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Task-Set Switching and Long-Term Memory Retrieval

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The authors tested the hypothesis of a close relationship between the intentional component of task-set switching ("advance reconfiguration;" R. D. Rogers & S. Monsell, 1995) and long-term memory (LTM) retrieval. Consistent with this hypothesis, switch costs are reported to be larger when the switched-to task involves high retrieval demands (i.e., retrieval of episodic information) than when it involves low retrieval demands (i.e., retrieval of semantic information). In contrast, switch costs were not affected by a primary-task difficulty manipulation unrelated to intentional retrieval demands (Experiment 2). Also, the retrieval-demand effect on switch costs was eliminated when time for advanced preparation or task cues explicitly specifying the task rules were provided (Experiment 3). Overall, results were consistent with the hypothesis that the intentional switch-cost component reflects the time demands of retrieving appropriate task rules from LTM.

Because environment usually allows multiple paths of action, internal control settings are needed to specify the currently desired action. However, most people occasionally experience situations where internal settings are not strong enough to withstand the force of external triggers and, as a result, one may perform the wrong action. Extreme cases of such breakdown of internal settings produce symptoms associated with frontal-lobe pathology, such as *capture behavior,* whereby environmental stimuli trigger associated actions whether or not the context is appropriate (e.g., Lhermitte, 1983). Knowledge about how internal control settings are established, maintained, and deactivated should be the key to a better understanding of complex, organized action in the range of normal functioning as well as its breakdown in pathological cases.

In the cognitive literature, internal control settings are subsumed under the label *task sets* (e.g., D. A. Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995; Woodsworth, 1918). A way of assessing control of task sets was introduced early in the century in the form of the task-switch paradigm (Jersild, 1927; Pinard, 1932), which contrasts two situations: Participants must either switch tasks from trial to trial or they can work with the same task across trials. The response time (RT) difference between these two situations (i.e., the switch cost) is supposed to reflect processes involved in setting up a new task set (Rogers & Monsell, 1995), overcoming the interference from the preceding task set (D. A. Allport et al., 1994), or both. There has been sporadic interest in this paradigm throughout the century (e.g., Jersild, 1927; Pinard, 1932; Spector & Biederman, 1976); however, research on task switching has gained considerable momentum over recent years (e.g., D. A. Allport et al., 1994; Hayes, Davidson, Keele & Rafal, 1998; Mayr & Keele, 2000; Mayr & Kliegl, 2000; Meiran, 1996; Rogers & Monsell, 1995; Rogers et al., 1998; Shallice, 1994).

In the present study, we focus on one particular aspect of switching between task sets. Specifically, we ask what people can do to prepare for an upcoming task set. The idea we put to test is that processes involved in preparing for a task have much in common with processes involved in retrieving information from long-term memory (LTM). Before we develop the retrieval hypothesis and motivate the rationale behind our experiments, we provide a short account of relevant findings from the recent literature on task switching.

Basic Phenomena in Task Switching

Switch Costs Are Dissociable From Primary-Task Processes

Every experimental task requires some form of selection (i.e., between stimulus codes or response codes). Therefore, it is a critical question to what degree within-task selection of responses can be dissociated from selection between tasks. Two types of findings are relevant. First, in general, there seems to be no dependency between switch costs and primary-task difficulty (D. A. Allport et al., 1994; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, in press). This opposes the view that both types of selection are based on shared processes. The second type of evidence is correlational. Individual differences in switch costs seem to be largely independent of individual differences in primary-task processes. Moreover, switch costs across different combinations of tasks seem to share a substantial common component (Kray & Lindenberger, 2000; Salthouse, Fristoe, Lineweaver, & Coon, 1998). Thus, both the experimental and the correlational evidence suggest that task-set selection requires a unique set of processes not represented in standard RT paradigms.

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Switch Costs Are Associated With Stimulus-Elicited Competition Between Task Sets

Switch costs are small, sometimes even zero, when stimuli are uniquely associated with a task set. For example, suppose one task involves naming opposites of word stimuli and the other task involves adding 3 to number stimuli. When on opposite-naming trials only words and on adding-3 trials only numbers are shown, either no or only very small switch costs are found (Jersild, 1927). In contrast, substantial switch costs are observed whenever more than one potentially relevant task set is associated with a stimulus. Supposedly, in this case, endogenous control is necessary to resolve task-set competition elicited by automatic activation of both task sets associated with the stimulus.

Task Sets Can Be Prepared

Findings suggesting that switch costs decrease as a function of the preparatory interval indicate that people can somehow "reconfigure themselves" for an upcoming task. For example, Rogers and Monsell (1995) introduced the so-called *alternate-runs* paradigm in which participants had to switch back and forth between runs of two or four same-task trials. With larger preparatory intervals, a switch-cost reduction was obtained but only when different preparation intervals were blocked rather than intermixed within a block of trials. Rogers and Monsell argued that intermixing preparatory intervals may have led participants to refrain from active preparation because of an uncertainty about whether or not it could be completed. Importantly, the fact that preparation did occur in the blocked but not in the mixed condition allowed Rogers and Monsell to interpret the switch-cost reduction in terms of an active process rather than in terms of passive decay.

Meiran (1996) used a paradigm in which a cue indicated the relevant task for the upcoming trial. The use of this procedure allowed him to dissociate the preparatory component from a potential passive-decay component by manipulating two different temporal parameters: the interval between the response to the preceding trial and the task cue (i.e., the response cue interval [RCI]) and the interval between the cue and the next stimulus (i.e., the cue stimulus interval [CSI]). Whereas a long RCI allows only passive decay of the preceding task set, a long CSI allows decay and preparation. Importantly, a unique switch-cost reduction was associated with increase of the CSI, thus, suggesting again that preparation plays an important role. The question is, however, "What exactly does preparation imply?" Rogers and Monsell (1995) labeled the preparatory component *active reconfiguration,* Meiran (1996) speaks of a *proactive component,* and more recently, of *selective attention* to task-relevant dimensions (Meiran, in press). However, even with this specification the question remains, "How do people know what the relevant dimensions are and how do they respond to them once they are attended?" Thus, it seems that a comprehensive account of what people can do intentionally to reconfigure themselves is currently missing.

Preparation Cannot Fully Eliminate Switch Costs

Probably the most straightforward model of task switching would hold that switch costs reflect directly the duration of a proactive reconfiguration component. Consequently, if participants are allowed at least as much preparation time as the time it takes to execute the switch, then the costs should disappear. This simple model, however, is clearly not correct. In particular, D. A. Allport et al. (1994) provided ample evidence suggesting that a substantial portion of the switch costs remains even after long preparatory intervals (see also Meiran, 1996; Rogers & Monsell, 1995). D. A. Allport et al. interpreted these *residual switch costs* in terms of *task-set inertia,* that is, proactive interference from the preceding task set (for a different interpretation, see De Jong, in press). Consistent with this idea, D. A. Allport et al. also reported asymmetric switch costs: Switching from a difficult task supposedly requiring a "strong" set produced larger residual switch costs than switching from an easy task supposedly requiring a "weak" set. In the context of the present study, this latter finding is important mainly for methodological reasons. It suggests that the effects of task-difficulty manipulations in switching experiments may be ambiguous unless difficulty of the to-be-abandoned and difficulty of the to-be-established set are independently manipulated.

The LTM-Retrieval Hypothesis

As just reviewed, one component of task-set selection is a time-limited, endogenous process. The main evidence for this component is the finding that switch costs become smaller when the preparatory interval increases. Rogers and Monsell (1995) attributed this component to a "... stagelike (but incomplete) process of task-set reconfiguration, which is endogenously controlled and can be carried out in anticipation of the stimulus" (p. 228). They also stated that "to adopt a task-set is to select, link, and configure the elements of a chain of processes that will accomplish a task" (p. 208). As becomes clear from these passages, task-set reconfiguration is a rather elusive process that is either described in very general terms or is equated with a number of little-understood processes.

Both Rogers and Monsell (1995) and Meiran (1996) also referred to the Norman and Shallice (1986) model of high-level control as being generally compatible with their findings. In this model, the supervisory attention system (SAS) is responsible for endogenous control of action sets or schemas. The SAS achieves this by selectively adding positive and negative biases to simultaneously activated but competing action schemas. From this view, endogenous control of task switching essentially implies allocating activation between "preselected," competing schemas. In very general terms, this is compatible with current views of the role of working memory during complex performance (e.g., Anderson, 1993; Baddeley, 1986; Just & Carpenter, 1992). An important function of working memory is temporary storage of information during ongoing processing until it becomes relevant again. Similarly, in task-switching situations, both task sets may be contained within working memory. The currently relevant one receives above-selection threshold activation (i.e., through the SAS), whereas the currently irrelevant one is deactivated but still on temporary hold. In other words, selection processes would occur among "special-status" candidate schemas contained in working memory.

In the task-switching domain, constructs such as working memory, activation, or selection are rarely used with the precision necessary to arrive at strong claims about what a process such as active reconfiguration entails. However, we believe that one position that can be derived from the above short review is that back-and-forth switching between two or more well-practiced tasks is basically a process of switching activation between schemas in working memory, or some specialized entity of it, such as a goal stack (e.g., Anderson, 1993; Just & Carpenter, 1992). Although we do not deny that a process of selection within working memory exists, we question that it adequately characterizes the process of reconfiguration during the preparatory interval.

The alternative view proposed in this study is derived from considerations about what happens to task sets that are in competition with the currently relevant task set. In the case of ambiguous stimuli, that is, when more than one task set is associated with the stimulus, goal-directed action is possible only if the relevant task set is selected and if the irrelevant task set is prevented from exerting control. When taking the working-memory view seriously, this produces an odd situation. Of the two sets simultaneously present within working memory, one needs to be fully activated whereas the other one has to be kept in an activated but sub-selection-threshold mode (because it becomes relevant again in the near future) but at the same time it must be prevented from interfering with the relevant set. It seems that this would require an additional type of mechanism that counteracts interference within working memory.

We believe that a more parsimonious conception would hold that selection of a task set and its activation in working memory are identical processes. Consequently, a task set that is not selected is not in working memory. This avoids the necessity of specifying additional processes required to eliminate task-set competition within working memory. All that is needed are processes to select codes into working memory and possibly also processes to delete codes from working memory (e.g., Hasher, Zacks, & May, 1999; Mayr & Keele, 2000). Obviously, once a task set is eliminated from working memory, switching back to it requires more than the reallocation of attention within the working memory. Rather, every switch to an intermediately irrelevant set entails a process of LTM retrieval. Thus, switch costs would, at least to some degree, reflect the process of actively re-retrieving what needs to be done on the next trial from LTM. More specifically, we hypothesize that this LTM retrieval process constitutes a large share, if not all, of what participants can do to prepare for a task set before the stimulus arrives. Typically, a distinction is made between endogenous, controlled retrieval and exogenous, automatic retrieval (e.g., Jacoby, 1991). Unless stated otherwise, we imply the former when referring to LTM retrieval in the context of active preparation for an upcoming task. The role of the latter, unintentional type of retrieval during selection of sets will be dealt with in the General Discussion.

