy conditions explain this triple interaction: First, in high-demanding blocks with 75% task switches, RTs for the corresponding improbable repetition were strongly slowed, an effect that was especially pronounced in the local condition, where switch costs completely vanished. The fact that RTs for improbable task repetitions were significantly slower in the local than in the global condition, in our opinion, clearly supports the assumption of an inhibitory mechanism. If the RT increase for the improbable task repetitions within the high-demanding block had been solely due to the higher frequency of task shifts, we should have found comparable increases in both expectancy conditions, because the frequencies of task shifts were identical in both conditions. However, our analyses revealed a significantly stronger increase in RTs for task repetitions in the local expectancy condition, in which participants received additional information about the next upcoming task. A comparable but less pronounced effect was found for task shifts: In the local condition, RTs for shifts were significantly slower in the 75% repetition blocks than in the 75% shift blocks,

Table 1
Mean Error Rates (With Standard Deviations) as a Function of Frequency Condition, Task Type, and Expectancy Condition

		Local Expectancy		Global Expectancy	
Frequency Condition	Task Type	*M*	*SD*	*M*	*SD*
75% rep/25% shift	Repetition	4.00	3.65	4.00	3.47
	Shift	5.50	5.71	3.95	6.21
75% shift/25% rep	Repetition	5.62	6.03	4.58	4.43
	Shift	5.62	5.65	4.91	4.27

whereas they did not differ between frequency conditions in the global condition.

This difference in shift RTs between frequency conditions in the local condition could either be interpreted in terms of an inhibition of the shift task in the 75% repetition blocks, or as a result of the specific preparation of the shift task in 75% shift blocks, or both. According to our general assumption that preparation is adjusted to the expected task demands, we suspect that participants used the probability cues for preparation especially in the 75% shift blocks, leading to the observed effect of fastest shift RTs and slowest repetition RTs. What happened in the 75% repetition block in the local condition, whether or not the shift task was subjected to specific inhibition, cannot be decided within the present paradigm.

Taken together, the data presented in this article support our assumption that preparation in the task-switching paradigm is adapted to the current task demands. This interpretation is in line with previous findings showing that the implementation of cognitive control can be adjusted dynamically to expected task requirements (e.g., MacDonald et al., 2000). Moreover, the results presented here go beyond existing findings by showing that this preparatory adjustment is not only triggered by explicit cues. In addition, we were able to show that even global probability information can be used for dynamic adjustment of preparation. That is, participants used the information about frequent task switches in an upcoming block to prepare for a switch and presumably to inhibit the just-executed task. The fact that this preparation effect was less pronounced in the global condition than in the local condition is probably a consequence of what De Jong (2000) calls the failure-to-engage hypothesis. Participants do not engage in preparatory activity as much as they could on every trial. This holds true not only for the local condition, but obviously even more for the global condition.

In this article, we have presented further evidence that cognitive control can dynamically be adjusted to experienced task demands. Participants put more effort in preparatory activity in situations with higher task demands (blocks with 75% shifts). By contrast, in situations that are not really challenging to the cognitive system (blocks with 75% repetitions), participants prepare less.

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