

# Backward Inhibition as a Means of Sequential Task-Set Control: Evidence for Reduction of Task Competition

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Endogenously initiated transitions between tasks are associated with inhibition of the attentional set for the task preceding the transition, as demonstrated by slowed reactions to a task most recently switched away from (U. Mayr & S. W. Keele, 2000). Using an altered methodological approach, the authors found that this backward inhibition counteracts perseverative tendencies when switching to a new task in that it selectively reduces interference exerted by the preceding task set. The reduction of interference was dependent on endogenous preparation for the new task and did not occur for unpredictable task switches or for task switches that were precluded without information about the identity of the new task.

Human behavior is usually considered to be intentional and goal-directed. Rather than responding in stereotyped ways to external stimulation, people are able to choose among an almost unlimited number of possible responses that correspond to their behavioral goals of the moment. That is, the very same external stimulus may be responded to by actions that are completely unrelated to each other if the goal of the person has changed between presentations. Obviously, then, an internal configuration relating stimuli to responses other than the one that was effective on the previous encounter must have become dominant. Such goal-related internal determinants of behavior have been referred to as mental sets or (inasmuch as achieving a behavioral goal is readily described in terms of accomplishing a specific task) as task

sets. Task sets are thus thought to involve all processes necessary and sufficient for the production of a task-specific, or goal-specific, action upon a current stimulus. Consequently, they are “assumed to specify the configuration of perceptual, attentional, mnemonic, and motor processes critical for a particular task goal” (Mayr & Keele, 2000, p. 5). It is widely assumed that putting goal-appropriate task sets into place when they are needed is accomplished by so-called *executive functions*, a class of cognitive operations distinct from operations directly concerned with task processing (e.g., Meyer & Kieras, 1997; Rogers & Monsell, 1995; Smith & Jonides, 1999). Recent research has begun to address the precise mechanisms underlying engagement of a new task set and disengagement of an old task set (Allport, Styles, & Hsieh, 1994; Mayr & Keele, 2000; Mayr & Kliegl, 2000; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001). The purpose of the current experiments was to test the hypothesis that in the case of endogenous engagement of a new task set, execution of that set is facilitated by selective inhibition of the task set that determined behavior directly before.

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The experiments reported in this article were part of a doctoral dissertation submitted by Mike Hübner to the Universität der Bundeswehr Hamburg. Part of this research was presented at the European Society of Cognitive Psychology Conference in Edinburgh, Great Britain (September 2001). This research was funded by Grant KL488/5-2 from the German Research Society (Deutsche Forschungsgemeinschaft).

We thank Katherine Arbutnott, Iring Koch, Todd Woodward, and an anonymous reviewer for valuable comments on an earlier version of this article. We also thank Aquiles Luna-Rodriguez, Jan Dettmers, Vladislav Estrine, and Karen Mielke for their assistance at all stages of the project. Finally, we thank Detlev Rhenius for providing room facilities for data collection at the University of Hamburg, Hamburg, Germany.

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## Task-Set Switching Is Associated With Behavioral Costs

Observations in certain clinical populations as well as in laboratory studies with neurologically normal participants have shown that replacing one task set by another is not free from behavioral costs. In the extreme, people consistently fall short in implementing a new task set against the persisting activation of a just executed one. The phrase *stuck-in-set perseveration* (Sandson & Albert, 1984, 1987) refers to the inappropriate maintenance of a task set: for example, if a patient continues to sort cards with respect to item color although instructed to switch to a different criterion, such as item shape.

In contrast with the unsuccessful replacement of one task set by another, neurologically intact individuals are usually flexible enough to select the appropriate response even under conditions of frequent task switches that involve varying stimulus–response

(S-R) translation demands. Nevertheless, certain reaction time (RT) and accuracy costs are consistently observed when a switch to a new task is required—relative to a task repetition—given that both tasks operate on the same sort of stimuli (e.g., Allport et al., 1994; Fagot, 1994; Jersild, 1927; Meiran, 1996; Rogers & Monsell, 1995; Spector & Biederman, 1976). At the moment, there is still disagreement concerning whether this impediment of task-switch performance is best ascribed to proactive interference exerted by the preceding task set or to the insertion of an executive process of task-set reconfiguration prior to task processing. However, even proponents of the task-set reconfiguration view note that the set for a preceding task retains some activation at the time of executing the new task (i.e., after the alleged reconfiguration process), thereby interfering with performance by competition for action (see Monsell, Yeung, & Azuma, 2000, for an overview of theoretical positions). An obvious consequence of such interference can be seen in effects of exogenous task cuing and cross talk. That is, task-switching costs are generally increased when a stimulus affords not only the current but also the to-be-abandoned task, especially when the stimulus is associated with different responses in both tasks (e.g., Fagot, 1994; Rogers & Monsell, 1995).