A very similar view as proposed here, as well as initial evidence for the retrieval hypothesis, comes from a recent paper by Rubinstein et al. (in press). On the basis of the proposal that one important component of task switching is LTM retrieval of task rules, Rubenstein et al. predicted that switch costs should increase with complexity of task rules because it should take longer to retrieve a complex set of rules than a simple set of rules. This prediction was confirmed; at the same time other manipulations of task difficulty were shown to leave switch costs unaffected. Although consistent with the LTM-retrieval view, these findings could be challenged. First, Rubinstein et al. manipulated the critical variable, *rule complexity*, by comparing blocks of complex tasks with blocks of simple tasks. Therefore, it is not possible to isolate the effects of switching to a complex task set from the effects of switching from a complex task set. Given reports that switch costs are associated with the difficulty of the to-be-abandoned task sets (D. A. Allport et al., 1994), it is possible that the difficulty effects reported by Rubinstein et al. reflect disengagement processes rather than engagement processes. Second, Rubinstein et al. did not manipulate preparatory intervals. Thus, it still needs to be shown that their reported retrieval-related effects are actually associated with the intentional, preparatory component of task switching.

Overview of Experiments

The main goal in this study is to specify and test the hypothesis that LTM retrieval is associated with task switching and specifically with the proactive reconfiguration component. Our initial experimental approach is related to that of D. A. Allport et al. (1994) and Rubinstein et al. (1998) in that we try to make inferences about switch-related processes through specific interactions between the switch manipulation and manipulations of primary-task demands. Specifically, we predict an increase of switch costs as a function of primary-task retrieval demands. The rationale for this prediction is that retrieval in the course of task switching and retrieval within the task being switched to should lead to structural interference and, thus, to increased switch costs. As reported earlier, both D. A. Allport et al. and Rubinstein et al. found switch costs to be insensitive to a number of variables affecting difficulty of the primary task (see also Rogers & Monsell, 1995). D. A. Allport et al. even argued that it is the difficulty of the to-be-abandoned task set relative to the difficulty of the to-be-established task set that leads to increases in switch costs. Thus, an interaction between a specific aspect of difficulty of the to-be-established task and switch costs would itself be a nontrivial finding.

In Experiment 1 we report evidence for the predicted effect of retrieval demands on switch costs. In Experiment 2 we show that the obtained difficulty effect is specific for retrieval demand rather than for general difficulty of the primary task. Finally, in Experiment 3, we add manipulations of the preparatory interval and of the amount of information provided by task cues. Results from these experiments suggest that the retrieval-demand effect on switch costs is specifically associated with the preparatory switch component.

Experiment 1

In the first experiment, we used the alternate-runs paradigm introduced by Rogers and Monsell (1995). Within each block, participants performed alternating four-trial runs of two tasks (AAAABBBB . . .), so that a switch occurred every four trials. Use of this runs-of-four schema allows one to examine whether a switch can be completed within a single trial (as argued by Rogers & Monsell, 1995) or whether it requires several trials.

For a conservative test of the predicted retrieval-demand effect on switch costs, our primary contrast is between two conditions that both require LTM retrieval but to different degrees. In the "semantic" condition, a fixed set of 16 words was to be evaluated on one of two possible semantic criteria (i.e., size and living/nonliving; D. A. Allport et al., 1994). This condition served as a control for the "episodic" condition in which preexperimentally learned, episodic information was supposed to be retrieved about each of the 16 words (i.e., its color and screen location during the learning phase). In contrast with the semantic condition in the episodic condition participants were required to activate a particular episodic context. We expected this to lead to an increase in switch costs—what we call the retrieval-demand effect.

An important feature of our paradigm is that we not only manipulate retrieval load of the to-be-engaged task but also of the to-be-disengaged task. In contrast with earlier studies that looked at difficulty effects on switch costs (e.g., D. A. Allport et al., 1994; Rubinstein et al., 1998), this allows us to distinguish between difficulty effects on task-set engagement versus difficulty effects on task-set disengagement.

Method

Participants. Thirty-two students at the University of Potsdam or last-year students from a neighboring high school received a compensation of DM 20 (about U.S. $15) for participating in this experiment.

Task and stimuli. Sixteen concrete nouns were used. Four referred to large, nonliving objects (*table, bicycle, coat, TV set*); four to small, nonliving objects (*pebble, knob, cup, marble*); four to large, living objects (*horse, shark, eagle, lion*); and four to small, living objects (*mouse, sparrow, goldfish, lizard*). Thus, each word could be classified in terms of two independent semantic dimensions: size and living/nonliving. Following D. A. Allport et al. (1994), the size dimension was defined as "larger or smaller than a soccer ball." In addition, the nouns were associated in a preexperimental learning phase (to be described in the *Procedure and design* section) with a value on the two episodic dimensions: location on the computer screen and font color. The four possible episodic combinations of values (i.e., yellow and top, yellow and bottom, blue and top, blue and bottom) were completely crossed with the four possible semantic combinations of values resulting in 16 distinct semantic–episodic combinations, each represented by one word. Within combinations of semantic values, associations between nouns and episodic values occurred randomly across participants.

In the primary task, participants were presented a noun and had to judge it in terms of one of the four possible dimensions (living/nonliving, size, location, and color). As a response, participants either pressed the right arrow key on the Macintosh keyboard for large, living, top, and blue objects or the left arrow key for small, nonliving, bottom, and yellow objects. Within a given block of trials, two different tasks were relevant.

Within a block, the dimension relevant for a particular trial was specified by an AAAABBBB alternate-runs schema (see Rogers & Monsell, 1995). For example, in a pure semantic block, participants judged a run of four successively presented words in terms of the living/nonliving dimension, followed by a run of four words that had to be judged in terms of the size dimension. This pattern would be repeated throughout the block. On each trial, one word (in a font size of 24 points) was presented centrally on a monitor together with a stimulus indicating the current position within the AAAABBBB cycle. This position indicator was a filled circle at one of eight positions marked by open circles and arranged as a 4-cm (1.6-in.) octagon that surrounded the word. The position indicator cycled from trial-to-trial clockwise around the octagon and switches occurred for half of the participants when the signal moved across the vertical axis and for the other half when it moved across the horizontal axis. Prior to each block, participants were informed about the dimensions relevant for that block. This occurred by labeling each of the positions of the octagon with the dimensions that were relevant when the position indicator was shown at that position. This information was not present within the block.

Procedure and design. At the beginning of an experimental session, participants went through a learning-to-criterion procedure in which associations between nouns and episodic features were learned. Each cycle of the learning-to-criterion procedure consisted of a learning phase and a test phase. During the learning phase, nouns were shown in a random order with a rate of 5 s per word in their episodic context. Thus, each noun was presented either on the bottom or on the top of the screen and in yellow or blue font. In the test phase, each noun was presented centrally on the screen in white font, together with a query about one of the episodic features. Participants responded using the left and right arrow keys and the same response schema as in the primary task (see *Task and stimuli*).

The order of presentation in the test phase was random. Because there were two episodic features, we presented each noun twice, once for each of the possible queries (i.e., location or color). When participants accurately recalled both episodic features four times in sequence, a noun was dropped out of the procedure. The learning-to-criterion phase continued until all 16 nouns were dropped out of the list. The presentation-test cycles started anew and continued until each dimension was produced for each word correctly two times in a row. This two-stage process was used to ensure high proficiency with the to-be-learned episodic features.

To get acquainted with the primary task, participants next went through a block of 64 trials in which each noun was presented once with each of the four possible queries (size, living/nonliving, color, and position). On each trial, a noun was presented together with a query and the relevant response schema. The order of the presentation was random.

Two sets of four blocks each with the experimental task followed next. The first set served as a practice phase and each block contained 64 trials. The second set of four blocks of 128 trials was used as the actual testing phase. As indicated in *Task and stimuli,* prior to each block participants were informed about the two relevant dimensions for that block. The response stimulus interval (RSI) was 100 ms. Word stimuli were randomly selected without replacement within successive sets of 16 trials. No word repetitions were allowed at transition points between sets.

The goal of the experimental procedure was to represent with equal numbers of trials all possible trial-to-trial transition combinations given through the three factors: (a) retrieval demand of the last abandoned task, (b) retrieval demand of the engaged task, and (c) position within same-task runs. Therefore, of the four blocks within both the practice and the test phases, one had to be all semantic, one all episodic, and two had to be mixed semantic and episodic. There was only one possible task combination for each of the two homogeneous blocks (e.g., living/nonliving and size for all semantic), but there were four possible combinations for the mixed blocks. For one half of the participants, we used two possible mixed combinations (living/nonliving and color or size and position), and for the second half, we used the other two possible combinations (living/nonliving and position or size and color). The sequence of blocks alternated between homogeneous and heterogeneous blocks and dimensions were selected such that exactly one of the two dimensions from the preceding block was retained for the next block. Four different sequences of four blocks were used across participants such that across sequences each dimension occurred on each sequence position equally often. All of the aspects mentioned (i.e., starting position of position indicator, dimension combinations for heterogeneous blocks, and sequence of blocks) were counterbalanced across participants.

Results

Trials from all blocks were classified according to (a) whether an episodic or a semantic dimension had to be used in the current trial (engaged-task retrieval demand); (b) whether the other dimension relevant in that block (but currently irrelevant) was episodic or semantic (disengaged-task retrieval demand); and (c) the position within a same-task run of trials (1–4) where Position 1 would be the first trial after a task switch. Incorrect responses and responses following incorrect responses were excluded from analysis. Also, all RTs that were more than three standard deviations from an individual participant's mean for each design cell were excluded. The remaining RTs and error scores were averaged for each design cell and served as dependent variables. Figure 1 shows RTs and error percentages as a function of the type of relevant set, the type of irrelevant set, and run position, where Position 1 is the first trial after a set switch; Figure 2 shows switch costs computed as difference scores between Position 1 RTs and the mean RTs of Positions 3 and 4 as a function of the two manipulations of retrieval demand.

As shown in Figure 1, there was a very large RT difference between Run Position 1 and Run Position 2 suggesting that a major component of the switch process was located at the first trial of a switch. However, some additional reduction of RTs seemed to occur on later positions when the episodic task was relevant. Generally, the episodic task was more difficult for participants than the semantic task. More important, switch costs associated with switching to an episodic task were larger than switch costs associated with switching to a semantic task (see Figure 2). Also, switch costs seemed somewhat larger when switching away from an episodic task than when switching away from a semantic task.

