Dissociating proactively and retroactively cued task switching: a route towards neuropsychological analyses of cognitive control

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Abstract

Cognitive control is often examined in task switching paradigms with dissociable types of task switching. Proactive task-cuing presents switch cues, signaling both a change of task and the task to implement, which occur prior to imperative events. Proactive transition-cuing utilizes switch cues, signaling a change of task but not indicating the required task, which occur prior to imperative events. Retroactive transition-cuing utilizes switch cues, again signaling a change of task but not indicating the required task, which occur later than imperative events. Thirty-six healthy young adults participated in the study. Response time switch costs were most pronounced on proactive task-cuing, whereas perseveration errors showed highest prevalence on retroactive transition-cuing. Principal component analyses revealed evidence for two components corresponding to the distinction between proactive and retroactive task-cuing, thus implying a dissociation between proactively and retroactively cued task switching. Retroactive transition-cuing might be particularly sensitive to frontal lesions of the cortex.

Keywords: Executive functions; Cognitive control; Task switching; Pro- vs. retroactive cuing; Task vs. transition cuing

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1. Introduction

Task switching paradigms offer important means for investigating cognitive control. Response times (RTs) are slower and response accuracy is often lower for switch trials compared to repeat trials in task switching experiments (see Kiesel et al., 2010, for review). These behavioral costs associated with task switching have been attributed to a number of processes, including retrieving cue-task associations from memory (Logan & Bundesen, 2003; Schneider & Logan, 2007), reconfiguring task sets (Mayr & Kliegl, 2003; Monsell & Mizon, 2006), and overcoming inhibition of task sets (Mayr & Keele, 2000).

Task switching research has advanced with regard to the experimental methods employed. Specifically, the task-cuing paradigm has been developed in which task switches and repetitions are randomly ordered across trials and in which task cues precede or accompany the task stimulus (Meiran, 1996). In a typical task-cuing paradigm, the interval between cue and stimulus as well as the interval between response on the preceding trial and the onset of the cue can be varied (see Kiesel et al., 2010). However, there is also the possibility to manipulate the nature of the task cue. On the one hand, task cues may provide clear indicators of what task is required in the upcoming trial. Within the task switching literature, this type of cue is often referred to as an (explicit) task cue (Monsell, 2003). On the other hand, task cues may merely indicate that the current task needs to be abandoned, but they may not specify which of two or more possible tasks one should adopt. This type of cue is often described as a transition cue within the task switching literature (Schneider & Logan, 2007). These authors suggested that one important difference between switching directed by task and transition cues is that transition switching places higher demands on the retrieval of task sets. Studies examining the functional neuroanatomy of task switching showed that transition cues, signaling a change of task but not indicating the required task, were associated with recruitment of lateral prefrontal and parietal cortical areas, whereas (explicit) task cues, signaling both a change of task and the task to implement, were associated with recruitment of parietal areas only (Forstmann, Brass, Koch & von Cramon, 2005; West, Langley & Bailey, 2011).

Despite the often pronounced claims that task switching paradigms activate cognitive control, neuropsychological studies of task switching are rather scarce, and their main results are quite contradictory (see Robbins, 2007; Shallice, Stuss, Picton, Alexander & Gillingham, 2008a, for reviews). Most studies of task switching that have been carried out in neurological patients have involved small numbers of patients. Aron, Monsell, Sahakian, Robbins (2004), using a predictable task switching paradigm without exogenous task cues (Rogers & Monsell, 1995), found that patients with left frontal lesions showed significantly larger RT switch costs than patients with right frontal lesions, whereas the right frontal group showed dramatically elevated error rates on switch trials compared to patients with left frontal lesions. The Shallice, Stuss, Picton, Alexander, and Gillingham (2008b) study which instead used the proactively cued task switching paradigm also found a left frontal effect, but this time on errors, whereas the major RT effect was a striking slowing on both switch and repeat trials for patients with superior medial prefrontal lesions.