#### Backward Inhibition of Task Set as a Counterforce to Carry-Over Effects

Given such nonintended aftereffects of a task set previously in use, Mayr and Keele (2000) proposed an inhibitory mechanism of sequential control, which supports endogenous transitions between task sets through rendering the to-be-abandoned set less accessible and thereby facilitating execution of the new task. Specifically, they proposed that “intentional shifts between internal control settings (i.e., goals or task-sets) are accompanied by an inhibitory process. This inhibition should be targeted at the representation of the to-be-abandoned control setting to prevent it from further influencing action” (Mayr & Keele, 2000, p. 4).

In the Mayr and Keele (2000) study, participants had to locate on each trial one deviant with respect to one of three dimensions (color, orientation, or movement) out of four objects that were presented in random sequences. The basic finding across six experiments was that RTs for a dimension that had been switched away from one trial before were prolonged compared with those for a dimension that had not been relevant during the two preceding trials (ABA vs. ABC sequences). This reduction of executability of a Lag 2 repeated task set was taken to reflect the residual of an inhibition that is installed when a switch to a new dimension has to be performed. Because on a switch from A to B inhibition is targeted at Set A, a subsequent switch back to A should be delayed because residual inhibition has to be overcome whereas a subsequent switch to C (which is not subject to recent inhibition) should be easier.

One more specific result of Mayr and Keele (2000) concerned the dependence of the backward inhibition mechanism on endogenous or top-down preparation for the upcoming task. In contrast with the finding of increased RTs for Lag 2 repeated dimensions on task sequences in which the identity of each task was precued, in a condition in which participants had to wait for the imperative stimulus to decide which task to perform (*bottom-up cuing*; Experiment 3), a nonsignificant reduction of RTs on Lag 2 set repetitions was observed. Note that in this condition, backward

inhibition did not occur, even though no task was ever repeated on the subsequent trial. That is, participants had to have full certainty to abandon the task just performed. This result suggests that foreknowledge about task transition alone is not sufficient for backward inhibition to occur.

#### Reduced (Intentional) Executability Has Been Shown; Reduced (Nonintentional) Interference Has Yet to Be Shown

Because it suppresses representations of a to-be-abandoned task set, backward inhibition is thus presumed to support the application of a new task set in that it relieves competition from the preceding one. In the words of Mayr and Keele (2000), it “would function as a counterforce to the persistent-activation property of control settings and would thus, ‘clear the slate’ for currently relevant task sets” (p. 5).

Although we do not doubt the validity of the finding of increased RTs on Lag 2 task-set repetitions as indicating the work of an inhibitory mechanism, we also note that by comparing ABA with ABC task sequences it has not been shown that this inhibition indeed facilitates the application of a new task set by reducing competition from the preceding one. Thus, on the basis of Mayr and Keele’s (2000) findings, we can state that backward inhibition affects a task set in a way that results in reduced intentional executability. However, it is not clear whether this necessarily implies reduction of nonintentional interference with subsequent processing of a new task. Findings from several sources provide evidence for possible dissociations between the effectiveness of intentional responding to task-relevant information and interference of processing the same information when it is irrelevant for a current task. For instance, in studies investigating the perception of global and local stimulus attributes, slowing of responses to the global level without corresponding decreases in interference of global information on responses to the local level have been reported (Hübner, 1997; Lamb & Yund, 1993; see also Lamb, Robertson, & Knight, 1989). At the very least, these studies show that measures of the activation of a specific task set derived from overt task execution may be inconclusive with respect to the task set’s effectiveness as distractor. Given that a major motivation for postulating backward inhibition is the notion of reduced task competition, more direct evidence based on decreased interference effects appears valuable.

The experiments reported in this article address this issue by examining the assumed perseveration-counteracting quality of the backward inhibition mechanism with an altered methodological approach. Rather than comparing the executability of task sets that were more or less recently switched away from, we focused instead on the impact of a to-be-abandoned task set on performance in the following task. If backward inhibition facilitates the application of a new task set by reducing competition from the preceding one, we should find interference from the preceding task set on performance in the new task to be selectively reduced given inhibition conditions.

#### Experiment 1

To examine whether backward inhibition reduces interference from a preceding task set, we applied a task-switching paradigm

with three tasks: one that on each trial acted as the relevant task, one that was executed directly in advance (i.e., the preceding task), and one that was not executed as recently (i.e., the control task). Critical task-switch trials contained (in addition to the target stimulus) a stimulus attribute either from the preceding task or from the control task. Our method of presenting stimuli from an irrelevant task was based on Eriksen and Eriksen's (1974) flanker paradigm, in which the target stimulus is displayed in a predictable (central) location and flanked on both sides by the irrelevant stimulus.

As noted above, it has been shown that transitions to a new task take longer when the stimulus contains an attribute that affords the current and a previously executed task than when the stimulus is uniquely associated with only one of the tasks used in an experiment (e.g., Fagot, 1994; Rogers & Monsell, 1995). This interference has been attributed to automatic cuing of the previous task set. Our hypothesis was that if backward inhibition selectively reduces competition from the preceding task set, then an irrelevant stimulus from the preceding task should interfere less with performance than an irrelevant stimulus from the control task, whose last execution was further in the past.<sup>1</sup> Because in the Mayr and Keele (2000) study backward inhibition was bound to endogenous preparation for the upcoming task, we expected to find reduced interference from stimuli of the preceding task on task switches that were top-down precued but not on unpredictable task switches that could not be prepared.