For statistical evaluation of these observations we used a 2 (engaged-task retrieval demand) × 2 (abandoned-task retrieval demand × 4 (run position) analysis of variance (ANOVA). To identify the location(s) of the switch effect, we specified a repeated contrast for the run position factor (i.e., Contrast 1: Position 1 vs. 2; Contrast 2: Position 2 vs. 3; Contrast 3: Position 3 vs. 4). Here and throughout, the criterion for rejecting the null hypothesis was set to $p = .05$. Consistent with observations from Figure 1, the first contrast of the position factor was highly significant, $F(1, 31) = 158.3$, $MSE = 4{,}025{,}274.9$. However, there was also a small, significant effect associated with the contrast between Position 2 versus Position 3, $F(1, 31) = 5.8$, $MSE = 128{,}658.8$, but there was no effect associated with the Position 3 versus Position 4 contrast, $F(1, 31) = 0.58$, $MSE = 120{,}510.4$. There was a large main effect due to the fact that the episodic task was more difficult than the semantic task, $F(1, 31) = 177.05$, $MSE = 17{,}043{,}416.2$; also, there was a small tendency for disengaged episodic task sets to produce longer RTs than the abandoned semantic task sets, $F(1, 31) = 3.25$, $MSE = 688{,}334.1$, $p < .09$. However, the interaction between the two retrieval-demand factors was nonsignificant, $F(1, 31) = 1.6$, $MSE = 531{,}479.2$.

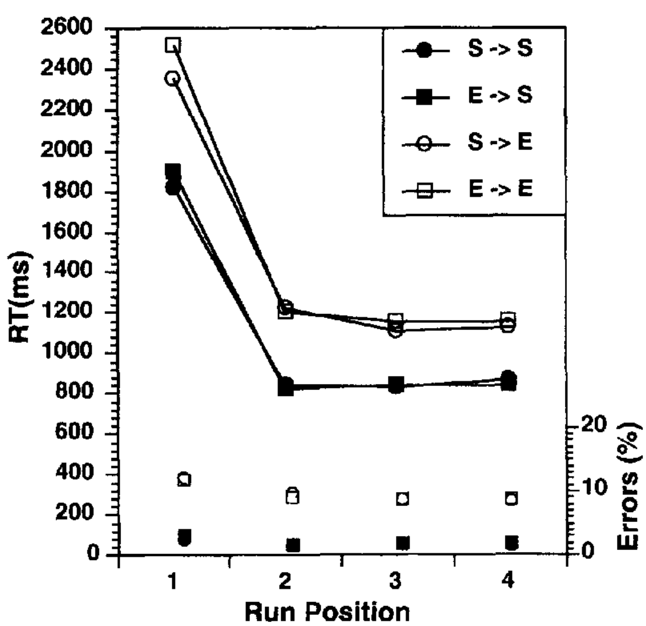

Figure 1. Mean response times (RTs) and errors (%) as a function of the retrieval demands of the engaged task and the abandoned task, as well as run position for Experiment 1. S = semantic tasks; E = episodic tasks; the arrow (→) implies that the last switch was from the first task to the latter task.

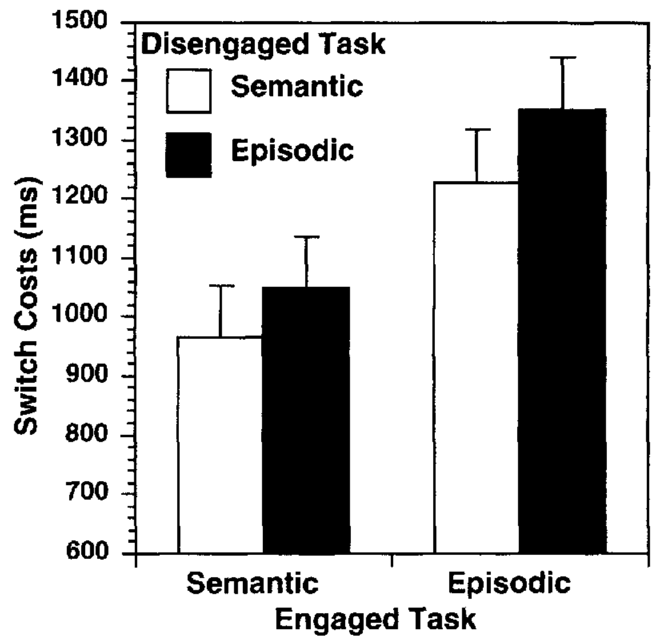

Figure 2. Mean switch costs as a function of the retrieval demands of the engaged task and the abandoned task for Experiment 1. Switch costs were computed as difference scores between Position 1 response times (RTs) and the average across Position 3 and Position 4 RTs. Error bars represent 95% within-subject confidence intervals for the interaction between the engaged-task retrieval demand and the switch contrast (Loftus & Masson, 1994).

The critical interaction between the first position contrast and engaged-task retrieval demand was highly significant, $F(1, 31) = 12.5$, $MSE = 393{,}203.1$, suggesting that, as predicted, switching to an episodic task takes longer than switching to a semantic task (i.e., the retrieval-demand effect). This effect was not limited to the first position but was also apparent for the second contrast, $F(1, 31) = 8.5$, $MSE = 94{,}801.8$. There was a RT reduction from Position 2 to Position 3 for episodic ($M = 78$ ms) but not for semantic tasks ($M = -1$ ms). Thus, for the semantic task we replicated the finding by Rogers and Monsell (1995) that switch costs arise only on the first post-switch trial. In contrast, for episodic tasks, the switch process not only took more time on the first post-switch trial but also was not completed on that trial and extended into the second post-switch trial. Because of the prolonged switch effect in the episodic condition, we used Positions 3 and 4 as a baseline for computing the switch costs shown in Figure 2. There was also evidence for a set-inertia type of process (D. A. Allport et al., 1994) in the form of larger costs when switching from the more difficult episodic task than from the easier semantic task, $F(1, 31) = 4.8$, $MSE = 495{,}483.4$. However, the retrieval demand of the engaged task and the abandoned task did not interact with each other, $F(1, 31) = 0.72$, $MSE = 316{,}315.5$.

Error percentages are shown in Figure 1. Participants made more errors in the episodic task than in the semantic task, $F(1, 31) = 18.5$, $MSE = 972.0$, and also somewhat more errors on switch trials (Contrast 1), $F(1, 31) = 4.8$, $MSE = 75.2$. This latter effect was qualified by the tendency toward a retrieval-demand effect on switch costs in terms of errors, $F(1, 31) = 3.2$, $MSE = 87.8$, $p < .09$. No other effects were significant.

Discussion

Two kinds of primary-task difficulty effects on switch costs were found in this experiment. First, switching to a task with high retrieval demands (i.e., episodic retrieval) took longer than switching to a task with low retrieval demands (i.e., semantic retrieval). This result was predicted on the basis of our proposal that set switching involves a LTM retrieval process that interferes with LTM retrieval processes required during the primary task. Interestingly, when switching to an episodic task, costs were not only larger but apparently the switch was also less successful than when switching to a semantic task. Consistent with the general idea proposed here, the demands of retrieving the upcoming task set and retrieving task-specific information on the same trial may lead to mutual disruption or interference so that part of the establishment of the episodic task set needs to be completed on the second postswitch trial.

The second smaller difficulty effect was associated with retrieval demands of the to-be-abandoned task. Switch costs were larger when switching from episodic tasks than when switching from semantic tasks. This bears similarity to the asymmetric switch-cost finding (i.e., larger switch costs going from difficult to simple tasks) suggested by D. A. Allport et al. (1994) to indicate the existence of task-set inertia. The idea is that a more difficult-to-establish task requires a stronger task set which then takes more time to abandon. There is, however, also an important difference between our findings and those reported by D. A. Allport et al. In D. A. Allport et al.'s research, the critical comparison was between two conditions, namely, switching from an easy task (i.e., the dominant color–word reading task in a Stroop situation) to a difficult task (i.e., the nondominant color naming task in a Stroop situation) versus switching from the difficult to the easy task. The critical result was that the latter required much larger switch costs than the former. D. A. Allport et al. interpreted this as suggesting that the *relative* differences in dominance between two tasks is the critical factor, such that the less dominant task requires the stronger task set. However, given that D. A. Allport et al. did not independently manipulate dominance (or difficulty) of the to-be-abandoned and the to-be-established task set (i.e., requiring 2 × 2 conditions) it is not clear whether the critical factor is the relative or the *absolute* difficulty of a task set. Interestingly, when applying the relative-difficulty criterion to our fully orthogonal design, larger switch costs should have been expected when switching from the (nondominant) episodic to the (dominant) semantic task than from one episodic to another episodic task. In other words, we should have found a characteristic interaction between difficulty of the to-be-established task and difficulty of the to-be-abandoned task. The fact that we found two main effects and no indication of the critical interaction pattern suggests at the very least that more work is needed before straightforward assumptions like the "relative-dominance model" advocated by D. A. Allport et al. can be accepted. At the same time, difficulty of the abandoned task was manipulated here mainly to allow unambiguous interpretation of the engaged task effects on switch costs. In this respect, the finding of difficulty effects associated with the abandoned task underscores the necessity of this experimental approach.

Experiment 2

In Experiment 1, we found a large retrieval-demand effect on switch costs associated with the to-be-established task, a result that is fully compatible with the idea that set switching requires LTM retrieval. However, to be satisfied with this interpretation, we need to rule out a possible alternative. The episodic primary task is more difficult than the semantic primary task. Thus, larger switch costs for the episodic task may simply reflect an unspecific difficulty or complexity effect. This possibility receives some support from the observation that in Experiment 1, switch costs proportionalized with respect to the no-switch baseline were roughly similar for semantic and episodic tasks (i.e., 119% for semantic and 114% for episodic tasks). It should be noted that such a pattern could easily be explained by the assumption that retrieval demand affects both primary-task RTs and switch costs. However, it still needs to be shown that not all general difficulty manipulations also lead to an increase in switch costs.

For this reason, we introduced an additional difficulty manipulation. Words to be evaluated were presented either in regular or inverted text (e.g., "elgae" instead of "eagle"). In pilot experiments, we established that this manipulation produces RT effects at least as large as the semantic–episodic manipulation. Arguably, reading inverted text itself requires LTM retrieval. However, at least after some practice, this retrieval should be automatic so that this manipulation allows a conservative test of the hypothesis that intentional retrieval constitutes a critical switch-cost component. The most critical prediction of the retrieval hypothesis is that switching to a semantic task when words are inverted requires less time than switching to an episodic task when words are not inverted even though no-switch RTs in the latter are the same or shorter than in the former.

To probe the generality of the retrieval-demand effect on switch costs, we also introduced a change in procedure for this experiment. In Experiment 1, two task sets were specified as potentially relevant for each block of trials whereas the other task sets were irrelevant. In principle, it is possible that the kind of difficulty effects on switch costs we had found in Experiment 1 may have been elicited at least partly by the overall block context rather than by demands associated with the local transitions between tasks. Specifically, the effects of the abandoned task's retrieval load on switch costs could either result from "local" switching demands or from the fact that the local switch occurs within a generally more difficult situation. Therefore, we wanted to establish a situation in which the block context is the same for all critical conditions. This was achieved by presenting the four tasks in a randomly cued manner with the constraint that task repetitions should occur with $p = .5$. In order to not introduce a memory load of four arbitrary cue-task associations, we used combined verbal–spatial cues in this experiment.

