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Probe-specific proportion task repetition effects on switching costs

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In two experiments, participants were presented with successive presentations of animal names (e.g., GORILLA, WHALE)—a prime display followed by a probe display. In response to each display, participants judged either the typical habitat or the relative size of those animals, repeating the same task in response to both displays on half of the experimental trials and switching from one task to the other on the other half of trials. Our results demonstrate that switch costs can be reduced when either the probe's identity or its location is predictive of a change in task. This result establishes that the presentation of a stimulus can serve as a rapid cue for facilitating a switch in task, independent of processes occurring both at the time of the prime task and during the intervening period between the prime and probe tasks. We discuss the implications of these results for prevailing explanations of task switching costs.

People typically perform a task more slowly following the completion of some other task than after performing the same task (Allport, Styles, & Hsieh, 1994; Jersild, 1927; Monsell, 2003; Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995; Spector & Biederman, 1976). Such costs of task switching are thought to reflect two distinct components. One source of these switch costs is considered to be unconsciously and exogenously determined by the interaction of processes occurring during the performance of the task to be switched from and processes associated with subsequent performance of a different task. Alternatively, switch costs may arise from time-consuming endogenous control processes—often referred to as *task-set reconfiguration processes* (see Monsell, 2003, p. 135).

Observations of smaller task switching costs when participants are provided with time to prepare for a task change are typically interpreted as reflecting the contribution of time-consuming, endogenous efforts to configure a new task set. In contrast, when participants are given ample time to prepare for a task switch, a residual switching cost is often observed (De Jong, 2000; De Jong, Berendsen, & Cools, 1999; Goschke, 2000; Lien, Ruthruff, Remington, & Johnston, 2005; Meiran, 1996; Meiran & Chorev, 2005; Meiran, Chorev, & Sapir, 2000; Nieuwenhuis & Monsell, 2002; Rogers & Monsell, 1995; Schuch & Koch, 2003; but see Verbruggen, Liefooghe, Vandierendonck, & Demanet, 2007). These residual switching costs are often thought to arise from additional sources of impairment that are not within the participant's conscious control.

Exogenous Sources of Task Switching Costs

One class of exogenous influences that have been proposed as contributing to task switching costs emphasizes processes occurring at the time of performing the task that participants are required to switch from (the prime task). Task switching costs occur because processes engaged by completion of the prime task interfere with efforts to perform a different task in response to a subsequent display (the probe task). For example, Allport and colleagues (Allport et al., 1994; Meuter & Allport, 1999) have proposed that such costs are the outcome of persistent inhibition and/or activation of the prime task set. A number of other researchers have since provided further evidence in support of the idea that task switching costs are at least partly a consequence of inhibition and activation of the prime task set (Mayr, 2002, 2006; Mayr & Keele, 2000; Mayr & Kliegl, 2003; Monsell et al., 2000; Yeung & Monsell, 2003). By this view, performance of a prime task increases the activation level of mental representations corresponding to that task and decreases (or inhibits) the activation level of task-set representations corresponding to the alternate task.

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Other researchers have focused on the requirement for participants to rely on a task cue to select between two alternative tasks in many studies of task switching (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Mayr & Kliegl, 2003; Monsell & Mizon, 2006). Using this procedure, the prime and probe task cues would naturally be the same on task repetition trials, but would differ on task switch trials. Thus, at least a proportion of task switching costs might occur because presentation of the prime task cue facilitates perception and use of the probe task cue on task repetition trials. When responding to the probe on task switch trials, participants might be slower to respond because it takes them relatively longer to process the probe task cue.

Finally, a number of studies have focused on the role of automatic episodic retrieval processes in giving rise to task switching costs. This approach involves application of well-known memory principles, such as those of encoding specificity (Tulving & Thomson, 1973) and transfer-appropriate processing (Morris, Bransford, & Franks, 1977), to investigations of short-term priming effects (Hommel, 1998, 2004; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Leboe & Milliken, 2004; Leboe, Mondor, & Leboe, 2006; Leboe, Whittlesea, & Milliken, 2005; Milliken, Joordens, Merikle, & Seiffert, 1998; Neill, 1997; Neill & Mathis, 1998). From an episodic retrieval perspective, impaired responding to the probe on task switch trials may occur because presentation of the probe display causes the retrieval of processes and/or stimulus–response bindings associated with the prime episode. Since the prime task typically requires processes that are not appropriate for generating a correct response to the probe on task switch trials, retrieval of the prime episode interferes with performance of the probe task (Leboe et al., 2005; Rothermund, Wentura, & De Houwer, 2005; Waszak, Hommel, & Allport, 2003, 2004, 2005; Wong & Leboe, in press).