### Method

**Participants.** A group of 18 male students of the Universität der Bundeswehr Hamburg participated in a single-session experiment in exchange for partial fulfillment of course requirements. Participants ranged in age from 18 to 26 years.

**Stimuli and responses.** The participants sat with their eyes approximately 60 cm from the screen of an IBM-compatible personal computer (486 AT). Experiment 1 involved three simple classification tasks. In Task 1 participants decided whether a number stimulus was odd or even. Stimuli for Task 1 were 2, 3, 4, 5, 6, 7, 8, and 9. In Task 2 participants decided whether a letter stimulus was a vowel or a consonant. Stimuli for Task 2 were *D, E, H, I, O, P, T,* and *U*. In Task 3 participants decided whether a symbol stimulus contained straight lines only or (a) curved line(s) as well. Stimuli for Task 3 were §, &, j, ?, #, +, <, and j. All characters were taken from the Courier New font. All stimuli of Task 1 were displayed in red, all stimuli of Task 2 were displayed in blue, and all stimuli of Task 3 were displayed in yellow. The characters subtended 0.2°–0.7° horizontally and 1.2°–1.5° vertically. They were displayed on dark gray background at the center of a light gray rectangular frame that was also the center of the screen. Each of the three tasks was assigned to a separate pair of response keys. Response keys were < and – for Task 1, Y and . for Task 2, and X and , for Task 3. (These keys are the outmost left and outmost right keys on the second row from the bottom of a standard German keyboard.) On each of the response keys was a sticker in the color of the corresponding task stimuli. Participants pressed the three left keys with the index finger, middle finger, and ring finger of their left hand and the three right keys with the index finger, middle finger, and ring finger of their right hand, respectively. Half the subjects were assigned the responses *even, vowel,* and *straight lines only* to their left hand and *odd, consonant,* and *curved line(s) also* to their right hand. This assignment was reversed for the other half of the participants.

In an experimental block there were 108 experimental trials preceded by five warm-up trials that did not enter into analysis. Of those 108 trials, 36 were task switches and 72 were task repetitions. On a task-switch trial, the target stimulus was either presented alone, flanked by a stimulus of the

preceding task, or flanked by a stimulus of the control task, with equal probability (i.e., one third each). Flanker characters were displayed 1.6° center-to-center to the left and to the right of the target. Onsets of target and flankers were synchronized. Orthogonal to flanking conditions, a random half of the task-switch trials were presented with a precue and the other half were presented without a precue. Precues consisted of the word *neu* [new] presented in the color of the stimuli of the following task. Note that with stimulus presentation based on Eriksen and Eriksen's (1974) flanker method, the precue was helpful but not necessary for accurate task performance, because the relevant task was always unequivocally indicated by the type of the central stimulus. Thus, there were six precued and six nonprecued task switches in each of the three flanking conditions during an experimental block. Task switches occurred with equal probability to one of the two tasks not presented on the preceding trial. Each task switch was followed by either one, two, or three repetitions of the same task, with equal probability. Varying numbers of task-repetition trials were included to make task switches without precues unpredictable. Remember that on unpredictable task switches, no backward inhibition was expected. Task repetitions were always presented without flankers and were never precued. Each target and flanker stimulus was chosen randomly out of the set of the characters of the corresponding task.

Figure 1 displays an example of a possible task-switch sequence with flankers from the preceding task and with flankers from the control task in Experiment 1. Different shades indicate the colors red (numbers), blue (letters), and yellow (symbols).

On each trial, target and flanker stimuli remained on the screen until a response key was pressed. The response–stimulus interval, the interval between the response to a preceding stimulus and the onset of a new imperative stimulus, was set to 2,000 ms. For trials that were administered without a precue, no stimulus appeared on the screen during the response–stimulus interval. In the case of a precued task switch, however, the *neu* precue appeared after a response–cue interval of 500 ms and remained on the screen for 300 ms. Thus, the cue–stimulus interval, which can be considered the interval for preparation for a new task, was 1,500 ms. Note that a preparation interval of this length should provide ample time for maximal preparation for the new task (e.g., see Meiran, 1996; Rogers & Monsell, 1995).