Method

Participants. Thirty-two students at the University of Potsdam served as participants in exchange for course credits or a payment of DM 20 (about U.S. $15).

Task, stimuli, and procedure. For the sake of generalizability across stimulus materials, we used 16 new words but with task dimensions and response assignments the same as those used in Experiment 1 (*large and nonliving: boulder, cloud, tricycle, bureau; large and living: oak, alligator, bison, crane; small and nonliving: ruby, purse, snowflake, knife;* and *small and living: tulip, spider, mushroom, weasel*). Words were presented in the center of the screen with a font size of 24 points and were surrounded by four, small open circles forming the corners of a virtual square with a side length of 5 cm. Each circle was assigned to one of the four possible tasks and it was filled if the corresponding task was relevant. Two different task-to-position assignments were used across participants. Going clockwise from the upper left corner, the first assignment was size, color, position, living/nonliving and the second assignment was living/nonliving, size, color, position. We deliberately used assignments in which the two tasks belonging to the same type of retrieval demand were adjacent to each other because we feared that other assignments might be confusing to participants. The potential drawback is a confound between the type of transitions between tasks and the type of transitions between locations. Specifically, semantic-to-semantic or episodic-to-episodic transitions always were between adjacent locations whereas half of the semantic-to-episodic or episodic-to-semantic transitions were between nonadjacent positions. It should be noted, however, that this confound is orthogonal to our primary question concerning the episodic switch-cost effect. Nevertheless, we also conducted analyses of "mixed" transitions between positions to examine whether the primary effects of interest here are affected by this confound.

During actual testing, task labels (e.g., color) were shown next to the circles (and outside the virtual square); during the initial practice block, the stimulus-response (S-R) assignment was indicated instead of the task labels by means of the relative spatial positions of the critical dimension values (e.g., yellow–blue). Task cues (i.e., the filled circles) were presented 100 ms before the word appeared; the response-cue interval was also 100 ms.

Tasks were selected randomly among the four possible tasks with the constraint that task repetitions should occur with a probability of $p = .5$. Also, words were presented in an inverted manner with a probability of $p = .5$. Preexperimental learning of episodic associations occurred in the same way as in Experiment 1. Participants were exposed to one 128-item practice block followed by eight 128-item test blocks.

Results

Each trial was classified in terms of reading difficulty (regular–inverted), engaged-task retrieval demand (semantic–episodic), disengaged-task retrieval demand (semantic–episodic), and whether there was a switch between the preceding and the current trial (no-switch/switch). In the case of no-switch trials, the last task set deviating from the present set before the current run of same-set trials was used for specifying the semantic–episodic status of the abandoned task set. We included an additional criterion for classifying trials in this experiment, namely, whether the trial before the present trial itself was a no-switch trial. It should be noted that if this was the case and the present trial is again a no-switch trial, then a run of at least three consecutive same-task trials is implied whereas a switch trial would imply switching away from a task set that had been used at least two times in a row. Inclusion of this factor was post hoc after finding that without such a distinction the sought for retrieval-demand effect on switch costs was only relatively small (but still reliable) and, therefore, allowed only a weak test of the role of specific versus general difficulty effects. The additional factor can be motivated also for independent reasons. First, in Experiment 1 we found that the retrieval-demand effect extends to some degree into the second postswitch trial. Second, Meiran (1996) had reported evidence for so-called micropractice. In the case of randomly cued tasks, task sets become better established with repeated use in consecutive trials. These two results together suggest that at least in the context of randomly cued switching situations, longer same-task runs may constitute a more appropriate baseline condition than first-order task-set repetitions. This may be particularly true when, as in the present case, selection is rather difficult (i.e., among four different tasks), possibly inducing a worst-case strategy in which participants generally prepare for a switch case and, thus, are relatively unprepared for a set repetition.

Using the same exclusion criteria as in Experiment 1, we computed average RTs for the resulting design cells and submitted them to an ANOVA. Tables 1 and 2 present RTs and accuracies from all design cells. An ANOVA of the complete design revealed a highly significant interaction among the status of the prior trial (i.e., switch vs. no-switch), the engaged-task retrieval demand, and the switch/no-switch factor, $F(1, 31) = 11.7$, $MSE = 14{,}376.2$, that was not compromised by higher order interactions. The absolute size of this interaction was 107 ms. As can be seen in Figure 3, the source of this interaction was the relatively long no-switch RTs in episodic tasks after a task switch, which led to a relative reduction of the corresponding switch cost. This pattern suggests that participants treated a first order no-switch trial, at least to some degree, as a switch trial and that this partly eliminates the component responsible for the sought for retrieval-demand effect from the "actual" switch cost.

Given the interaction with the set-repetition factor, we analyzed the data separately for trials after switch and no-switch trials. After switch trials, the retrieval-demand effect on switch costs was 31 ms and not reliable, $F(1, 31) = 1.13$, $MSE = 43{,}056.1$. However, after no-switch trials, the retrieval-demand effect on switch costs was 138 ms and highly reliable, $F(1, 31) = 12.5$, $MSE = 51{,}121.7$. Only in the presence of such an effect does it make sense to compare the retrieval-demand effect with the reading-difficulty effect on switch costs. Therefore, in the following we focus on the trials following task repetitions. The critical mean RTs are shown in Figure 4. As can be seen, word inversion had a large general effect, $F(1, 31) = 118.7$, $MSE = 96{,}705.3$, as did the semantic–episodic manipulation, $F(1, 31) = 74.9$, $MSE = 91{,}757.7$. However, in contrast to the type of retrieval, $F(1, 31) = 12.5$, $MSE = 51{,}121.7$, the word inversion did not interact with switch costs, $F(1, 31) = 0.0$, $MSE = 21{,}806.4$. For the most critical test, namely that between the inverted semantic and the regular episodic condition (see framed values in Figure 4) we found that for the no-switch baseline, inverted semantic RTs were longer than noninverted episodic RTs, $F(1, 31) = 9.98$, $MSE = 61{,}005.6$. Nevertheless, a retrieval-demand effect on switch-costs was obtained here, $F(1, 31) = 9.04$, $MSE = 34{,}893.6$. Also, switch costs were larger for abandoned episodic than for abandoned semantic tasks, $F(1, 31) = 6.95$, $MSE = 95{,}635.6$. Thus, there seemed to be no evidence in these data suggesting that the modulation of switch costs through primary-task retrieval demands that were obtained in

Table 1
Experiment 2: Mean Response Times (and Standard Deviations) as a Function of Switch Status on Preceding Trial, Switch Status of Current Trial, Retrieval Demands, and Reading Difficulty (Regular vs. Inverted Words)

Switch status on preceeding trial and reading difficulty	Current trial	Retrieval demands S → S	E → S	S → E	E → E
Switch on preceding trial					
Regular words	No-switch	959 (133)	1,035 (156)	1,231 (217)	1,268 (263)
	Switch	1,654 (384)	1,668 (322)	1,952 (407)	1,898 (432)
Inverted words	No-switch	1,350 (275)	1,314 (241)	1,524 (305)	1,513 (329)
	Switch	1,913 (443)	1,973 (412)	2,222 (476)	2,161 (551)
No-switch on preceding trial					
Regular words	No-switch	965 (155)	961 (136)	1,161 (188)	1,120 (184)
	Switch	1,588 (360)	1,615 (377)	1,912 (420)	1,908 (448)
Inverted words	No-switch	1,303 (316)	1,255 (424)	1,414 (262)	1,433 (244)
	Switch	1,872 (443)	1,943 (439)	2,236 (440)	2,172 (520)

Note. S = semantic tasks; E = episodic tasks; arrow implies that the last switch was from the first to the second.

Experiment 1 could be explained in terms of general difficulty effects.[1]

A potential problem in the present design was that the manipulation of reading difficulty was more powerful than the semantic–episodic manipulation for RTs but not in terms of errors. For the no-switch baseline condition, accuracy was lower in the episodic than in the semantic condition, $F(1, 31) = 13.1$, $MSE = 1{,}500.1$, whereas there was no such difference associated with the inversion main effect, $F(1, 31) = 0.3$, $MSE = 1{,}981.2$. However, for the critical comparison between semantic inverted and episodic regular words the accuracy difference was small ($M = .975$ vs. $M = .987$), $F(1, 31) = 3.80$, $MSE = 1{,}321.8$. Moreover, we computed a score for each individual participant that reflected the signed accuracy difference between semantic inverted and episodic regular no-switch trials and classified participants by means of a median split into those with large difference scores and small difference scores. When including this factor in the ANOVA of RTs from the semantic inverted and the episodic regular condition, we obtained no evidence for a modulation of the retrieval-demand effect through the accuracy-difference factor, $F(1, 31) = 0.08$, $MSE = 26{,}731.8$. Thus, we can be reasonably confident that the retrieval-demand effect cannot be attributed to a difference in accuracy between the semantic and the episodic condition.

Discussion

Before turning to the main result of this experiment, we first need to discuss the fact that the retrieval-demand effect on switch costs was obtained here but only when we looked at trials that followed no-switch trials. This finding was not predicted a priori. However, it does make sense if we assume that people may differ in the degree to which they prepare for no-switch versus switch trials depending on the to-be-expected "processing costs." Specifically, when more than only two tasks are involved, selecting a new task in case of a switch trial is relatively demanding. These selection costs should be minimized when bringing oneself into a position where the mean "retrieval distance" to all possible tasks is reduced. This could occur by suppressing the last-used task set (at least at a subset of trials) to better prepare for transitions to new task sets. If a task-set repetition does occur, then the usual benefits from repetitions should be somewhat reduced because at least to some degree the just-suppressed task set needs to be reestablished. This "reestablishing component" may be the same process that is responsible for the retrieval-demand effect. Obviously, if this process is already contained in the baseline condition, then it cannot be detected within the switch costs.