Another line of research on cognitive control has its roots in neuropsychological tools for the assessment of executive dysfunctions (see Strauss, Sherman & Spreen, 2006, for review). Specifically, the Wisconsin Card Sorting Test (WCST; Berg, 1948; Grant & Berg, 1948; Heaton, Chelune, Talley, Kay & Curtiss, 1993; Nelson, 1976) is often considered as a paradigmatic example of this approach (Barceló & Knight, 2002; Milner, 1963; Demakis, 2003; Kopp, Tabeling, Moschner & Wessel, 2006; Nyhus & Barceló, 2009). WCST cards differ with regard to the color, the shape, and the number of the depicted stimuli, and these three stimulus dimensions define the possible sorting rules (i.e., tasks). Efficient performance on the WCST depends on the deduction of the rules which are effective for sorting cards, but rules change when a specified number of consecutive sorts has been completed correctly. Any failure to abandon the formerly effective rule will lead to erroneous, perseverative performance. On average, patients with frontal damage generate more perseverative errors on the WCST than patients with non-frontal damage (Demakis, 2003). Patients with focal lateral prefrontal lesions also showed enhanced rates of non-perseverative (set loss) errors, suggesting random fluctuations in their sorting behavior (Barceló & Knight, 2002).

At first glance, the WCST represents just another instance of a task-cuing paradigm. However, the task cues employed by the WCST possess some highly specific characteristics. To cite the original articles: "As the S [subject] sorted the response cards he was informed whether he was 'right' or 'wrong'" (Berg, 1948; Grant & Berg, 1948). Thus, "wrong"-cues which follow erroneous sorts signal the need to switch rules on the WCST, but they do not indicate the required rules (i.e., they are transition cues). Furthermore, let us consider a situation in which rule *s* is appropriate in context *S*, whereas rule *c* is the appropriate rule in context *C* (Figure 1). Suppose that the context changes from *S* to *C* on a particular transition trial. If subjects are unaware of the context change, they will perform rule *s* on the transition trial and will therefore receive a "wrong"-cue which, in turn, should trigger rule-switching on the next trial. Thus, subjects are bound to fail on transition trials, and monitoring the occurrence of these sorting errors is essential for successful performance on the WCST. Throughout this article, this particular method of task-cuing is called retroactive transitional cuing (Figure 1b and c). In contrast to this task-cuing method, many task-cuing paradigms, including those employing transition cues, provide prospective information about context changes so that subjects are aware of them at the time of context transitions, and they will be able to perform rule *c* on transition trials. Throughout this article, this task-cuing method is called proactive transitional cuing (Figure 1a).

Given the evidence described in the previous paragraphs, the current study sought to compare behavioral switch costs obtained on proactive task-cuing, proactive transition-cuing, and retroactive transition-cuing. These procedures differ with respect to the nature of the cues (task cues, but not transition cues, signal the task to implement) and their timing (proactive cues occur prior to imperative events, retroactive cues occur later than imperative events).

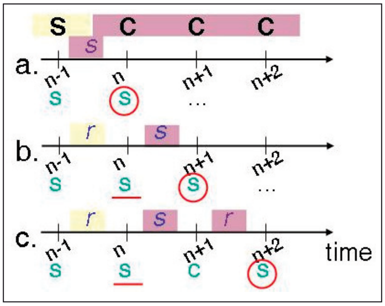

Figure 1

Illustration of the distinction between proactive (a.) and retroactive (b., c.) transitional task-cuing as well as between perseverative (a., b.) and non-perseverative (c.) errors across an exemplary series of consecutive trials. A transition between two effective rules on trial n is depicted, highlighted by the boxes at the top. Effective rules are depicted in bold upper case letters (S = shape rule, C = color rule). Transition cues are depicted in lower case italic letters above the time axes (r = repeat cue, s = switch cue); applied rules are shown in lower case letters below the time axes (s = shape rule, c = color rule).