**Procedure.** Participants first received written instructions emphasizing correct and fast responses. The experimental session was preceded by four practice blocks that served to familiarize participants with the stimuli, cues, and requirements of the tasks. The first practice block consisted of two cycles of three sequences of 18 trials of each task. In this block, with the onset of each stimulus participants received an additional instruction about the relevant classification. This classification instruction was displayed on top of the light gray rectangle frame and was spatially compatible with response assignment: for example, *Vokal/Konsonant* [vowel/consonant] for a participant who responded to vowels with the left middle finger and to

<sup>1</sup> One may note that for this logic to work, we must make the additional assumption that backward inhibition dissipates over time even with the task set subject to it not being executed. Otherwise, the control task should be associated with just as much inhibition as the preceding task, no matter how much they are separated in time. The same constraint applies, however, for the ABA–ABC method that Mayr and Keele (2000) used. Because in that study backward inhibition could be demonstrated, the assumption of passive decay seems warranted. Note also that when the three tasks used are presented in random sequences, as was done in the current study, the probability for each of the three tasks to fall into any of the two categories of preceding task and control task is identical. Thus, comparing interference from the preceding task set with interference of the control task set amounts on average to comparing interference of the preceding task set with interference of the same task set when it was placed earlier in the sequence.

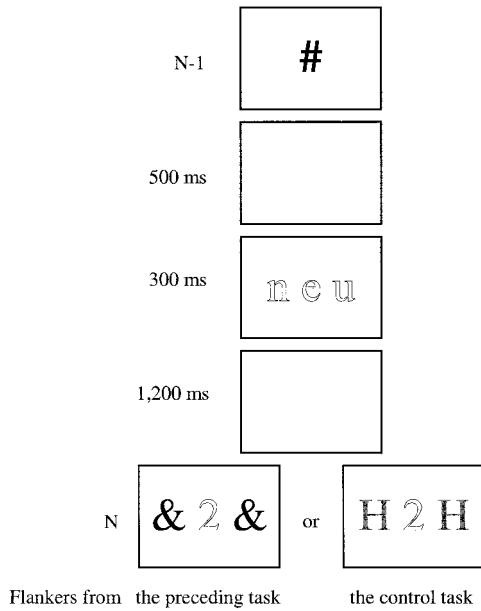


Figure 1. Example of a possible task-switch sequence with flankers from the preceding task and with flankers from the control task in Experiment 1. Different shades indicate the colors red (numbers), blue (letters), and yellow (symbols).

consonants with the right middle finger. The first practice block was the only block in which this aid occurred. In the second practice block, there were 120 trials, all of which were task switches. The sequence of tasks was random, with the only constraint being that the same task was not presented on two consecutive trials. No flankers occurred in the first two practice blocks. Before the third practice block began, participants were informed about the optional appearance of flankers at both sides of a target character. It was emphasized that flankers were irrelevant for task execution. The third practice block again contained 120 task-switch trials. On a random half of the trials, the target stimulus was flanked by a random character of the preceding task, whereas on the other half of the trials, the target stimulus was flanked by a random character of the control task. During the first three practice blocks, trials were never precued.

The fourth practice block was formally identical to the following experimental blocks. Before the fourth practice block, participants were informed about the *new* cue and were instructed to try to use it to prepare for the upcoming trial. A percentage of incorrect responses less than 10% was required in this block for entering into the first experimental block; otherwise, the block was repeated. All participants succeeded at first attempt. Then followed seven experimental blocks. Only these blocks were subject to the statistical analyses. Whenever an incorrect response occurred, the word *falsch* [false] was displayed for 500 ms and the trial was repeated with the same stimulus. These repetitions of incorrect trials were excluded from the statistical analyses.

After each block, participants received feedback about percentages of error and about mean RT of correct responses and were free to rest for some time. A complete session took between 75 and 90 min.

Results and Discussion

We report statistical analyses for only task-switch trials, because only these were of primary interest for our purpose. All trials including immediate repetitions of a character (i.e., a target on Trial *N* – 1 reappearing as distractor on Trial *N*) were excluded

from the analyses. Because the flanker character was chosen randomly among all eight stimuli of a task, this happened to be the case for approximately one eighth of the trials that were flanked with a character from the preceding task. Target–distractor repetitions were excluded because they might constitute a special case of facilitated processing: For example, Kane, Hasher, Stoltzfus, Zacks, and Connelly (1994) found shorter RTs for trials in which the target of the preceding trial reappeared as a distractor in a word naming task than for control trials in which the distractor was unrelated to the target of the preceding trial (see Neill, 1978, for a similar result).

Overall accuracy was very high, with only 2.6% incorrect responses on task-switch trials. Table 1 displays the mean error proportions and standard deviations of all experimental conditions on task-switch trials. A repeated measures analysis of variance (ANOVA) with the factors of cue condition (precued or not precued) and flanking condition (no flankers, flankers from the preceding task, or flankers from the control task) on error percentages did not yield any significant effects (*ps* > .21).

Only RT data for correct responses were analyzed. A natural logarithm transformation was applied to RTs prior to all analyses reported in this article. For each participant, the mean log<sub>RT</sub> for each experimental condition was computed and served as the basic datum in subsequent analyses. The logarithmic transformation was used to minimize the influence of outliers (see Ratcliff, 1993, for a review). In Figure 2, the antilogs of mean log<sub>RTs</sub> (which are geometric means) are reported. The left panel of Figure 2 shows the geometric means of RT data as a function of cue condition and flanking condition in Experiment 1.