The main finding in this experiment was that the retrieval-demand effect on switch costs is apparently not due to the greater overall difficulty of the engaged episodic task. An engaged semantic task equated with the engaged episodic task in terms of baseline RTs still produced a smaller task-switch effect. Together with

[1] As indicated in the *Method* section, 50% of the mixed transitions (i.e., semantic–episodic or episodic–semantic) occurred between diagonally placed cue locations, whereas "homogeneous" transitions (semantic–semantic or episodic–episodic) were always between adjacent cue locations. To examine the possible role of this confound, we compared diagonal- and adjacent-mixed transitions. Diagonal transitions took 41 ms longer than adjacent transitions, $t(31) = 2.97$, however, this effect was the same whether the switched-to set was semantic (45 ms) or episodic (36 ms), $F(1, 31) = 0.11$. Thus, this factor did not influence any of the critical findings. However, this factor is responsible for an unexpected three-way interaction between the switch factor and the semantic–episodic contrast for the abandoned and the engaged task, $F(1, 31) = 7.43$, $MSE = 38{,}476.7$, suggesting that switch costs for incongruent transitions (semantic to episodic or episodic to semantic; $M = 703$ ms, $SD = 274$ ms) were slower than those for congruent transitions (semantic to semantic or episodic to episodic; $M = 655$ ms, $SD = 288$ ms). When excluding all diagonal transitions, which constitute about 50% of the incongruent transitions, this effect disappeared (incongruent switch costs, $M = 682$ ms, $SD = 259$ ms; congruent switch costs, $M = 655$ ms, $SD = 287$ ms), $F(1, 31) = 2.58$, $MSE = 36{,}259.1$, whereas all theoretically critical effects remained stable.

Table 2
Experiment 2: Mean Error Percentages (and Standard Deviations) as a Function of Switch Status on Preceding Trial, Switch Status of Current Trial, Retrieval Demands, and Reading Difficulty (Regular vs. Inverted Words)

Switch status on preceding trial and reading difficulty	Current trial	Retrieval demands			
		S → S	E → S	S → E	E → E
Switch on preceding trial					
Regular words	No-switch	2.13 (4.16)	1.28 (2.36)	3.41 (3.83)	3.09 (4.15)
	Switch	2.84 (5.22)	2.31 (3.55)	4.28 (4.62)	4.13 (6.60)
Inverted words	No-switch	3.00 (5.01)	2.00 (3.66)	3.19 (5.36)	2.00 (3.58)
	Switch	4.06 (5.65)	3.31 (4.98)	4.87 (4.70)	3.72 (5.40)
No-switch on preceding trial					
Regular words	No-switch	0.75 (2.76)	1.62 (3.39)	2.31 (4.34)	2.59 (5.10)
	Switch	2.53 (4.81)	2.63 (4.38)	4.09 (4.51)	5.28 (6.62)
Inverted words	No-switch	0.72 (2.30)	1.69 (2.25)	2.69 (4.05)	3.69 (8.01)
	Switch	1.62 (6.28)	2.84 (3.84)	5.06 (4.60)	3.66 (4.16)

Note. S = semantic tasks; E = episodic tasks; arrow implies that the last switch was from the first to the second.

similar results about the absence of difficulty effects on switch costs reported by D. A. Allport et al. (1994) and Rubinstein et al. (in press), our finding supports the interpretation that the difficulty effect on switch costs is specific to LTM retrieval demands. At the same time, it appears to be a close-to-impossible task to rule out the possibility of other difficulty manipulations that could also modulate switch costs. Further substantiation of the claim that the retrieval-demand effect points to LTM retrieval as a critical, proactive component in task switching needs to be attained through

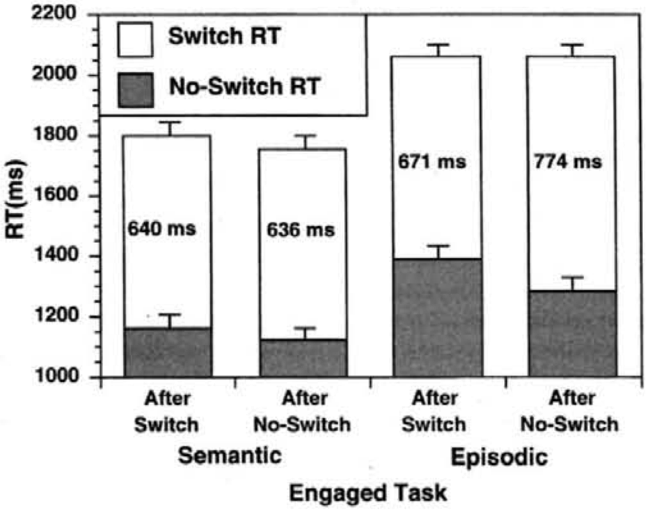

Figure 3. Mean response times (RTs) as a function of the retrieval demands of the engaged task, status of the preceding trial (no-switch vs. switch), and the switch contrast for Experiment 2. Error bars represent 95% within-participant confidence intervals for the interaction between engaged-task retrieval demand, switch contrast for the current trial, and switch contrast for the preceding trial (Loftus & Masson, 1994).

more specific tests of the retrieval hypothesis. We tried to achieve this in the final experiment.

Experiment 3

If, as we claim, the retrieval-demand effect on switch costs is associated with the proactive or endogenous task-switch component, then it should be affected by the amount of time participants are allowed to prepare for the upcoming task. In contrast, the retrieval-demand effect should not be affected by manipulations of "passive-decay" time between successive trials that cannot be used for preparation. Following Meiran (1996), within a task-cuing paradigm we contrast here three different switching situations to isolate "passive" and "proactive" modulations of switch costs. The critical experimental contrasts were established through the manipulation of two intervals: the time between the preceding response and the next task cue (i.e., the RCI) and the time between the cue and the next stimulus (i.e., the CSI). It should be noted that RCI and CSI together constitute the passive-decay time whereas the CSI is the time that can be used for preparation. Thus, when comparing a situation in which RCI and CSI are both short (100–100) with one in which the RCI is long but the CSI remains short (900–100) only passive-decay time is manipulated. Accordingly, we may obtain a general reduction of switch costs in the 900–100 condition that is due to decay (although this is not always found, see Meiran, 1996) but the size of the retrieval-demand effect should not change. In contrast, a comparison of the 900–100 condition with the 100–900 condition allows one to examine the effect of preparation time while leaving decay time constant. Thus, for the 100–900 condition, we expected that both switch costs and the retrieval-demand effect are reduced or eliminated.

As another test of the retrieval hypothesis, we also manipulated the type of task cues given. What needs to be retrieved during task-set preparation are the rules that ensure adequate stimulus analysis and that translate the result into the required action. If this

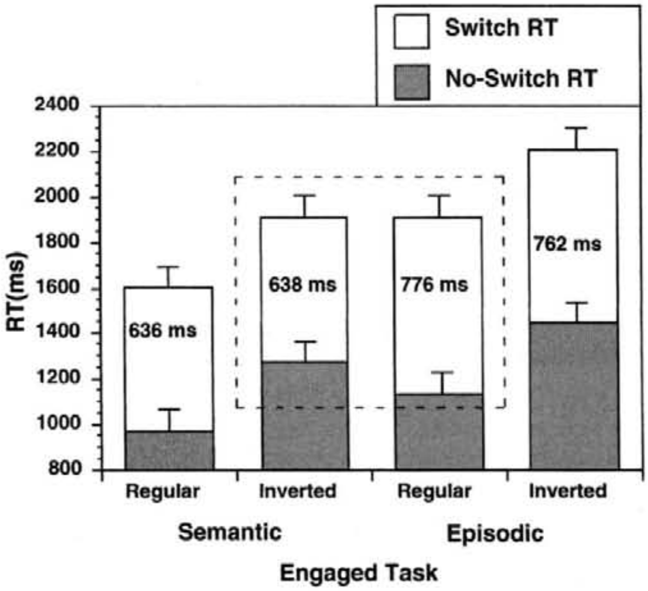

Figure 4. Mean response times (RTs) as a function of the retrieval demands of the engaged task, reading difficulty (regular vs. inverted words), and the switch contrast for Experiment 2. Error bars represent 95% within-participant confidence intervals for the interaction between the engaged-task retrieval demand and the switch contrast (Loftus & Masson, 1994).

information is provided directly by the task cue, then LTM retrieval should not be necessary. As a result, switch costs, preparatory effects on switch costs and, again, the retrieval-demand effect should be reduced. To test this, we established a condition in which one group of participants received two spatial locations that served as cues for the two dimensions relevant for a particular block. Thus, this condition established a situation that is similar to the alternate-runs technique used in Experiment 1 where arbitrary spatial signals were used as task cues. A second group received task cues consisting of an explicit presentation of the response assignment. Here, the two values of the required dimension were presented in a way that was spatially compatible with the response assignment (e.g., small–large when the left key had to be pressed for small and the right key for large objects). We predict that in this group, the effect of LTM retrieval on switch costs should be markedly reduced, thus leading to overall smaller switch costs, smaller preparatory effects, and most important, a smaller retrieval-demand effect on switch costs.

Method

Participants. Forty-eight students at the University of Potsdam served as participants in exchange for course credits or a payment of DM 20 (about U.S. $15).

Task and stimuli. The same 16 word stimuli, task dimensions, and response assignments were used as in Experiment 1. Words were presented in white, 24-point type and centered on a black screen. The words were presented in a 4-cm wide × 1.5-cm high (1.6-in. wide × 0.6-in. high) open box which remained on the screen throughout a block as a fixation aid. For a given block of trials, two dimensions were relevant.

Prior to the appearance of a word, a task cue was presented which specified the dimension relevant for that word. In the spatial-cue condition, a small white circle appeared immediately below and above a small box in which the word would be shown. The circle was visible until a response was made. Prior to each block, each of the two dimensions was assigned to one of the circle locations by presenting the dimension label next to the corresponding location. Participants could inspect this instruction as long as they wished. In the stimulus-response (S-R) cue condition, the response assignment relevant for a particular task was presented above the position of the word stimulus. The dimension value assigned to the left-key response was presented on the left-hand side, and the dimension value assigned to the right-key response was presented on the right-hand side (i.e., small–large, nonliving–living, bottom–top, or yellow–blue).

The number of trials per block was 124 plus 8 initial practice trials. For any given block, the two relevant task cues were presented in a random sequence. Words, and thus required responses, were drawn randomly for each item with the exception that immediate repetitions of words were not allowed.

Procedure and design. The preexperimental learning-to-criterion phase for the episodic associations was identical to the one used in Experiment 1. Prior to actual testing, participants were exposed to one 128-item practice block in which the four possible task cues and three possible temporal combinations (described below) were presented in a random sequence. Participants were randomly assigned to one of the three cuing conditions.

Actual testing occurred in three sets of four blocks each. The three sets of blocks were distinguished by different timing combinations concerning the RCI and the CSI. In the first type of blocks (100–100), both RCI and CSI time were 100 ms. In the second type of blocks (900–100), RCI was 900 ms and CSI was 100 ms. In the third type of blocks (100–900), RCI was 100 ms and CSI was 900 ms. The order of these three types of blocks was counterbalanced across participants.

Within each timing condition, four blocks with different task-set combinations were used the same way as in Experiment 1. The order of blocks was again counterbalanced across participants, but for a particular participant block order was consistent across sets of blocks with the same timing conditions.

Results

The same basic design was used as in Experiment 1 with the addition of cue type as a between-participant factor and two nonorthogonal contrasts for the three level RCI-CSI manipulation. The first compared the 100–100 condition with the 900–100 condition (i.e., the decay contrast) and the second compared the 900–100 condition with the 100–900 condition (i.e., the preparation contrast).