a. *Proactive transition-cuing. Illustration of a rule switching failure, i.e. a perseveration error on trial n (cfr. the circled s), after the receipt of a proactive switch cue on this trial.*
b. *Retroactive transition-cuing. Illustration of a rule switching failure, i.e. a perseveration error on trial n+1 (cfr. the circled s). The former rule was applied again on trial n+1, after the receipt of a retroactive switch cue on trial n (i.e., the sort on trial n had been classified as being "wrong" by the feedback stimulus. Note, that the subject is bound to fail on trial n (cfr. the underlined s), and on all other transition trials, since proactive switch cues are not provided. In consequence, the "wrong" feedback on trial n signals a rule transition, and trial n+1 constitutes the switch trial.*
c. *Retroactive transition-cuing. Illustration of a non-perseverative (set loss) error on trial n+2 (cfr. the circled s). Following a successful switch to the currently effective rule on trial n+1, the alternative rule was applied on trial n+2, after the receipt of a retroactive repeat cue on trial n+1 (i.e., the sort on trial n+1 had been classified as being "right" by the feedback stimulus).*

Clear dissociations between switch costs on the three experimental conditions would suggest separable neural circuitry mediating performance on distinct types of task switching. Several hypotheses are conceivable: first, switch costs on task-cuing conditions may differ from switch costs on transition-cuing conditions. Second, switch costs on proactive task-cuing conditions may differ from switch costs on retroactive task-cuing conditions. Third, the retroactive transitional task-cuing condition may specifically impose additional costs on switching between tasks. One possibility is that the well-documented sensitivity of the WCST to frontal lesions (Barceló & Knight, 2002; Demakis, 2003; Milner, 1963) is related to the fact that the WCST, in contrast to many other task switching paradigms, employs retroactive transition-cuing, thereby combining task switching with action monitoring (Gehring & Knight, 2000; Ridderinkhof, Ullsperger, Crone & Nieuwenhuis, 2004; Ullsperger, von Cramon & Müller, 2002) in a unique manner, as discussed above.

2. Methods

2.1. Subjects

Subjects were thirty-six (four male) students enrolled in introductory psychology courses (age: M = 21.7 years, SD = 3.7, min. 19, max. 37). Their Edinburgh Handedness Score (Oldfield, 1971) amounted to M = 78.3, SD = 33.4 (one left-handed subject, one ambidextrous subject).

2.2. Materials

Visual stimuli (Figure 2) were composed of two stimulus cards, presented above a test card; all cards were configured around the center of a computer screen (Eizo FlexScan T766 19"; 1280 × 1024 pixels at 100 Hz presentation rate). The cards subtended squares of 3.1° × 3.1° (test card) and 1.5° × 1.5° (stimulus cards), respectively. The left stimulus card always depicted a red ellipse (0.6° × 1.2°), whereas the right stimulus card always depicted a blue rectangle (0.6° × 1.2°). The test card either contained a blue ellipse (shown in Figure 2), or it contained a red rectangle (not shown in Figure 2). The card stimuli featured a white background; they were dis-

played in front of a gray background which extended over the complete computer screen.
Participants had to assign the test card to one of the two stimulus cards (Figure 2). Card sorting could be based on one of two different sorting rules (categories). According to one category (color), the red rectangle matches the red ellipse (left stimulus card), whereas the blue ellipse matches the blue rectangle (right stimulus card). According to the other category (shape), the blue ellipse matches the red ellipse (left stimulus card), whereas the red rectangle matches the blue rectangle (right stimulus card). Thus, on any given trial, participants needed to retrieve the currently prevailing category in order to be able to correctly assign the test card to one of the two stimulus cards.

Participants used their index fingers for responding (on a standard computer keyboard); pressing the "arrow left"-button (handled by the left index finger) indicated the choice of the left stimulus card, whereas pressing the "arrow-right"-button (handled by the right index) indicated the choice of the right stimulus card.