Whether the different exogenous sources of task switching costs described above represent alternative or complementary sources of task switching impairment is unclear. Resolving this issue lies outside our present objectives. Instead, our primary goal was simply to test the limits of exogenous influences on task switching costs. In particular, our emphasis was on processes occurring solely at the time of the probe task that might modulate interference caused by the need to switch from one task to another. For example, Mayr and Bryck (2007) recently demonstrated that task switching costs can depend on incidental features of the probe task, such as the location on the screen in which a task-related stimulus is displayed. In their design, task switching costs were smaller when each of their two tasks were assigned a unique screen location than they were when the two tasks were performed on stimuli presented to the same screen location. In other words, when a location cue was always associated with performance of one task and not the other, the interference associated with switching to that task was reduced in comparison with a condition for which the location of the stimulus display was not uniquely associated with either task. The aim of the present study is to further understand constraints over the extent to which contextual cues present at the time of probe onset may be used to influence switch costs. In the General Discussion, we will discuss implications of our findings for current theoretical positions on processes mediating task switching interference.

The Present Study

We adapted the experimental strategy for the present study from recent investigations using the Stroop color naming task (Stroop, 1935; see MacLeod, 1991, for a review). These previous studies have demonstrated that the magnitude of Stroop interference can depend on exogenous contextual cues appearing at the time of target onset (Crump, Gong, & Milliken, 2006; Jacoby, Lindsay, & Hessels, 2003; see also Corballis & Gratton, 2003, for a similar manipulation using the flanker task). We were interested in determining whether similar kinds of contextual cues would also be effective in modulating the magnitude of interference that occurs as a consequence of the need to switch from one task to another. This type of demonstration would further establish the prevalence of contextually guided influences across paradigms for studying perception and attention. Moreover, such evidence would help clarify the range with which contextually guided influences can provide control over processes mediating task switching. To further motivate the experimental manipulations employed in the present work, we will now briefly summarize relevant work from the Stroop domain and draw out the analogy between research in the Stroop and task switching literatures.

In a Stroop task (Stroop, 1935), participants identify the ink or font color of a color word (for a review, see MacLeod, 1991). The classic Stroop effect is the observation that responses are slower and less accurate on incongruent trials (e.g., red in BLUE) than on congruent trials (e.g., red in RED). The size of this Stroop effect has been shown to depend on the proportion of congruent items in a block of trials. Specifically, the Stroop effect is larger within blocks of trials that contain a high proportion of congruent items than within blocks of trials that contain a low proportion of congruent items (Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; Tzelgov, Henik, & Berger, 1992). This *proportion congruency effect* is commonly attributed to the deployment of different word-reading strategies between the high- and low-proportion-congruent blocks of trials (Logan, Zbrodoff, & Williamson, 1984; West & Baylis, 1998; but see also Dishon-Berkovits & Algom, 2000, for an alternative view).

An analogical pattern of findings has been demonstrated in the task switching literature. For example, task switching interference depends on the block-wide probability of receiving a task repetition or task switch trial (Dreisbach, Haider, & Kluwe, 2002; Schneider & Logan, 2006). Specifically, measures of task switching interference are larger when the probability of receiving a task-repeat trial is high than when it is low. This result has received an interpretation similar to that for proportion congruency effects observed with the Stroop task—namely, that differences in the proportion of task switch versus task repetition trials induce participants to explicitly prepare different strategies prior to the onset of the probe display. When the likelihood of task repetition is high, participants likely use the interval between completion of the prime task and the onset of the probe display to prepare repetition of the same task. When the likelihood of task repetition is low, participants likely use the interval between the prime and probe tasks to prepare themselves to perform a task switch. As a result, these proportion task repetition effects on task switching interference are typically attributed to conscious, strategic influences.

More recently, a number of researchers have demonstrated proportion congruency effects on Stroop interference that cannot be attributed to strategic influences. For example, the Stroop effect can be modulated at the time of target onset by the presentation of a contextual cue that is associated with the likelihood of congruency on previous experimental trials (Crump et al., 2006; Crump, Vaquero, & Milliken, 2008; Jacoby et al., 2003). These demonstrations highlight the role of exogenous contextual cues in providing control over processes mediating Stroop interference. The purpose of the present experiments was to further extend the analogy between proportion congruency effects that have been observed using the Stroop procedure and observations of proportion task repetition effects in previous studies of task switching. The objective was to determine whether the same type of exogenous influences that are known to modulate the Stroop effect might also play a role in modulating task switching interference. We explored this analogy across two experiments that map onto two recent experiments reported in the Stroop literature.

First, Jacoby et al. (2003) manipulated the proportion of congruent trials for specific color words, selecting one pair of color words (e.g., YELLOW and GREEN) to appear in a congruent color on 80% of trials, and another pair of color words (e.g., BLUE and RED) to appear in a congruent color on only 20% of trials. Importantly, all of these item types were mixed together in the same blocks of trials. In this way, participants were not able to accurately predict whether the upcoming trial would be congruent or incongruent. Instead, the Stroop item itself served as an exogenous contextual cue for the likelihood that the current item was congruent. The results yielded an item-specific proportion-congruent Stroop effect, demonstrating larger Stroop interference for the high- than for the low-proportion-congruent Stroop items. The first experiment in the present set of studies extended the item-specific proportion-congruent manipulation to a task switching paradigm. Specifically, we were interested in determining whether task switching interference could be modulated by probe items that were associated with the probability of being required to perform a task repetition versus a task switch.