The same trial exclusion criteria were used as in Experiments 1 and 2. Tables 3 and 4 contain RTs and error percentages for all design cells. To facilitate communication of the main results, we focus on switch costs only (after having checked that the pattern of no-switch results did not compromise the pattern of switch costs).[2] Theoretically most relevant are the switch costs and the retrieval-demand effect as a function of the preparation-time manipulation

[2] Analysis of no-switch baseline RTs revealed (a) overall longer RTs when the relevant task was episodic (M = 1,098 ms, SD = 217 ms) than semantic (M = 910 ms, SD = 162 ms) in nature, $F(1, 47) = 116.3$, MSE = 1,088,203.6; (b) somewhat longer RTs when the preceding task was episodic (M = 1,063 ms, SD = 211 ms) than semantic (M = 1,017 ms, SD = 210 ms) in nature, $F(1, 47) = 16.1$, MSE = 127,658.6; and (c) an additional 44-ms increase in RT when both relevant and irrelevant tasks were episodic, $F(1, 47) = 5.2$, MSE = 185,385.3. Also, there was a general decrease in RTs when the preparatory interval was long (M = 959 ms, SD = 207 ms) compared with when it was short (M = 1,110 ms, SD = 291 ms), $F(1, 47) = 47.2$, MSE = 369,357.9.

Table 3
Experiment 3: Mean Response Times (and Standard Deviations) as a Function of Cuing Condition, RCI-CSI Constellation, Retrieval Demands, and the Switch Contrast

		Retrieval demands			
RCI-CSI	Switch contrast	S → S	E → S	S → E	E → E
Spatial cue					
100–100	No-switch	985 (236)	983 (220)	1,190 (205)	1,267 (325)
	Switch	1,351 (289)	1,396 (260)	1,634 (347)	1,851 (492)
900–100	No-switch	1,027 (199)	1,034 (197)	1,234 (224)	1,288 (315)
	Switch	1,277 (261)	1,309 (235)	1,572 (286)	1,769 (439)
100–900	No-switch	865 (156)	831 (132)	1,078 (239)	1,145 (305)
	Switch	1,001 (207)	1,093 (222)	1,270 (272)	1,384 (377)
S-R cue					
100–100	No-switch	895 (171)	911 (217)	1,130 (217)	1,154 (198)
	Switch	1,171 (323)	1,184 (316)	1,447 (318)	1,408 (275)
900–100	No-switch	881 (213)	941 (248)	1,215 (551)	1,263 (442)
	Switch	1,014 (279)	1,113 (304)	1,389 (595)	1,382 (463)
100–900	No-switch	778 (157)	795 (966)	1,056 (303)	1,133 (377)
	Switch	900 (217)	966 (227)	1,219 (402)	1,280 (485)

Note. RCI = response cue interval; CSI = cue stimulus interval; S = semantic tasks; E = episodic tasks; S-R = stimulus-response; arrow implies that the last switch was from the first to the second.

and the cue condition. These results are shown in the upper panel of Figure 5. The type-of-cue factor produced not only a main effect, $F(1, 47) = 20.8$, $MSE = 1{,}600{,}773.9$, but also interactions with (a) retrieval demands of the current set, $F(1, 47) = 6.9$, $MSE = 466{,}566$; (b) retrieval demands of the disengaged set, $F(1, 47) = 13.0$, $MSE = 278{,}054.2$; (c) the preparation contrast, $F(1, 47) = 18.2$, $MSE = 197{,}258.3$; (d) the combination of the current and the disengaged-set retrieval demand, $F(1, 47) = 5.7$, $MSE = 234{,}831.9$; (e) the combination of the preparation contrast and the current retrieval demand, $F(1, 47) = 10.4$, $MSE = 96{,}320.0$; and, finally, (f) the combination of all foregoing factors, $F(1, 47) = 5.25$, $MSE = 137{,}265.6$. Given that these effects and inspection of Figure 5 suggested qualitative differences as a function of cue type, we conducted separate analyses for each of the two cue conditions and we report the results first for the engaged-task retrieval demand factor, then for the disengaged-task retrieval demand factor, and, finally, for the interaction between the two.

As Figure 5 shows, for the spatial-cue condition, switch costs became smaller, both as a function of decay, $F(1, 47) = 17.2$, $MSE = 255{,}832.7$, and as a function of preparation, $F(1, 47) = 37.7$, $MSE = 186{,}494.4$. Also, despite a marked preparation effect, there was a substantial average residual switch cost of 207 ms. Thus, we replicated the general pattern of findings reported by Rogers and Monsell (1995) and Meiran (1996, in press) of a decay component, a preparatory component, and a residual switch component. Moreover, in the spatial-cue condition, there was a marked

Table 4
Experiment 3: Mean Error Percentages (and Standard Deviations) as a Function of RCI-CSI Condition, Temporal Constellation, Retrieval Demands, and the Switch Contrast

		Retrieval demands			
RCI-CSI	Switch contrast	S → S	E → S	S → E	E → E
Spatial cue					
100–100	No-switch	1.56 (2.01)	1.14 (1.48)	5.70 (5.46)	5.62 (6.53)
	Switch	3.12 (3.61)	2.66 (2.98)	7.18 (6.43)	6.99 (5.35)
900–100	No-switch	2.51 (2.47)	1.46 (2.17)	6.05 (4.65)	6.47 (6.34)
	Switch	2.88 (2.88)	2.78 (2.84)	7.36 (5.26)	7.12 (6.26)
100–900	No-switch	1.83 (2.52)	1.35 (1.15)	7.05 (5.80)	6.58 (6.24)
	Switch	2.83 (3.07)	3.25 (2.40)	7.48 (6.74)	8.96 (8.95)
S-R cue					
100–100	No-switch	2.13 (2.28)	1.75 (2.61)	4.38 (4.05)	5.08 (4.02)
	Switch	2.35 (2.49)	2.32 (4.38)	6.42 (6.46)	5.09 (7.40)
900–100	No-switch	3.02 (3.45)	1.13 (2.00)	5.06 (4.22)	3.98 (3.43)
	Switch	1.95 (2.12)	1.84 (2.43)	4.76 (3.56)	3.68 (3.03)
100–900	No-switch	1.55 (1.81)	1.37 (2.32)	4.64 (4.52)	4.16 (3.68)
	Switch	1.48 (2.23)	1.60 (2.39)	5.77 (5.61)	3.35 (2.61)

Note. RCI = response cue interval; CSI = cue stimulus interval; S = semantic tasks; E = episodic tasks; S-R = stimulus-response; arrow implies that the last switch was from the first to the second.

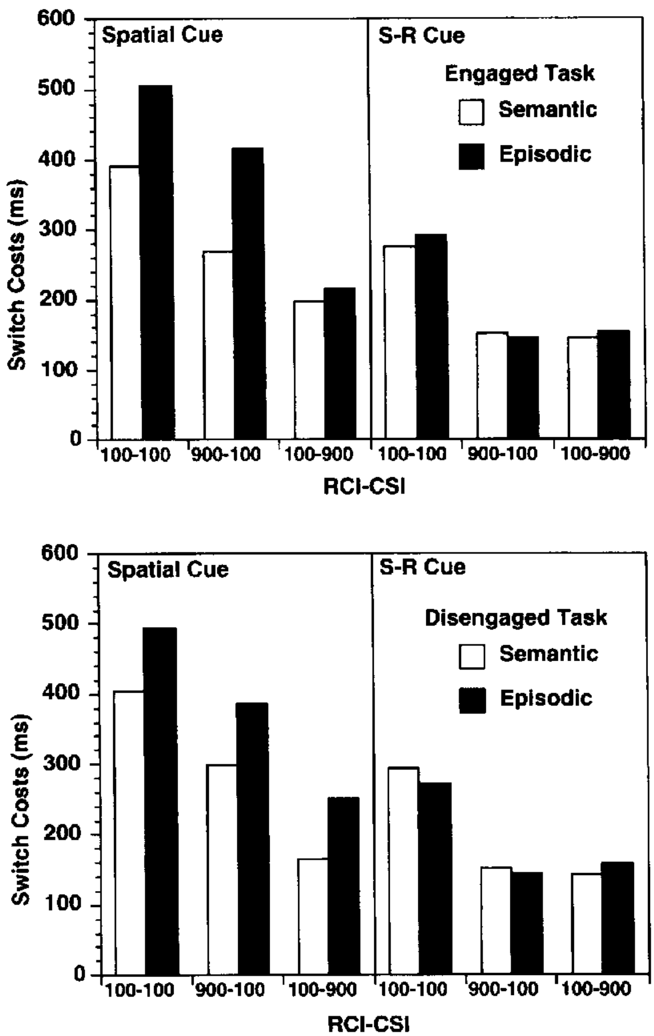

Figure 5. Upper panel: Mean switch costs as a function of the retrieval demands of the engaged task, RCI-CSI constellation, and cue type for Experiment 3. Lower panel: Mean switch costs of the retrieval demands of the abandoned task, RCI-CSI constellation, and cue type for Experiment 3. S-R = stimulus-response; RCI-CSI = response cue interval–cue stimulus interval.

retrieval-demand effect for the 100–100 and the 900–100 condition which, however, disappeared for the 100–900 condition. Accordingly, there was a significant retrieval-demand main effect, $F(1, 23) = 10.0$, $MSE = 742{,}752.7$; an interaction with the preparation contrast, $F(1, 23) = 16.3$, $MSE = 98{,}438.8$; but no interaction with the decay contrast, $F(1, 23) = 1.13$, $MSE = 8{,}553.0$. Thus, this pattern of results is exactly as predicted: A retrieval-demand effect is present if the preparation time does not suffice to retrieve the next task set before stimulus onset but is eliminated when preparation time does suffice for task-set retrieval. Further, the retrieval-demand effect is not affected by the decay interval.

The pattern of results for the S-R cue condition was very different. Aside from the fact that switch costs were generally smaller here, there also was no evidence for a preparation effect, $F(1, 23) = 0.0$, $MSE = 208{,}022.0$, and there was no evidence for a retrieval-demand effect, $F(1, 23) = 0.2$, $MSE = 190{,}380.4$. Only the decay effect was comparable to that of the spatial-cue condition, $F(1, 23) = 16.8$, $MSE = 412{,}498.5$. This pattern strongly suggests that presentation of the S-R cue leads to immediate availability of the relevant task rules, thus, making self-initiated retrieval of task rules unnecessary. As a consequence, and consistent with our assumptions, this eliminated the retrieval-demand effect.