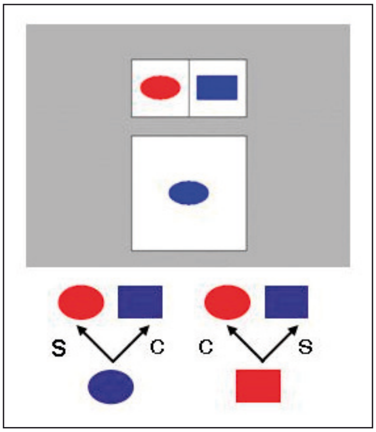

Figure 2

An illustration of imperative events and their associated responses. Upper part: Imperative events, i.e. two stimulus cards (upper cards) and a test card (lower card) are presented. Lower part: The application of the color (c) rule leads to a right-hand response if the test card contains a blue ellipse, whereas the application of the same rule leads to a left-hand response if the test card contains a red rectangle. The application of the shape (s) rule leads to a left-hand response if the test card contains a blue ellipse, whereas the application of the same rule leads to a right-hand response if the test card contains a red rectangle.

2.3. Procedure

Trials were initiated by presenting an auditory cue in both proactive task switching conditions. These auditory stimuli consisted of simple tones that were presented via earphones (250 ms duration, 10 ms rise/fall times, 65 dB; 250 Hz or 1.000 Hz, respectively). In the proactive task-cuing condition, one of the tones (e.g., the 250 Hz tone) signaled that the correct sorting category was "color", whereas the other tone (e.g., the 1.000 Hz tone) signaled that "shape" was the correct category for the upcoming imperative events. In the proactive transition-cuing condition, one of the tones (e.g., the 250 Hz tone) signaled that the correct sorting category switched relative to the category that was effective during the last trial, whereas the other tone (e.g., the 1.000 Hz tone) signaled that the formerly valid category was repeating on the current trial. Inter-stimulus intervals were set at 2.000 ms in both proactive task switching conditions. Inter-trial-intervals lasted 2.000 ms, starting with the response to the imperative events. In case of an incorrect response, the participant was reminded to the currently correct category during that interval.

No proactive cues were presented in the retroactive transition-cuing procedure. Instead of that, auditory feedback stimuli of the same type as described above served as transition cues. Specifically, one of the tones (e.g., the 250 Hz tone) signaled that the correct category had been applied in the elapsed trial, whereas the other tone (e.g., the 1.000 Hz tone) signaled that the wrong category had been selected on this trial. Response-cue intervals were set at 2.000 ms in the retroactive task switching condition. Inter-trial-intervals lasted 2.000 ms, starting with the onset of the feedback cues.

In all three task switching conditions, the mapping between pitch and sorting category (color/shape, switch/repeat, correct/wrong) was counterbalanced across participants. Participants completed all three experimental conditions within separate blocks of trials (120 trials each). The order of experimental conditions was counterbalanced across participants. The serial order of the trials within a block of trials was pseudo-randomly determined, as detailed in our earlier report (Kopp et al., 2006). The same pseudo-random sequence was reiterated on all three task switching conditions. Blocks of trials consisted of thirty-two runs of trials in which the sorting category remained the same. The average run length amounted to 3.75 trials (sixteen times three trials, eight times four trials and eight times five trials). Thus, each block of trials contained, besides the opening trial, thirty-one transition trials and eighty-eight repeat trials.

The experiment was controlled by the Presentation® software (http://www.neuro-bs.com). They were instructed that their task would be to respond according to the appropriate sorting category which would change from time to time in an unpredictable manner. They were also informed about the initial category which was always color. They were discouraged to guess categories.

2.4. Measures and analyses

Median RTs and response accuracy on the three task switching conditions, separately for switch and repeat trials, were computed for each participant. The percentage of set loss errors was computed on repeat trials, as detailed in Figure 1c. The percentage of perseveration errors was computed on switch trials, as detailed in Figure 1. It is important to note that, as Figure 1a shows, transition trials equal switch trials in proactive task switching procedures because cues occur prior to imperative events. In contrast, as illustrated by Figure 1b, switch trials succeed transition trials in retroactive task switching procedures because cues occur later than imperative events.