A repeated measures ANOVA with the factors of cue condition (precued or not precued) and flanking condition (no flankers, flankers from the preceding task, or flankers from the control task) yielded significant main effects for cue condition, *F*(1, 17) = 31.44, *p* < .01, *MSE* = 0.0520, and flanking condition, *F*(2, 34) = 47.29, *p* < .01, *MSE* = 0.0013. Also, the interaction was significant, *F*(2, 34) = 9.96, *p* < .01, *MSE* = 0.0012. Planned comparisons showed that unflanked trials were responded to faster than flanked trials, *F*(1, 17) = 64.97, *p* < .01, *MSE* = 0.0019, and this difference was larger on nonprecued trials than on precued trials, *F*(1, 17) = 5.78, *p* < .03, *MSE* = 0.0016.

For flanked trials only, there was a significant interaction between cue condition and flanking condition, *F*(1, 17) = 17.92, *p* < .01, *MSE* = 0.0008. In the nonprecued condition, flankers from the preceding task were associated with higher RTs than flankers from the control task, *F*(1, 17) = 9.44, *p* < .01, *MSE* = 0.0010. In sharp

Table 1  
Mean Error Proportions and Standard Deviations for All Experimental Conditions on Task-Switch Trials in Experiment 1

	Flankers					
	None		From preceding task		From control task	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Precue						
No	.029	.039	.037	.053	.024	.027
Yes	.020	.022	.027	.037	.020	.027



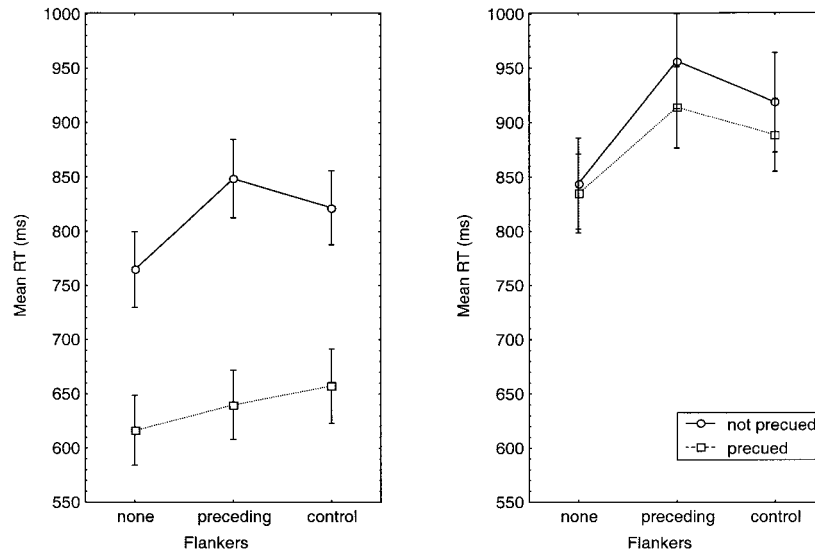


Figure 2. Geometric means of reaction times (RTs) as a function of cue condition (not precued or precued) and flanking condition (no flankers, flankers from the preceding task, or flankers from the control task) for Experiments 1 (left) and 2 (right). Error bars represent standard errors of the means.

contrast and most important with respect to our predictions, this effect was reversed in the precue condition,  $F(1, 17) = 10.20, p < .01, MSE = 0.0006$ . Thus, in the case of foreknowledge about the identity of the upcoming task, backward inhibition occurred, as indicated by reduced interference from flankers of the preceding task compared with flankers from the control task.

In summary, Experiment 1 provided four main findings: First, participants made use of the precues to prepare for a new task, as indicated by strongly reduced RTs for precued task switches. Second, flanking characters from an irrelevant task increased RTs. Third, in the absence of an opportunity to prepare for the upcoming task, flankers from the preceding task interfered more than flankers from the control task. We account for this in terms of residual activation of the task set most recently executed: If an abandoned task set is not inhibited, interference is stronger the more recently it has been in use. Fourth and most important with regard to our predictions, on switch trials that were precued, flankers from the preceding task interfered significantly less than flankers from the control task. This was expected on the assumption that the preceding task set is subject to backward inhibition, and it supports the idea that backward inhibition counters perseverative tendencies linked with a to-be-abandoned task set.

### Experiment 2

To ensure that the reduction of interference from stimuli of the preceding task found in Experiment 1 can be attributed to the work of a backward inhibition mechanism, we should rule out an alternative explanation. This alternative explanation can be based on the fact that flanker compatibility effects are usually accounted for by continuous flow conceptions, in which it is assumed that in early stages of processing, participants cannot distinguish between target and distractor stimuli (e.g., Gratton, Coles, & Donchin, 1992). During this phase, partial outputs of stimulus analysis are fed into the response system, thus activating both of the responses

associated with the target and the flankers and resulting in RT delay if those responses differ from one another. One important determinant for flanker interference may therefore be the time it takes to identify distractor information as irrelevant, because only after this identification may activation of the incorrect response be prevented. Because in Experiment 1 only task switches were associated with flanking stimuli (i.e., two thirds of the task switch trials), it is conceivable that in the case of a precued switch trial, participants prepared for the appearance of flankers in a way that allowed them to classify information from them as irrelevant as quickly as possible, to reduce competition by the incorrect response. One might argue that representations of stimuli from the task just performed are more active in memory (or more expected) than those of the control task and, therefore, might be more quickly classified as irrelevant. If this is the case, we would expect reduced interference from flankers from the preceding task as a result of task-unspecific preparation to select against flanking characters, without any backward inhibition taking place.