Second, Crump et al. (2006) extended the findings of Jacoby et al. (2003) by demonstrating that an association between color–word congruency and the location of a Stroop item can also influence the degree of Stroop interference observed. In their design, the proportion of congruent trials was manipulated between different location contexts in which items could appear. For example, items appearing above fixation were congruent on 75% of trials, whereas items appearing below fixation were congruent on only 25% of trials. In this way, the location context—which also appeared at the time of target onset—acted as an exogenous contextual cue to the likelihood that the current item was congruent. The results of this experiment yielded a location-specific proportion-congruent Stroop effect, with larger Stroop interference for items appearing in the high- than in the low-proportion-congruent location. Our second experiment extends this location-specific proportion-congruent manipulation into a task switching paradigm. Specifically, we were interested in determining whether task switching costs would depend on an association between the location of a probe stimulus and task cues and the participants' requirement to switch versus repeat the prime task across an experimental session.

EXPERIMENT 1

The purpose of Experiment 1 was to determine whether the identity of a target appearing in a probe display would be capable of modulating the cost of task switching through its association with the requirement to switch tasks on previous trials. We chose half of the words from our stimulus set to appear as probes on task repetition trials 75% of the time, and to appear on task switch trials only 25% of the time (mostly task repetition probes). In contrast, the other half of the words appeared as probes on task repetition trials only 25% of the time, and they appeared as probes for task switch trials 75% of the time (mostly task switch probes). To illustrate, supposing the word RABBIT was a high-probability task repetition probe, its appearance as the probe would predict a task repetition on .75 of experimental trials, whereas its appearance would be associated with a task switch on only .25 of trials. In contrast, supposing the word MOUSE was a low-probability task repetition probe, its appearance as the probe would predict a task repetition on only .25 of experimental trials and a task switch on .75 of experimental trials.

To reiterate, the contribution of this proportion task repetition versus task switch manipulation on task switching interference cannot be due to a preparatory strategy engaged prior to appearance of the probe word. Instead, taking advantage of these contingencies between the identity of the probe, and the likelihood of being required to switch tasks, must follow the appearance of the probe display. Consequently, the observation of any modulation of task switching costs based on the identity of the probe must reflect a relatively automatic influence on task switching costs. Of course, it is possible that this automatic influence contributes to task switching costs by either encouraging or discouraging engagement of a consciously controlled task-set reconfiguration process. In any case, such a modulation of the cost of task switching would demonstrate that a learned association between the need to switch tasks and the probe's identity can rapidly induce either an increase or decrease in the contribution of the prime task to performance of a probe task.

Method

Participants. Fifty students enrolled in an Introduction to Psychology course at the University of Manitoba participated in this study in exchange for course credit. All participants had normal color vision and normal or corrected-to-normal visual acuity.

Apparatus and Stimuli. Participants were seated in front of a 15-in. color monitor that was connected to a 486 microcomputer. MEL2 software was used to present stimuli and record the speed and accuracy of participant responses. The stimuli consisted of eight well-known animal names that were chosen so that an equal number of words corresponded to both categories of animal habitat (land vs. sea) and animal size (big vs. small). Specifically, two names represented small sea animals (TROUT and SHRIMP), two represented large sea animals (SHARK and WHALE), two represented small land animals (MOUSE and RABBIT), and the remaining two represented big land animals (TIGER and GORILLA). For 29 of the participants, this same set of stimuli provided words for both prime and probe displays. For the remaining 21 participants, these stimuli appeared only as probes, whereas primes consisted of a different set of words corresponding to each possible response (BISON, SQUIRREL, OCTOPUS, and OYSTER). A row of symbols appearing above and below the target word cued participants about which task to perform in response to the prime and probe displays. Specifically, the presentation of 5 pound signs (#####) above and below either the prime or probe words indicated that a judgment of animal size was required, whereas a row of asterisks (*****) above and below either the prime or probe words indicated that a judgment of animal habitat was required.

Procedure. Participants completed 2 practice blocks and 10 experimental blocks, each composed of 32 trials. They were asked to respond to the presentation of each word as quickly and as accurately as possible by pressing buttons on the keyboard corresponding to the keys "v," "b," "n," and "m." In the order of "v," "b," "n," and "m," the response mappings were big animal/land animal/sea animal/small animal. To help participants learn the mapping of keys with designated responses, the keys "v," "b," "n," and "m" were labeled accordingly. Thus, the "v" key was labeled as *B* (big animal), the "b" key was labeled as *L* (land animal), the "n" key was labeled as *SE* (sea animal), and the "m" key was labeled as *SM* (small animal).