When distribution normality was tested using Kolmogorov-Smirnov one-sample tests, RTs were found to be distributed normally (all $p > .05$), whereas error measures did not show normal distributions (all $p < .05$). Therefore, a conventional two-way analysis of variance (ANOVA) was used for RTs, whereas Friedman tests and Wilcoxon signed ranks tests were used for the error measures as a consequence of their non-normality. Further, natural log (ln) transformed RTs entered into the ANOVA. Log-transformation of the dependent variable is an accepted method for the general methodological issue that ordinal interactions can be interpreted as indicating performance dissociations only if they cannot be made to disappear by monotonic transformations, such as, for example, simple multiplication (Loftus, 1978). A significance criterion of $\alpha = 0.05$ was used throughout these statistical analyses. In addition, principal component analyses (extraction of components with an eigenvalue greater than 1.0, varimax rotation method) were conducted separately for ln-transformed RTs and error measures to identify the underlying dimensional structures.

3. Results

3.1. Response times

Median RTs are presented in Table 1 for the three task switching conditions (i.e., proactive task-cuing, proactive retroactive transition-cuing retroactive transition-cuing), further broken down by type of trial (i.e., switch trial, repeat trial). Task switching conditions did not differentially affect ln-transformed RTs, F (2, 70) < 1, but RTs were longer for switch trials relative to repeat trials, F (1, 35) = 81.02, $p < 0.001$, $\eta_p^2 = 0.70$. RT switch costs were affected by task switching conditions, F (2, 70) = 5.19, $p < 0.009$, $\eta_p^2 = 0.13$. Simple contrasts revealed reliable differences between switch costs on proactive task-cuing and proactive transition-cuing, F (1, 35) = 6.35, $p < 0.017$, $\eta_p^2 = 0.15$, as well as on proactive task-cuing and retroactive transition-cuing, F (1, 35) = 8.36, $p < 0.008$, $\eta_p^2 = 0.19$. Thus, speed costs related to switching were larger on proactive task-cuing than on proactive or retroactive transition-cuing.

Two components with an eigenvalue greater than 1.0 explained 58.10% and 21.97% of the variation, respectively. RTs from proactive task switching conditions loaded on the first component (proactive task switching: loadings > .804, retroactive task switching: loadings < .232), whereas RTs from retroactive task switching conditions loaded on the second component (retroactive task switching: loadings > .930, proactive task switching: loadings < .277). Thus, the two components might be conceptualized as response speed in proactive vs. retroactive task switching conditions, respectively.

3.2. Set loss errors

The median percentages of set loss errors on repeat trials are presented in Table 1. The omnibus Friedman test indicated no significant differences among the three task switching conditions (*Chi-square* = 1.77, $df = 2$, $p > .05$).

3.3. Perseveration errors

The median percentages of perseveration errors on switch trials are presented in Table 1. The omnibus Friedman test indicated significant differences among the three task switching conditions (*Chi-square* = 8.16, $df = 2$, $p < .018$). Wilcoxon statistics indicated a significant difference among proactive and retroactive transition-cuing conditions, Wilcoxon $Z = -2.497$, $p < 0.014$, without reliable differences among proactive task-cuing and proactive transition-cuing conditions, Wilcoxon $Z = -.911$, $p > 0.05$, as well as among proactive task-cuing and retroactive transition-cuing conditions, Wilcoxon $Z = -1.384$, $p > 0.05$. Thus, perseveration errors occurred more frequently on retroactive transition-cuing when compared to proactive transition-cuing.