To control for this possibility, we conducted Experiment 2. In Experiment 2, one half of the task-switch trials were again presented with precues. However, this time precues did not specify the identity of the upcoming task. The only information provided by a precue was that there was going to be a task switch on the next trial, leaving open which of the two possible tasks would follow. The probability of the presentation of flankers on switch trials was the same as in Experiment 1. If participants prepare for flanking characters in the manner speculated above and if this accounts for the “backward inhibition” effect in Experiment 1, then we should again find less interference from flankers of the preceding task than from flankers of the control task in the precue condition of Experiment 2.

Presenting task-unspecific switch precues in Experiment 2 also served another purpose, which bears important implications with respect to the characteristics of the backward inhibition mecha-

nism. Note that we should also expect reduced interference from flankers from the preceding task in the precue condition of Experiment 2 if foreknowledge about a subsequent task switch alone (i.e., without prespecification of the identity of the upcoming task) is sufficient for backward inhibition to occur. Although perhaps intuitively appealing, the previously noted lack of backward inhibition in Mayr and Keele's (2000, Experiment 3) bottom-up cuing condition argues against this notion. Because this experiment involved no task repetitions, participants could be certain that after each task execution there was going to be a task switch. However, as reported above, no backward inhibition occurred under these circumstances. Although this result suggests that task-specific preparation is a necessary condition for backward inhibition to occur, this interpretation might be doubted; in Mayr and Keele's manipulation it is not clear whether participants did indeed represent the three tasks in separate task sets. Recall that in Mayr and Keele's paradigm, each task was to determine the odd item among a set of four items, and tasks differed with respect to the relevant perceptual dimension. Because in the bottom-up cuing condition there were no additional task cues, each stimulus display had to be unequivocal with respect to the presently relevant task to ensure accurate performance. This means that each display could include only one deviant item on only one of the three dimensions among which participants switched. Presenting only one deviant item in each display, however, might have allowed participants to respond to a singleton rather than to a switch between different perceptual dimensions or task sets. To counter this danger, Mayr and Keele included in each display a distractor item that differed from all the others with respect to an additional irrelevant dimension (i.e., size). However, even with this manipulation, it is still possible that participants continuously responded to the item different from all the others in any dimension except size rather than successively adopting different task sets. If this was the case, then no distinct task sets were switched between, and consequently the observed lack of a Lag 2 dimension repetition disadvantage could not be ascribed to reduced accessibility of the corresponding task set.

Therefore, independent confirmation of the notion that backward inhibition is bound to task-specific preparation would be valuable. A finding of no reduction of interference from the preceding task set in the precue condition of Experiment 2 would constitute such confirmation, because it would demonstrate that the mere knowledge of having to abandon a task set without the option to prepare specifically for the new task is not sufficient for backward inhibition to occur. Such a result would be in line with the lateral inhibition account of backward inhibition put forward by Mayr and Keele (2000) with the idea that backward inhibition emerges only as a consequence of the activation of a new task set.

In summary, a finding of no reduction of interference from flankers of the preceding task in the precue condition of Experiment 2 would (a) dispute the idea that the effect in Experiment 1 can be ascribed to accelerated classification of flankers from the preceding task as irrelevant and (b) demonstrate that backward inhibition is bound to the option of task-specific preparation.

### Method

**Participants.** A group of 17 male students of the Universität der Bundeswehr Hamburg participated in a single-session experiment in exchange for partial fulfillment of course requirements. Participants ranged in age from 21 to 27 years.

**Stimuli and responses.** Stimuli and responses were the same as in Experiment 1 with the exception that *new* cues were displayed in white rather than in the color of the following target stimulus, thus providing no advance information about which of the two possible tasks would follow.

**Procedure.** The procedure of Experiment 2 was the same as that of Experiment 1. Again, all participants scored below the 10% error criterion in the last practice block at first attempt. A complete session took between 75 and 90 min.

### Results and Discussion

The same analyses as in Experiment 1 with the same constraints for exclusion of data were applied to the data of Experiment 2. Overall accuracy was again very high. There were only 1.9% incorrect responses on task-switch trials. Table 2 displays the mean error proportions and standard deviations for all experimental conditions on task-switch trials in Experiment 2. A repeated measures ANOVA with the factors of cue condition (precue or not precue) and flanking condition (no flankers, flankers from the preceding task, or flankers from the control task) on error percentages yielded a significant main effect of flanking condition,  $F(2, 32) = 3.55, p < .05, MSE = 0.0004$ . All other effects remained insignificant ( $ps > .27$ ).