Each block began with the appearance of the prompt "Press 'b' to begin" at the center of the screen. After the participant initiated the block by pressing the "b" key, the first trial began with the presentation of a fixation cross "+" at the left-hand side of the computer screen for 500 msec. This fixation cross was then replaced by the prime word and prime task cues at the same location. The prime word and task cues remained on the screen until the participant made a buttonpress, categorizing the animal corresponding to the word as either a land or a sea animal (animal habitat task) or as a big or small animal (animal size task). If the buttonpress was incorrect, the prime display disappeared and the word "Wrong!" appeared on the screen for 500 msec at the same location as the prime word and task cues. If the participant's response was correct, the prime word and task cues disappeared and a fixation cross appeared at the right-hand side of the screen, persisting for 500 msec, followed by presentation of the probe word and task cues. Incorrect responses to the probe task initiated replacement of the probe word and task cues by the word "Wrong!" for 500 msec. Correct responses were followed by the disappearance of the probe display and the onset of a fixation cross appearing at the left-hand side of the screen, signaling the beginning of the next trial.

Prior to each trial, both prime and probe words were drawn randomly from the relevant set of animal names, with the constraint that the two words were never identical. Within each block, the probe task required a judgment of animal size on one half of trials and a judgment of animal habitat on the remaining half of trials. Thus, the probe task required an animal size judgment on 16 trials and an animal habitat judgment on the remaining 16 trials within each block. For both of these sets of trials, the probe task matched the prime task on 8 trials, whereas the prime and probe tasks differed on the remaining 8 trials. Thus, participants were equally likely to perform a task switch versus a task repetition both within blocks and across the experimental session as a whole.

In addition to manipulation of the prime and probe task, we established an association between the identity of probe words and the probability that participants would be required to repeat the same task that they performed in response to the prime display. Words from the original set of eight were divided into two sets. Set A consisted of the words TIGER, SHARK, RABBIT, and TROUT, whereas Set B consisted of the words GORILLA, WHALE, MOUSE, and SHRIMP. Within each set, two words corresponded to each of the four possible responses to the two probe tasks: land animal (TIGER, RABBIT), sea animal (SHARK, TROUT), big animal (TIGER, SHARK), and small animal (RABBIT, TROUT). For half of the participants, words in one set were defined as mostly task repetition probes, and words in the other set were defined as mostly task switch probes.

Within blocks—and, therefore, across the experimental session—words corresponding to each set appeared in random order and with equal frequency. Moreover, the presentation of a mostly task repetition probe required performance of the same task in response to both the prime and probe display on 75% of trials within each block. The presentation of one of these probes was associated with the requirement to switch tasks on only 25% of trials. In contrast, the presentation of a mostly task switch probe required repetition of the prime task on only 25% of trials, whereas the presentation of one of these probes would be associated with a task switch on 75% of trials. The assignment of each word set to the mostly task repetition and mostly task switch conditions was reversed for the other half of participants. Despite this association between the identity of probes and the likelihood that participants were required to repeat versus switch tasks, the specific word that appeared in the probe display was not predictive of the probe task that participants would be required to perform. Across the experimental session, the appearance of mostly task repetition and mostly task switch probes required a judgment of animal habitat or animal size on an equal number of trials. Trials corresponding to each experimental condition occurred in random order within blocks.

For 29 of the participants, prime words were also drawn from Sets A and B, and, on an equal proportion of trials, participants were required to perform either a land–sea or a big–small judgment in response to the presentation of words drawn from these two sets. We were concerned, however, about the consequences of using the same set of stimuli for presentation as both primes and probes. The primary factor of interest in this experiment was the association between specific probe words and the likelihood that participants would be required to repeat the prime task or switch to a different task. As described below, specific probe words might be associated with task repetition trials 75% of the time, whereas others would be associated with task repetition trials only 25% of the time. Nevertheless, when those same words appeared as primes, performance of the prime task would be a repetition of the preceding probe task about 50% of the time and would require a switch from the preceding probe task on about an equal proportion of instances. Thus, the true probability of being required to perform a task switch given the presentation of a specific word was actually lower than 75% for mostly task repetition probes, and it was actually higher than 25% for mostly task switch probes.

For the remaining 21 participants, words from Sets A and B never appeared in the prime display. Instead, a new set of four words (BISON, SQUIRREL, OCTOPUS, and OYSTER) were generated corresponding to every possible combination of animal habitat (land vs. sea) and animal size (big vs. small). The inclusion of this group of participants allowed us to evaluate whether encountering mostly task repetition and mostly task switch probes in the prime display had a significant impact on the effect of task repetition probability on the size of task switching costs. In our subsequent data analysis, whether or not words from Sets A and B also appeared as primes had no impact either in the form of main effects or in interactions with other factors ($F < 1$, in all instances). For this reason, we collapsed across these two groups of participants in our discussion of the results in the following section.