The principal component analysis for set loss and perseveration error measures yielded two components with an eigenvalue greater than 1.0 which explained 43.25% and 28.63% of the variation, respectively. The error measures from proactive task switching conditions loaded on the first component (proactive task switching: loadings > .573, retroactive task switching: loadings < .410), whereas the error measures from retroactive task switching conditions loaded on the second component (retroactive task switching: loadings > .861, proactive task switching: loadings < .113). Thus, the two components might be conceptualized as response accuracy in proactive vs. retroactive task switching conditions, respectively.

Table 1. Response times (RTs) and error scores (perseveration errors, per, and set loss errors, set)

	RTs (ms)		per (%)		set (%)	
	Mdn	*IQ R*	*Mdn*	*IQ R*	*Mdn*	*IQ R*
Proactive task-cuing, switch trials.	832	170	6.7	6.7	–	–
Proactive task-cuing, repeat trials.	710	164	–	–	1.7	3.3
Proactive transition-cuing, switch trials.	774	207	3.3	6.7	–	–
Proactive transition-cuing, repeat trials.	699	218	–	–	1.1	2.2
Retroactive transition-cuing, switch trials.	791	287	8.3	15.8	–	–
Retroactive transition-cuing, repeat trials.	703	310	–	–	2.8	7.5

Note: IQ R = Inter-quartile range.

4. Discussion

The present data show that (a) task-cuing exerted more pronounced effects on RT switch costs than did transition-cuing and that (b) perseveration errors occurred more often on the retroactive, compared to the proactive, transitional task-cuing condition. The results of the principal component analyses showed that cue timing (proactive, retroactive) structured the variation of response speed and accuracy in similar ways. Taken together, these data suggest that proactively and retroactively cued task switching may be dissociable, and further that they might be mediated by separable neural circuitry, although the latter claim certainly needs careful neuropsychological analyses, based on direct comparisons between proactively and retroactively cued task switching. To conclude, the proposed method offers a route towards a unification of experimental and neuropsychological research on cognitive control. Interestingly, experimental task switching research, usually relying on proactive task-cuing, has focused on measuring response speed, whereas neuropsychological task switching research, usually relying on retroactive transition-cuing, has focused on measuring response accuracy.

The two aspects of behavioral switch costs (response speed, response accuracy) were differentially sensitive to the experimental manipulations. RT switch costs showed a pattern that was compatible with the first hypothesis, according to which task-cued switch costs differ from transition-cued switch costs. Further research is required to disentangle the origins of this dissociation. In contrast to that, perseveration errors occurred most often on switch trials of the retroactive transitional task-cuing condition, a finding that seems compatible with the third hypothesis, according to which the combination of retroactive cue timing and transitional cuing imposes additional costs on task switching. It had been noted in the introduction to this article that retroactive transition-cuing combines task switching with action monitoring (Gehring & Knight, 2000; Ridderinkhof, Ullsperger, Crone & Nieuwenhuis, 2004; Ullsperger, von Cramon & Müller, 2002) in a unique manner. It therefore seems reasonable to assume that the increased number of perseveration errors is related to the need to monitor the consequences of one's actions, as discussed in more detail below. Finally, the results of the principal component analyses suggest that the distinction between proactive task-cuing conditions and retroactive task-cuing conditions might be important to consider whenever task switching paradigms are applied in neuropsychological studies.

The distinction between proactive and retroactive transition-cuing is similar, though not identical, to Braver and colleagues' distinction between proactive and reactive mechanisms of cognitive control within the dual mechanisms of control framework (Braver, Gray & Burgess, 2007). Mechanisms of proactive control, based on sustained activation prior to imperative events which may enforce behavioral changes, are future-oriented; they make use of the available predictive contextual information and permit to attend, in a preparatory and selective manner, to relevant sources of information. In contrast, mechanisms of reactive control, based on transient activation following such an imperative event, are past-oriented. They are focused on the resolution of interference from irrelevant sources of information because they do not allow selecting relevant information in advance. There are two points of divergence between the two approaches. First, proactive cognitive control, as defined in this article, implies future-oriented as well as past-oriented processing because transition cues, signaling a change of task but not indicating the required task, place high demands on the retrieval of task sets (Schneider & Logan, 2007). Second, retroactive cognitive control, as defined in this article, implies a quite specific form of past-oriented processing, namely the ability to monitor the consequences of one's actions and to adapt behavioral strategies accordingly (Gehring & Knight, 2000; Ridderinkhof et al., 2004; Ullsperger et al., 2002).