Figure 2 (right) shows the geometric means of RT data as a function of cue condition and flanking condition in Experiment 2. A repeated measures ANOVA with the factors of cue condition (precue or not precue) and flanking condition (no flankers, flankers from the preceding task, or flankers from the control task) on RT data yielded only a significant main effect of flanking condition,  $F(2, 32) = 48.95, p < .01, MSE = 0.0022$ . The main effect of cue condition and the interaction were not significant ( $ps > .20$ ). Planned comparisons showed that unflanked trials were responded to faster than flanked trials,  $F(1, 16) = 56.82, p < .01, MSE = 0.0034$ .

For flanked trials only, trials with flankers from the preceding task were associated with longer RTs than trials with flankers from the control task,  $F(1, 16) = 20.93, p < .01, MSE = 0.0096$ . There was, however, no interaction with cue condition,  $F(1, 16) = 0.34, p < .57, MSE = 0.0033$ . Thus, the effect of increased interference from flankers from the preceding task did not differ between precue and nonprecue switch trials.

Experiment 2 yielded two important findings: First, as in Experiment 1 flanked trials took longer to respond to than unflanked trials, again demonstrating interference from stimuli that were associated with an irrelevant task. In contrast with Experiment 1, however, in Experiment 2 flankers of the preceding task interfered

Table 2  
Mean Error Proportions and Standard Deviations for All  
Experimental Conditions on Task-Switch Trials in Experiment 2

	Flankers					
	None		From preceding task		From control task	
Precue	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
No	.013	.015	.024	.031	.025	.034
Yes	.013	.015	.011	.018	.025	.029

more than flankers from the control task for both unpredictable and precued switch trials. This indicates that expecting a task switch without anticipation of the specific task is not sufficient to obtain reduced interference from flankers of the preceding task. Thus, the selective reduction of interference from flankers of the preceding task observed in Experiment 1 cannot be attributed to specific expectations about these flankers whenever participants anticipate a task switch.<sup>2</sup> As argued above, in combination with the results of Experiment 1, this also means that backward inhibition depends on the option of preparation for the upcoming task. The result is thus in line with Mayr and Keele's (2000) account of lateral inhibition that takes place as a by-product of task preparation but does not occur without activation of the upcoming task (see also Dreisbach, Haider, & Kluwe, 2002, for further evidence suggesting that task-set inhibition is dependent on preparation).

### General Discussion

This article is concerned with the mental processes involved in setting up internal determinants relevant for efficient goal-directed action under varying S-R translation demands. Previous research has shown that performance is impaired under such conditions compared with that under conditions of constant S-R relations, and this is especially the case on trials in which the application of a different S-R mapping is required than that applied one trial before (e.g., Allport et al., 1994; Meiran, 1996; Rogers & Monsell, 1995). In this context, an executive process that reduces interference by inhibiting representations of the previous task set has been suggested, and this backward inhibition evidenced as prolonged RTs when switching back to a task that was abandoned one trial before (Mayr & Keele, 2000). With this manipulation, however, reduced (intentional) accessibility of an inhibited task set rather than reduced (nonintentional) interference with the application of a new task set was demonstrated. Thus, this demonstration fell short of showing that the backward inhibition mechanism facilitates processing of the new task, which had been the major reason for the postulation of its existence. The work reported in this article aimed at filling this gap by investigating whether backward inhibition has the effect of shielding the application of a novel task set by selectively reducing interference from the preceding one.

By replicating Mayr and Keele's (2000) findings of backward inhibition with a different methodological approach, we provided evidence that the backward inhibition mechanism reduces interference from a directly preceding task set compared with a task set not as recently applied when a switch to a new task is endogenously prepared for (Experiment 1). Thus, backward inhibition facilitates switching task sets by reducing perseverative tendencies. This effect was reversed for task switches that were unpredictable per se (Experiments 1 and 2) or precued without task identity (Experiment 2), thus supporting the hypothesis that backward inhibition can be conceived of as a lateral inhibition-like phenomenon that does not take place without endogenous activation of the impending task set.

Given the dependence of the backward inhibition effect on endogenous preparation, an obvious question that arises is whether the effect increases if longer preparation is possible. It is well known from the task switching literature that task performance benefits from increased intervals of task preparation, and this is disproportionately the case for task-switch trials (e.g., Meiran,

1996; Rogers & Monsell, 1995). To investigate dependencies of the backward inhibition effect on the amount of task preparation, we replicated Experiment 1 but included variation of the length of the preparation interval between two experimental groups. Consistent with the results of Experiment 1, selective reduction of interference from flankers from the preceding task was obtained in conditions of short (300 ms) and long (1,000 ms) preparation time. Moreover, although increased preparation led to substantial RT reduction, the strength of the backward inhibition effect did not differ between the two groups. This result is in line with reports of nonsensitivity of backward inhibition (measured as the difference in performance between ABA and ABC task sequences) with respect to the length of the preparation interval by Mayr and Keele (2000, Experiment 1) and with respect to the strength of cue-task associations (Arbuthnott & Woodward, 2002). It is also noteworthy that in the studies of Fagot (1994) and of Rogers and Monsell (1995), effects of exogenous cuing of the irrelevant (preceding) task set were not significantly reduced by increasing preparation time, as would be expected if the strength of the backward inhibition effect varied with the amount of preparation.