Results and Discussion

The speed and accuracy of responses to the prime and probe words were recorded for each trial. The critical dependent variable, however, was the speed and accuracy of response to the probe depending on whether the preceding task was the same or different (task repetition vs. task switch trials) and whether this effect of the prime task depended on the identity of the probe word (mostly task repetition probes vs. mostly task switch probes). The nature of the probe task (animal size vs. animal habitat) also varied across trials. Response times (RTs) that were either less or greater than 3 standard deviations away from the mean (for each participant and within each condition) were discarded as outliers. Across our experiments, this outlier elimination procedure led to the exclusion of less than 3% of RTs from further analysis. In the present experiment and in all subsequent experiments, we also eliminated all trials for which participants responded incorrectly to the prime display. For each condition of Experiment 1, overall mean RTs when participants responded correctly to the probe word and error rates are displayed in Table 1.

We were concerned that our observed costs of task switching might depend on whether response to the prime and probe task required a same versus a different response. Note that switching tasks always required generating a buttonpress response to the probe that differed from the buttonpress response generated to the prime. The keys corresponding to the two categories of animal size differed from the keys corresponding to the two categories of animal habitat. On half of the task repetition trials, however, participants generated the same response to both prime and probe displays. For example, supposing that both prime and probe tasks required animal size judgments, the presentation of a word representing a small animal in both displays (MOUSE followed by RABBIT) would require participants to make the same response twice. Consequently, differences in performance between task repetition and task switch trials might simply reflect a response repetition benefit originating from 50% of the task repetition trials. In addition, response repetition trials might be entirely responsible for any modulation of task switching costs that we observe as a function of task repetition probability.

Table 1
Mean Response Times (RTs, in Milliseconds) and Proportion of Errors (PE) in Experiment 1 As a Function of Probe Task (Animal Size vs. Animal Habitat), Probe Identity (Mostly Task Repetition Probes vs. Mostly Task Switch Probes), and Prime Task (Same vs. Different)

	Probe Task			
	Animal Size		Animal Habitat	
Prime Task	RT	PE	RT	PE
Mostly Task Repetition Probes				
Same	929	.021	937	.038
Same response	916	.018	907	.033
Different response	941	.025	967	.043
Different	1,163	.046	1,184	.062
Switch cost	−234	−.025	−247	−.024
SE	18.6	.007	19.5	.009
Mostly Task Switch Probes				
Same	938	.021	940	.029
Same response	930	.017	909	.021
Different response	945	.024	972	.036
Different	1,100	.036	1,203	.064
Switch cost	−162	−.015	−263	−.035
SE	18.1	.008	19.9	.008

Note—*SE* represents the between-participants standard error of the mean difference between task repetition and task switch trials.

Although we obtained evidence that response repetition generally speeded performance on task repetition trials, neither the observation of task switching costs nor the impact of task switch probability on task switching costs was significantly influenced by this factor. That is, the statistically significant switching costs and significant effects of task switch probability reported in our Results sections were also significant after removing response repetition trials from our analysis. As a result, for the same task conditions, the analyses we report for both of the experiments reported in the present article were based on the average of same response and different response trials. Even so, for the reader's information, the data tables for both experiments separately present the data for same task–same response and same task–different response trials.

After calculating each participant's mean accurate RTs and their proportion of incorrect responses when responding to the probe for each condition, these data were submitted to separate 2 × 2 × 2 repeated measures ANOVAs, treating task repetition probability (mostly task repetition probes vs. mostly task switch probes), probe task (animal size vs. animal habitat), and prime task (same vs. different) as within-participants factors.

This analysis revealed significant main effects of probe task [$F(1,49) = 8.48$, $MS_e = 13{,}351.88$, $p < .005$] and prime task [$F(1,49) = 234.33$, $MS_e = 21{,}848.12$, $p < .001$]. Participants responded about 33 msec faster when the probe task was animal size than when it was animal habitat (1,033 vs. 1,066 msec) and about 226 msec faster to probe words when the prime and probe tasks were the same than when they differed (937 vs. 1,163 msec). There was also a significant interaction between probe task and prime task [$F(1,49) = 13.60$, $MS_e = 5{,}738.84$, $p < .001$], arising from larger costs of switching from the animal size to the animal habitat task than from the animal habitat task to the animal size task. When the probe task was animal size, probe responses were about 198 msec faster on same-task trials than on different-task trials (934 vs. 1,132 msec) [$F(1,49) = 153.47$, $MS_e = 12{,}816.08$, $p < .001$], whereas when the probe task was animal habitat, probe responses were about 255 msec faster on same-task trials than on different-task trials (939 vs. 1,194 msec) [$F(1,49) = 218.73$, $MS_e = 14{,}770.88$, $p < .001$].