Next, we turn to the effect of the abandoned-task retrieval demand shown in the lower panel of Figure 5. For the spatial-cue condition, this effect was highly significant, $F(1, 23) = 15.6$, $MSE = 424{,}253.4$, and it was neither modulated by the decay contrast, $F(1, 23) = 0.0$, $MSE = 155{,}808.2$, nor by the preparation contrast, $F(1, 23) = 0.0$, $MSE = 142{,}585.2$. The fact that the semantic–episodic disengagement effect was not modulated by preparation time is consistent with the idea that it is supposed to reflect a passive component, possibly having to do with "task-set inertia" from the preceding task set (D. A. Allport et al., 1994). What is more surprising is the fact that in the S-R cue condition there was no semantic–episodic disengagement effect for any of the three combinations between decay and preparation intervals, $F(1, 23) = 0.1$, $MSE = 131{,}855.0$. Thus, the cue-type factor which was supposed to affect the approach to the upcoming task set seemed to have an additional, marked effect on the disengagement from the preceding task set.

Finally, another unexpected finding was the interaction between the engaged-task and the disengaged-task retrieval demand, preparation time, and cue type, $F(1, 47) = 4.2$, $MSE = 137{,}256.6$. Inspection of the data revealed that this effect can be attributed to a crossover interaction pattern between the semantic–episodic disengagement and engagement factor that appeared in certain conditions and that had the form of a task-congruency effect. (This effect should not be confused with a superficially similar effect that appeared in Experiment 2 and is reported in Footnote 1.) Specifically, in these conditions, RTs for "congruent" transitions (i.e., semantic to semantic or episodic to episodic) were faster than for "incongruent" transitions (i.e., semantic to episodic or episodic to semantic). Interestingly, there was at least a tendency towards such an interaction in all conditions in which intentional retrieval could not manifest itself in RTs, that is, for the long preparation time with spatial cues (congruency effect = 39 ms), $F(1, 23) = 2.8$, $MSE = 13{,}100.1$, as well as in all three S-R cue conditions (congruency effect = 23 ms, 46 ms, 32 ms for the 100–100, the 900–100, and the 100–900 condition, respectively), $F(1, 23) = 12.6$, $MSE = 77{,}186.8$. In contrast, in those two conditions in which intentional retrieval was manifest in the RTs, that is for the 100–100 and the 900–100 spatial-cue condition there was no such congruency effect (−48 ms and −57 ms, respectively), rather, the retrieval-demand effect was (nonsignificantly) larger when the abandoned task set was episodic in nature than when it was semantic in nature, $F(1, 23) = 2.9$, $MSE = 45{,}528.8$. It, thus, appears that once the relatively large retrieval-demand effect is removed through adequate experimental manipulations (i.e., long preparation time or potent task cue), a further, much smaller effect is uncovered that seems related to the similarity or congruency of the different tasks used.

An analysis of errors revealed no effects that qualified the RT findings. Participants committed reliably more errors in episodic tasks ($M = 5.8$, $SD = 4.5$) than in semantic tasks ($M = 2.1$, $SD = 1.5$), $F(1, 47) = 54.1$, $MSE = 176{,}474.4$, when the currently irrelevant task was episodic ($M = 4.1$, $SD = 2.8$) than when it was semantic ($M = 3.7$, $SD = 3.0$), $F(1, 47) = 6.7$, $MSE = 15{,}368.0$, and in switch trials ($M = 4.3$, $SD = 3.3$) than in no-switch trials ($M = 3.6$, $SD = 3.3$), $F(1, 47) = 15.5$, $MSE = 24{,}422.1$.[3]

Discussion

On the basis of the task-set retrieval idea, we had predicted that the retrieval-demand effect should be reduced for long preparatory intervals but not for long decay intervals and that it should be reduced or eliminated when task cues provide explicit information about task rules. These predictions were confirmed in a very clear way in Experiment 3. In particular, the fact that the retrieval-demand effect on switch costs was eliminated for the long preparatory interval provides strong support for the claim that the active reconfiguration component is associated with LTM retrieval. We propose that during the long preparation interval, retrieval of task rules can occur well before the "within-task" retrieval (of episodic information) so that no mutual interference arises.

Consideration of the cue effect points to an even stronger claim. We had found that provision of potent task cues that directly specify S-R rules eliminates both the entire preparation effect and the retrieval-demand effect on switch costs. In other words, everything participants can do intentionally on the basis of an arbitrary task cue is provided externally through S-R cues within a 100-ms cue-stimulus interval. Assuming that information provided by external cues is equivalent to internally retrieved task-specific information, we can infer that retrieval of the task set is identical with active configuration and, at least within the current paradigm, it is all that participants can do to prepare the upcoming task.

A question that could be raised at this point is whether presentation of S-R cues is necessary to markedly reduce the preparation component and the retrieval-demand effect. It is possible that what participants really need to do actively is to access the next "task node." Activation of the associated S-R rules could then be a fast, automatic process. To explore this possibility, we tested a new group of 24 participants using the same procedure that was used in Experiment 2, except the task cue simply contained the task label (e.g., color). The task label should facilitate activating the relevant task node, but does not provide information about the relevant rules. The results showed (a) that there was a decay effect of about the same size as in the spatial-cue and the S-R cue condition, (b) that as in the spatial-cue condition but unlike in the S-R cue condition there was a clear preparation effect, and (c) that there was a clear retrieval-demand effect that, however, was numerically smaller than in the spatial-cue condition. Thus, even though the task-label cue may have had some effect on the retrieval component, it generally was much more similar to the spatial-cue condition than to the S-R cue condition. These findings suggest that the critical information that needs to be retrieved during the preparatory interval is the relevant set of action rules.

On the basis of D. A. Allport et al.'s (1994) findings, one could suspect that the retrieval-demand effect associated with the abandoned task reflects task-set inertia and, thus, a process that should not be affected by activities directed at the upcoming task set. The finding that the retrieval load of the to-be-abandoned task set was independent of the preparation time is consistent with this assumption. However, there was one finding that does not immediately fit with the task-set inertia conception, namely that the semantic–episodic disengagement effect was strongly influenced by the type of cue. Specifically, the retrieval-demand effect of the abandoned set was only present for arbitrary, spatial cues but it was absent for S-R cues. If, as assumed, the type-of-cue manipulation affects only proactive processes directed at the next task set, this finding seems incompatible with the task-set inertia idea. However, if one assumes that task-set inertia is produced by interference from S-R associations from the preceding task, then cues that directly specify the relevant S-R associations for the upcoming task may replace the interfering S-R associations, thereby eliminating at least part of the inertia effect.

A final interesting aspect of the results of Experiment 3 was that in those conditions in which the retrieval-demand effect was eliminated, either by a long preparatory interval or by S-R cues, an additional switch-cost effect appeared: a small but across conditions consistent interaction between the semantic–episodic nature of the to-be-abandoned task set and the to-be-established task set. Given that RTs were fast for transitions from semantic-to-semantic or from episodic-to-episodic tasks but longer for transitions between different types of tasks, the most plausible interpretation is a "task-congruency" effect. What could be the reason for this effect? Given that it became apparent only when active, and as we would claim, retrieval-related processes did not affect switch costs, it cannot be associated with intentional control. Instead, it may reflect priming of specific processing pathways that semantic tasks have in common on the one hand and that episodic tasks have in common on the other but that are not shared between these two types of tasks. This task-congruency effect is probably present in all conditions but it is "covered" by the much stronger retrieval-related effects in those conditions in which active processes are directly reflected in switch costs. Future examinations of such task-congruency effects may provide important insights about those aspects of task-set reconfiguration that occur outside the range of intentional control. However, it is also important to note that the task-congruency effect was small and, therefore, did not compromise the critical retrieval-demand effect on switch costs.

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[3] Rogers and Monsell (1995, see also Meiran, 1996) reported an interesting interaction between the switch factor and the response-repetition factor, suggesting that positive response priming in the case of no-switch transitions disappears or even turns into a negative effect in the case of switch transitions (Rogers & Monsell, 1995). In Experiment 1, we obtained a nonsignificant tendency toward such a pattern with RT priming effects of 12 ms and −59 ms for no-switch and switch trials, respectively, and of corresponding error priming effects of −1.4% and −2.3%, with both $Fs < 2.6$, $p > .1$. For Experiment 2, the characteristic interaction pattern was again only obtained as a tendency for RTs (no-switch response priming = 0 ms, switch response priming = −32 ms), $F(1, 31) = 1.84$, $p > .1$, but as the opposite tendency for errors (no-switch response priming = −.65%, switch response priming = .15%), $F(1, 31) = 3.35$, $p > .05$. The same was true for Experiment 3 except that here the two opposing effects for RTs (no-switch response priming = 8 ms, switch response priming = −44 ms) and errors (no-switch response priming = −0.35%, switch response priming = 1.6%) were highly significant, $F(1, 47) = 34.4$, $p < .01$. Possibly, the large cognitive and memory demands in the tasks we used may have worked against obtaining clear evidence for a switch-by-response repetition interaction.

General Discussion

In this study, we tested the hypothesis that an important component in switching back and forth between two or more different task sets is the retrieval of the relevant action rules from LTM. Accordingly, we showed across three experiments that switch costs were larger when the switched-to task itself entailed high LTM-retrieval demands (i.e., episodic retrieval) than when retrieval demands were low (i.e., semantic retrieval). Such a result can be expected when LTM retrieval during task switching and LTM-retrieval during primary-task processing interfere with each other. Further, in Experiment 2 no difficulty effects on switch costs were obtained for another powerful difficulty manipulation that, however, was not related to controlled retrieval (i.e., the inversion of stimulus words). Along with other reports suggesting that switch costs are relatively insensitive to general difficulty manipulations (D. A. Allport et al., 1994; Rogers & Monsell, 1995; Rubinstein et al., in press) this result indicates that the retrieval-demand effect is specific for controlled LTM retrieval. Even more important was the finding from Experiment 3 that the retrieval-demand effect was selectively eliminated when people were allowed sufficient time for preparation. Thus, LTM retrieval can be associated with the proactive or endogenous component of task switching identified by Rogers and Monsell (1995) and Meiran (1996). Finally, this conclusion was further strengthened by the observation that both the preparatory effect on switch costs and the retrieval-demand effect were eliminated when relevant task rules (i.e., the critical S-R associations) were provided by the task cues directly. Although in need of replication in the context of other tasks, this result suggests that episodic retrieval may not only be necessary but may also be sufficient to explain the endogenous component of task switching.

The proposal that LTM retrieval is critical during task switching is neither new (Goschke, in press; Rubinstein et al., in press) or very surprising given the obvious role of LTM as a source of critical information for the guidance of action (e.g., Glenberg, 1997). As such, it serves as a baseline model that needs to be explored and falsified before considering more sophisticated alternatives. However, the task-set retrieval idea is less trivial when considering that in task-switching situations people typically switch rapidly between only two simple tasks. Thus, during each switch, information that was last used just a few seconds earlier needs to be reused again. At first sight, this seems like a situation in which critical information (i.e., the irrelevant task set) should be maintained in working memory while the currently relevant task is being executed. However, what we suggest along with others (e.g., A. Allport & Wylie, 1999; Rubinstein et al., in press) is that there may be a fundamental constraint with respect to the possibility of representing within working memory more than one task set applicable to the same stimulus. In this respect, we believe that the constraint on task sets is very similar to the impossibility of representing more than one interpretation of ambiguous stimuli at the same time (e.g., Chambers & Reisberg, 1985). Thus, what we suggest is that loading a task set into working memory is identical with selecting it for control of action. This, in turn, implies that any competing task set needs to leave working memory and then has to be re-retrieved from LTM once it becomes relevant again.