Taking all these findings together, the evidence strongly suggests that backward inhibition is triggered with equal strength whenever a new task set is being prepared for, irrespective of the total amount of preparation. It is an open question, however, whether the strength of the backward inhibition effect varies with other factors, such as the amount of stimulus-based support for perseveration. In the study of Dreisbach et al. (2002), performance in a task that was known to be unlikely to occur was reduced by explicit cuing, suggesting that the additional external activation of a probably irrelevant task set was countered by increased inhibition. Within the current paradigm, such dependencies may be explored by increasing the salience of the distractors: for example, by desynchronizing target and flanker onsets, by integrating both into the same perceptual object, or by unpredictably varying their locations.

One of the most obvious ways in which an irrelevant task set might interfere with the processing of a relevant task is by means of response conflict. If a stimulus is associated with different responses in two tasks, processes of S-R translation may activate the relevant as well as the irrelevant response. This ambiguity may then have to be resolved in a time-consuming manner. In the experiments reported in this article, response sets were disjointed between tasks, and thus target and flankers were always associated

<sup>2</sup> It is noteworthy that although in Experiment 2, as in Experiment 1, switch trials were equally often flanked with stimuli from the preceding task and from the control task, subjective probabilities may not have corresponded to this: In Experiment 2, participants could not foresee to which task they were going to have to switch; after execution of Task A it was equally likely that Task B or Task C would occur. If it was going to be Task B, flankers could be taken from Task A as well as from Task C. If it was going to be Task C, flankers could come from Task A or Task B. Thus, it might have appeared to participants that flankers from the preceding task were more likely than flankers from the control task. Such a conception, however, should have led to higher expectancies for flankers from the preceding task in the case of a precued task switch and thus should have yielded shorter response times for trials with flankers from the preceding task.

with different responses. This makes it undecidable whether the interference reduction found is due to a reduction of response conflict or to a more general form of task competition. Therefore, we conducted another experiment in which each of the three tasks was associated with the same pair of responses. This arrangement made it possible for us to distinguish target-flanker pairings that were response compatible (i.e., target and flankers that were mapped onto the same response) and target-flanker pairings that were response incompatible (i.e., target and flankers that were mapped onto different responses). If backward inhibition works by reducing response conflict, the effect should be enhanced on trials with response incompatible stimuli, because on response compatible trials there is no response conflict to be reduced. The results of this experiment were not that easy to interpret, because the backward inhibition effect did not reach significance in RTs. There was, however, a significant reduction in error rates on trials with flankers from the preceding task compared with flankers from the control task given endogenous preparation. Moreover, this effect was present only for response incompatible target-flanker pairings, suggesting that backward inhibition indeed reduces response conflict.

By what precise mechanisms is the reduction of interference brought about? According to Logan's (1988) instance theory of automatization, there are two possible ways in which a stimulus may be converted into its associated response: algorithmic processing (i.e., the application of task rules) or episodic retrieval of a response previously given to the same stimulus. The suppression of the S-R translation of the preceding task set that we found may thus, in principle, stem from reduced activity of either of the two mechanisms. Recently it has been demonstrated that a large part of the so-called task-switching costs is in fact stimulus specific, present only for stimuli that appeared previously in the context of a competing task (Allport & Wylie, 2000; Waszak, Hommel, & Allport, 2001). This effect is assumed to be due to the retrieval of attributes of the other task, associations to which were established when the current stimulus appeared earlier in the context of that task. Ascribing the reduction of interference observed in the current study to suppression of such retrieval of prior processing episodes for stimuli of the preceding task may seem an attractive option. However, because we did not include variations in the frequency with which specific stimuli appeared as targets in their associated task before being presented as distractors, we cannot judge whether the backward inhibition effect we observed would be reduced for distractors with a reduced number of instances to be retrieved. This appears to be an issue worth investigating in future research.

Another open question concerns the precise way in which the target of backward inhibition is selected: for instance, whether the directly preceding task set exclusively receives inhibition or whether other possible competitors (such as the control task set) are also subject to it to a smaller degree. It is possible that the decisive criterion in determining the amount of inhibition an unwanted task set receives is the amount of competition it exerts. With a procedure such as the one we used (i.e., applying three tasks with arbitrary S-R assignments), the most recently executed task set is likely to be the strongest competitor. However, a task set that is for some reason (such as extended practice or natural compatibility) more competitive than the directly preceding task set might even become more suppressed during the course of

activating the new task. Backward inhibition may thus turn out to be a particular instance of a more general mechanism that serves to reduce interference from all potentially competing task sets depending on their competitive strengths.

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Received December 17, 2001

Revision received July 17, 2002

Accepted August 12, 2002 ■