The most critical question was whether task repetition probability would contribute to the magnitude of task switching costs. Our analysis revealed a significant three-way interaction between task repetition probability, probe task, and prime task [$F(1,49) = 9.64$, $MS_e = 4{,}930.78$, $p < .005$]. This interaction originated from an effect of task repetition probability on switching costs when the probe task required a judgment of animal size that was not observed when the probe task required a judgment of animal habitat.

When the probe task required an animal size judgment, there was a significant two-way interaction between task repetition probability and prime task [$F(1,49) = 15.85$, $MS_e = 4{,}019.55$, $p < .001$]. When participants made animal size judgments in response to mostly task repetition probes, performance on task switch trials was 234 msec slower than performance on task repetition trials (1,163 vs. 929 msec) [$F(1,49) = 159.15$, $MS_e = 8{,}603.64$, $p < .001$]. In contrast, when participants made animal habitat judgments in response to mostly task switch probes, performance on task switch trials was only 162 msec slower than performance on task repetition trials (1,100 vs. 938 msec) [$F(1,49) = 80.33$, $MS_e = 8{,}231.99$, $p < .001$]. The task repetition probability of probe words had no effect on task switching costs when the probe task was animal habitat (task switch probability × prime–task interaction, $F < 1$).

In the analysis of error rates, there was a significant main effect of prime task [$F(1,49) = 30.51$, $MS_e = .002$, $p < .001$]: Participants were about 2.5% more likely to make an error on task switch trials than on task repetition trials (.052 vs. .027). There was also a main effect of probe task [$F(1,49) = 21.33$, $MS_e = .001$, $p < .001$], with participants making about 1.7% more errors when the probe task required a judgment of animal habitat than when the probe task required an animal size judgment (.048 vs. .031). The analysis of error rates revealed no other significant main effects or interactions.

Thus, a contingency between the identity of the probe and the requirement to repeat versus to switch tasks influenced the cost of task switching in Experiment 1, but only when the probe task required a judgment of animal size. On those trials, the cost of switching was significantly greater when participants responded to mostly task repetition probes than when they responded to mostly task switch probes. When the probe task required a judgment of animal habitat, participants' difficulty in switching tasks was about the same for probes assigned to the mostly task repetition and the mostly task switch conditions. We elaborate on the implications of these findings in the General Discussion.

EXPERIMENT 2

As mentioned in our introduction, previous studies have demonstrated that stimulus location is an effective cue for eliciting context-specific proportion-congruency effects in the Stroop color-naming task (Crump et al., 2006), as well as in the Eriksen flanker task (Corballis & Gratton, 2003). Drawing a direct analogy to these experiments, the purpose of Experiment 2 was to determine whether location can also act as an effective cue for the likelihood of being required to repeat a task versus switch to a different one. Experiment 2 employed the same basic design as Experiment 1, except the proportion of task repetition versus task switch trials depended on the location in which the probe display appeared. For example, probe displays appearing above fixation might require repetition of the prime task on 75% of trials (mostly task repetition condition). If so, then probe displays appearing below fixation would require repetition of the prime task on only 25% of trials (mostly task switch condition).

As was mentioned previously, it is known that task switching costs can be reduced when each task is presented in a task-specific location (Mayr & Bryck, 2007). However, in our design, the location cue was not predictive of either a specific task or a specific response, but was instead only predictive of the more abstract requirement to either repeat the prime task or switch to the alternative task. We conducted Experiment 2 as a means of investigating whether the magnitude of task switching costs observed would partly depend on this association between probe location and the requirement to switch tasks across trials.

Method

Participants. Eighteen students who were enrolled in an Introduction to Psychology course at the University of Manitoba participated in this study in exchange for course credit. All participants had normal color vision and normal or corrected-to-normal visual acuity.

Apparatus and Stimuli.The apparatus and stimuli of Experiment 2 were identical to those of Experiment 1.

Procedure. The sequence of events occurring on each trial of Experiment 2 was identical to that of Experiment 1, except that the probe word and probe task cues appeared in the top right-hand corner of the screen on half of the trials, whereas it appeared in the bottom right-hand corner of the screen on the other half of trials. The appearance of the probe display in each of these locations occurred randomly across trials. Participants were required to make a judgment of animal size or animal habitat on an equal proportion of trials, whether the probe display appeared to the top or bottom of the screen. However, for 9 of the participants, the appearance of a probe display in the top location required repetition of the prime task on 75% of trials and a task switch on 25% of trials. In contrast, these participants were required to repeat the prime task on only 25% of trials when the probe display was presented to the bottom location. Probes appearing at the bottom location required a switch to the alternative task on the remaining 75% of trials. This association between the probe's location and the requirement to switch tasks was reversed for the remaining 9 participants.

Results and Discussion

For each condition of Experiment 2, overall mean RTs when participants generated a correct response to the probe task, along with the proportion of incorrect responses to the probe word, are displayed in Table 2.