Semantic Versus Episodic Retrieval

The main manipulation we had used was one between semantic and episodic retrieval tasks. This manipulation could be viewed from two different theoretical perspectives. First, it could simply represent two levels on an unspecific retrieval-demand dimension. Second, there may be a qualitative distinction between semantic retrieval on the one hand and episodic retrieval on the other (Tulving, 1984). The classic semantic–episodic distinction in terms of two different memory stores may be problematic for theoretical and empirical reasons (e.g., Hintzman, 1984). However, there is evidence that processes involved in the retrieval of episodic versus semantic information have, to some degree, a distinct neurocognitive basis (Tulving, Kapur, Craik, Moscovitch, & Houle, 1994). Specifically, whereas retrieval of generic information about an object is context independent, retrieval of episodic information requires establishment of an explicit retrieval context (e.g., the list context in verbal learning experiments). Importantly, the latter is also the case for the retrieval of task rules (i.e., task instructions). Thus, an interesting hypothesis for future research is that a context-activation component is the common denominator between task switching and episodic retrieval.

The LTM-Retrieval Account and Important Task-Switch Phenomena

In the introduction section we described a set of key findings from the task-switching literature. In the following section we examine how the LTM-retrieval account of task-set switching deals with each of these phenomena.

Dissociation of between-task and within-task selection processes. Selection in typical choice-reaction time tasks shows many characteristics of automatic processing (i.e., a "prepared reflex"; Logan, 1978). Selection within a simple task set, thus, probably requires little to none of the kind of controlled LTM retrieval we have proposed to be a key feature of preparatory selection between task sets. In terms of cognitive control, the dissociation between task-selection processes and single-task processing may, thus, be along similar lines as that between controlled and automatic influences on retrieval from LTM (e.g., Jacoby, 1991). Thus, a testable prediction is that the dissociation between within-task selection and between-task selection that has been found in psychometric analyses (Kray & Lindenberger, 2000; Salthouse et al., 1998) can be attributed to the fact that LTM retrieval is involved in the latter but not in the former. More concretely, we predict common interindividual variability in switch costs and (episodic) memory performance that is independent of variability in no-switch RTs.

The role of competition. So far, when we referred to LTM retrieval, we implied an endogenous, controlled process. To cover the range of task-switching phenomena, automatic retrieval needs to be considered as well (e.g., Jacoby, 1991). Specifically, stimuli to which more than one task can be applied seem to have the potential of serving as exogenous retrieval cues both on the task-selection level and on the response-selection level. This is nicely illustrated with results reported by Rogers and Monsell (1995). They obtained much reduced switch costs when the stimulus aspect associated with the competing task was eliminated (i.e., resulting in nonambiguous stimuli) indicating that stimulus aspects can activate associated task sets. Further, when stimulus aspects relevant to both tasks were present (i.e., ambiguous stimuli), a response-congruency effect was obtained: RTs were faster when both stimulus aspects required the same responses than when they required different responses. This could be taken as an indication of both task sets being simultaneously active in working memory. However, in line with the framework presented here we propose that response interference arises from exogenously cued retrieval of the irrelevant LTM response code at the time of stimulus presentation.

Preparatory effects on switch costs. The preparatory switch-cost effect is the primary phenomenon to be accounted for by the idea of task-set retrieval from LTM. We can go a step further and ask to what degree LTM retrieval is sufficient to explain preparatory effects. In other words: Can participants do anything else to prepare for an upcoming task aside from loading the relevant task rules into working memory? An important result in this context is the finding from Experiment 3 that whatever participants can do to prepare for an upcoming task set within 900 ms is accomplished almost immediately by the provision of task cues that contain information about relevant S-R mappings. One interpretation of this result is that activation of relevant S-R rules is all there is to task-set preparation and if the relevant information is provided externally, it does not have to be generated from memory.

Recently, other researchers have suggested additional or alternative preparatory processes, such as changing an attentional bias (Meiran, in press) or "goal-switching" (Rubinstein et al., in press). What we argue here is that LTM retrieval is one critical component of preparation and the possibility that it actually is a sufficient explanation may serve as a baseline hypothesis against which to test hypotheses about additional processes.

Residual switch costs. An important finding in past research and also the present work has been that switch costs often seem to persist across long preparatory intervals (D. A. Allport et al., 1994; Meiran, 1996; Rogers & Monsell, 1995). From the perspective of LTM retrieval, task-switching situations are high-interference situations so that full establishment of a task set after a switch is an error-prone process. At the same time, it is important to note that an unsuccessful retrieval attempt will lead only in a minority of cases to an actual erroneous response (unlike the case in typical memory experiments). As soon as the stimulus appears, it will serve as a potent exogenous retrieval cue for all responses that are possible to that stimulus. Thus, participants only have to select the appropriate response, given the currently relevant dimension to attend to, without the need of endogenous retrieval of S-R associations. This will cost time, compared with a situation in which the appropriate S-R rules were ready before stimulus appearance, but it will still lead to a correct response in most cases. Thus, residual switch costs could be explained in terms of retrieval failures in a high-interference situation. Interestingly, recent findings by De Jong (in press) suggest that residual switch costs may actually represent a mixture of fully prepared and fully unprepared trials. Such an all-or-none pattern of preparedness for an upcoming task easily follows from the retrieval-failure account, possibly in combination with motivational constraints on preparation, as suggested by De Jong.

Task-Sets as LTM-Retrieval Structures

The account we propose here is not compatible with the view that working memory itself is an entity that can represent multiple, *competing* task sets or at least competing elements of different task sets. How about the currently common view that working memory entails both a limited focus plus an "outer region" of the set of LTM elements that are currently active (e.g., Cowan, 1988)? Here the issue is somewhat more complex. We would certainly propose that no more than one competing set can be part of the focus. However, could more than one competing task set be part of the active set of LTM elements? To answer this question one would need to know more about whether there are interactions either among active LTM elements or between active LTM elements and the current focus of attention. For example, there could be lateral inhibition between elements in the focus and competing elements in the outer region that suppress activation of the potentially interfering elements to (or even below) baseline activation. Mayr and Keele (2000) reported results suggesting that abandoned task sets receive suppression that renders them less accessible than task sets that had been abandoned less recently. Thus, it seems at least possible that even the outer region needs to consist of LTM elements that are congruent with the current task goal whereas all others are "deleted" or suppressed.

There is one model of the interplay between working memory and LTM that we think is potentially useful for the understanding of situations in which people need to change task sets endogenously, namely, the long-term working memory model proposed by Ericsson and Kintsch (1995). The critical concepts here are a very limited amount of currently active information plus LTM retrieval structures that, at least in case of well-organized knowledge (e.g., text comprehension in a familiar domain), allow relatively fast access to information outside the range of immediate access (i.e., in the order of several 100 ms). The distinctions between an outer region of working memory and LTM becomes irrelevant here (see McElree & Dosher, 1989).

Generalizing this view to the task-switching domain would imply that (a) task sets themselves are more or less complex retrieval structures and (b) that several task sets are associated with each other through a common "experimental context" node. Switching back and forth between two (or more) tasks can be pictured as "moving" the working memory focus back and forth along the retrieval paths. This can occur endogenously (i.e., during the cue-stimulus intervals), thus allowing preparation to occur. At the same time, moves along retrieval paths can be modulated by the provision of supportive (or interfering) cues, thus, allowing for task-set competition or cuing effects. From this perspective, the problem of endogenous control in task-switching situations is to position one's working memory focus adequately within the relevant retrieval structure.

There are a few subsidiary results obtained in the current experiments but also in other task-switching studies to which this view can be usefully applied. Take, for example, differences in results obtained with the alternate-runs paradigm (Experiment 1; Rogers & Monsell, 1995) on the one hand and the cuing paradigm (Experiment 3; Meiran, 1996) on the other. One difference seems to be that switch RTs are longer and no-switch RTs are somewhat shorter for the alternate-runs than for the cuing paradigm (see Figure 1 and Table 3). Even though comparisons across experiments need to be considered with caution, such a pattern is consistent with the retrieval-structure view. Specifically, it is plausible to assume that the alternate-runs paradigm and the cuing paradigm induce different tendencies to move back to the experimental context node after processing within a trial has finished. In the case of a no-switch run in the alternate-runs paradigm, participants know that they can remain focused on the just executed task. In contrast, in the cuing paradigm, it seems more rational to move the focus back toward the experimental context in order to minimize average retrieval distance to all possible task sets. As a result, participants would be in a relatively better position in case of a task switch but in a relatively less appropriate position in case of a task repetition. This same logic can also be applied to the unexpected finding from Experiment 2 that first-order no-switch trials were relatively long and contained a retrieval-related component (see Figure 3). Given that four possible tasks were used here within a block the tendency to "move" back to the point where distance to all possible task sets is smallest (i.e., the experimental context node) should be particularly large. Therefore, a large number of first-order no-switch trials would contain a "switching back" component so that the difference score between no-switch and switch RTs reflects less of the critical retrieval processes.

Another difference between the alternate-runs paradigm and the cuing paradigm can be found when looking at RTs across longer runs of no-switch trials. For the alternate-runs paradigm, RTs have been reported by Rogers and Monsell (1995) to be long only for the first trial after a switch and to remain constant from then onward. Basically, the same result was obtained in the current Experiment 1 for semantic tasks, whereas for episodic tasks there was a small carry-over of the switch cost to the second no-switch trial. In contrast, Meiran (1996) reported that task sets become continuously better adjusted with every use ("retroactive adjustment") leading to a monotonic reduction of RTs as a function of repeated sets. We suggest that such a "micropractice" pattern (Meiran, 1996; see also Salthouse et al., 1998) in the case of a cuing situation reflects short-term strengthening of immediately repeated cue-task associations. In contrast, in the alternate-runs paradigm the working-memory focus remains on the present task set in the case of no-switch trials so that cue-task associations are irrelevant and no comparable micropractice effect is to be expected.

The above speculations require more explicit empirical tests. For example, an interesting prediction from the retrieval-structure view is that switch costs may to a substantial degree be associated with changes in retrieval paths rather than to changes in task sets per se (Mayr & Kliegl, 1999). In any case, we believe that the retrieval structure notion applied to task-switching situations has the potential of producing important insights about the way people navigate through complex task environments by appropriately (or less appropriately) positioning their working memory focus.

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