Retroactive transitional task switching, but not proactive transitional task switching, uses contingencies akin to that in instrumental conditioning (Dickinson, 1994). This is because here transition cues identify the task to be executed on the upcoming trial relative to the task that had been completed on the preceding trial, thereby putting task switching under the control of action-outcome relations (Berg, 1948; Grant & Berg, 1948). The instrumental character of retroactive transitional task switching connects the paradigm to reinforcement learning (Sutton & Barto, 1998), with its well-documented sensitivity to dopaminergic reward systems of the brain (Montague, Dayan & Sejnowski, 1996; Suri & Schultz, 1999) which are under descending control that originates from the prefrontal cortex (Hazy, Frank & O'Reilly, 2007). These considerations suggest a route for an explanation of the well-documented sensitivity of the WCST to frontal lesions (Barceló & Knight, 2002; Demakis, 2003; Milner, 1963). It remains, however, to be delineated whether performance deficits on retroactive transitional task switching paradigms are actually preferentially associated with frontal lesions, when directly compared with proactive transitional task switching (Forstmann et al., 2005; West et al., 2011).

Another route for an explanation of a possible neurocognitive association between retroactive transitional task switching paradigms and prefrontal lesions comes from Petrides' (2005) monitoring model. The model has its roots in animal studies of working memory. Specifically, animals learned to select formerly unselected, familiar objects on the monitoring condition by retrieving the preceding object-action relations. By contrast, animals selected novel, unfamiliar objects on the recognition condition simply by evaluating the familiarity of the objects. Petrides showed that lesions of rostral, but not of caudal, areas of the dorsolateral prefrontal cortex were associated with severe monitoring deficits, suggesting important lateral prefrontal contributions to retroactive monitoring of object-action relations.

Given these considerations, it seems reasonable to suggest that retroactive transition-cuing involves more endogenous mechanisms serving cognitive control than either proactive task-cuing or proactive transition-cuing.

One of the reasons for this might be that retroactive transition cues are only very indirectly related to the requirement to switch tasks since they merely provide feedback about the consequences of one's actions in the first place and since the implication of this feedback concerning the requested task needs to be evaluated further. This conclusion might help to explain the discrepancy between Aron et al.'s (2004) and Shallice et al.'s (2008b) results because predictable task switching might likewise involve more endogenous mechanisms serving cognitive control than proactive task-cuing since here task switches must be generated internally, i.e. in the absence of explicit switch cues. One might express the objection against this interpretation that our essential findings are simple dissociations which may be subject to many non-specific characteristics of the experimental conditions, such as their difficulty and the like. Although such criticisms cannot be completely ruled out by the present data, one argument against this interpretation of the results is their specificity with regard to RTs and perseveration errors, which stands in contrast to fact that set loss errors occurred equally often on the three task switching conditions.

Switching based on task-cuing was more time-consuming, but not more error-prone, than switching based on transition-cuing, whereas switching based on retroactive transition-cuing was more error-prone, but not more time-consuming, than switching based on proactive transition-cuing. Based on the available neuropsychological evidence, we suggest that retroactive transition-cuing might place higher demands on frontal lobe mediated cognitive control than proactive transition-cuing. With regard to this issue, one should recall that the available neuropsychological evidence shows that frontal lesions are associated with the occurrence of more perseveration errors (Demakis, 2003; Milner, 1963), and possibly more set loss errors (Barceló & Knight, 2002), on a particular retroactive transitional task switching paradigm, namely the WCST.

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