Each participant's mean accurate RTs and error rates were submitted to separate 2 × 2 × 2 repeated measures ANOVAs, treating task repetition probability (mostly task repeated location vs. mostly task switch location), probe task (animal size vs. animal habitat), and prime task (same vs. different) as within-participants factors.

In the analysis of RTs, we observed a significant prime task × probe location interaction [$F(1,17) = 6.19$, $MS_e = 2{,}687.32$, $p < .05$], arising from larger costs of task switching when the probe's location was associated with a greater likelihood of repeating the prime task than when the probe's location was predictive of a task switch. When the probe's location was assigned to the mostly task repetition condition, probe RTs on task switch trials were about 201 msec slower than probe RTs on task repetition trials (1,129 vs. 928 msec) [$F(1,17) = 95.13$, $MS_e = 57{,}597.95$, $p < .001$]. In the mostly task switch condition,

Table 2
Mean Response Times (RTs, in Milliseconds) and Proportion of Errors (PE) in Experiment 2 As a Function of Probe Task (Animal Size vs. Animal Habitat), Task Switch Probability (Mostly Task Repetition Location vs. Mostly Task Switch Location), and Prime Task (Same vs. Different)

	Probe Task			
	Animal Size		Animal Habitat	
Prime Task	RT	PE	RT	PE
Mostly Task Repetition Location				
Same	915	.031	941	.046
Same response	900	.034	915	.039
Different response	931	.029	966	.053
Different	1,077	.044	1,180	.073
Switch cost	−162	−.013	−239	−.027
SE	26.3	.009	33.7	.017
Mostly Task Switch Location				
Same	940	.026	970	.031
Same response	908	.019	936	.025
Different response	971	.033	1,005	.036
Different	1,056	.053	1,163	.064
Switch cost	−116	−.027	−193	−.033
SE	22.6	.011	34.2	.012

Note—*SE* represents the between-participants standard error of the mean difference between task repetition and task switch trials.

however, probe RTs on task switch trials were only about 155 msec slower than probe RTs on task repetition trials (1,110 vs. 955 msec) [$F(1,17) = 36.79$, $MS_{\text{e}} = 11{,}711.81$, $p < .001$].

There was also a significant interaction between probe task and prime task [$F(1,17) = 6.13$, $MS_{\text{e}} = 8{,}791.46$, $p < .05$], so that the cost of switching to the animal habitat task was greater than the cost of switching to the animal size task. When the probe task required a judgment of animal habitat, participants were about 216 msec slower on task switch trials than on task repetition trials (1,172 vs. 956 msec) [$F(1,17) = 48.32$, $MS_{\text{e}} = 17{,}420.17$, $p < .001$]. When the probe task was animal size, participants were only about 139 msec slower on task switch trials than on task repetition trials (1,067 vs. 928 msec) [$F(1,17) = 43.42$, $MS_{\text{e}} = 7{,}993.73$, $p < .001$]. We observed no other significant main effects or interactions.

In the analysis of error rates, the only significant effect was a main effect of prime task [$F(1,17) = 11.23$, $MS_{\text{e}} = .002$, $p < .005$]; participants made an error on about 2.2% more task switch trials than task repetition trials (.055 vs. .033). The analysis of error rates produced no other significant main effects or interactions.

As in Experiment 1, switching costs were greater in Experiment 2 when the probe task required a judgment of animal habitat than when it required a judgment of animal size. Even so, unlike the effect of task switch probability on switching costs in Experiment 1, our manipulation of task switch probability based on probe location influenced switching costs independent of the nature of the probe task. If the cost of switching tasks is relatively weak—as it was when our participants switched from the animal habitat to the animal size task—it appears that a contingency between the requirement to switch tasks and either the probe's identity or the probe's location will have an impact on the magnitude of switching costs. In contrast, when the cost of switching is stronger—such as it was when our participants were required to switch from the animal size to the animal habitat task—only the location of the probe appears capable of modulating the size of switching costs on the basis of its association with the requirement to switch tasks.

We favor an explanation of this difference on the basis of a number of previous studies demonstrating that—as a more primitive stimulus property—location perception occurs more rapidly than the perception of stimulus identity (Grill-Spector, 2003; Johnston & Pashler, 1990; Treisman & Gelade, 1980). This relative ease of accessing stimulus location matters most when the cost of switching tasks is especially potent. In that case, participants' use of a feature of the probe display to predict the requirement to switch tasks must be accessed more rapidly to have any impact on reducing interference from having just performed a different prime task. In contrast, participants may rely on a more slowly accessed feature of the probe display to reduce the negative effect of having just performed a different probe task only when the baseline cost of task switching is somewhat lower.

GENERAL DISCUSSION

In two experiments, we demonstrated that the magnitude of task switching costs can depend on whether some feature of the probe display was predictive of a requirement to switch versus repeat the prime task. In Experiment 1, across experimental trials, the identity of the probe word was predictive of either a task repetition or a task switch. The outcome was that the cost of switching tasks was significantly larger for responding to probe words that were most often associated with repetition of the prime task, but only when the probe task required a judgment of animal size.

This finding provided partial evidence that participants can rapidly take advantage of a feature of the probe display as a way to modulate the contribution of the preceding prime event. We presume that, upon onset of the probe display, participants' identification of the probe word provided them with knowledge about the likelihood that they would be required to switch tasks on the basis of their experience with previous trials. When the probe word predicted a task repetition, participants allowed processes associated with the prime task to contribute more to their performance of the probe task, increasing the impairment observed on task switch trials. When the probe word predicted a task switch, however, participants used this association to reduce the contribution of the prime event to their performance of the probe task. The consequence was that the prime task was less of a source of interference on task switch trials, reducing the size of the switch costs we observed.

The association between probe word identity and the probability of task repetition did not contribute to task switching costs when the probe task required a judgment of animal habitat in Experiment 1. We suggest that this asymmetric influence of task repetition probability on the performance of our animal size and animal habitat tasks reflects a difference in the baseline cost of switching from one of these tasks to the other. Across our experiments, participants had significantly greater difficulty switching from the animal size task to the animal habitat task as compared with when they were required to perform the reverse task switch. Given the more potent source of interference that participants were required to overcome when switching from the animal size to the animal habitat task, we propose that accessing knowledge of the probe word's identity was too time consuming for participants to use probe identity as a basis of modulating the influence of the prime event. The results of our Experiment 2 provided evidence in support of this idea.

In Experiment 2, the probe word and task cues appeared at a location either above or below the location previously occupied by the prime word and task cues. One of the probe locations (top or bottom) predicted the requirement to perform the prime task again in response to the probe display, whereas appearance of the probe in the opposite location was associated with the requirement to switch to the alternate task. In consequence, task switching costs were higher when the probe display appeared in a location that was primarily associated with task repetitions than when the probe display appeared in a location that most frequently involved the requirement to switch tasks. In this case, this modulation of the size of task switching costs was true whether the probe task was animal size or animal habitat. We suggest that participants can access information about probe location with much greater speed than they can access information about probe identity. As a result, regardless of the nature of the task switch required, participants were able to use probe location to modulate the contribution of the prime task to performance of the probe task.

The results of the present study are consistent with an experiment recently described by Mayr and Bryck (2007). In their study, participants identified either the color (red vs. green) or the orientation (horizontal vs. vertical) of a rectangle. In one block of trials, all rectangles appeared to the left, requiring participants to perform both tasks in response to rectangles presented to the same location. In another block of trials, participants always performed the color identification task in response to rectangles presented in one location (e.g., the left), and always performed orientation judgments in response to rectangles presented to the opposite location (e.g., the right). The consequence was that task switching costs were substantially reduced when the location that rectangles appeared in always required participants to perform one task and not the other. Mayr and Bryck argued that participants, in some sense, outsourced control over task performance to contextual properties of the display. In other words, a reduction in switch costs was assumed to occur because the processing of incidental location cues allowed for the rapid reinstatement of task sets associated with those locations.

The present study can be thought of as an extension of this finding. However, there are important differences between our demonstration and that of Mayr and Bryck (2007). Specifically, in our Experiments 1 and 2, features of the probe display (probe identity in Experiment 1 and probe location in Experiment 2) were not more highly associated with performance of one task as opposed to the other. Instead, the magnitude of task switching costs in our experiments depended on an association between features of the probe display and the likelihood of being required to perform a task repetition versus a task switch. Apparently, processing features of the probe can trigger a somewhat more abstract process involved in controlling the extent to which information in a prime display and/or the processes engaged in during that event guide performance of the probe task. Indeed, as in the Mayr and Bryck study, the results of our Experiments 1 and 2 revealed that people can rapidly use features exclusive to a current stimulus display as a basis for predicting the requirement to switch tasks, revealing an influence on task switching costs that has rarely been the focus of research until quite recently.

Consciously Controlled Task-Set Reconfiguration Processes

Many investigations of task switching costs have emphasized the role of task-set reconfiguration processes that act to reduce task switching costs when the probe task is known and when there is a sufficient time interval between the performance of the prime task and the requirement to perform an alternative task (Dreisbach & Haider, 2006; Dreisbach et al., 2002; Goschke, 2000; Hübner, Dreisbach, Haider, & Kluwe, 2003; Meiran, 1996; Meiran et al., 2000; Monsell et al., 2000; Rogers & Monsell, 1995). Such deliberate engagement of a task-set configuration process cannot account for our observation that task switching costs can depend entirely on features of the probe display. Instead, these influences on the magnitude of task switching costs must reflect a rapid modulation of the contribution of processes occurring during the prime event to performance of the probe task. The present findings implicate an automatic influence on task switching costs rather than a modulation of endogenous task-set configuration processes. In particular, we suggest that participants in our experiments accessed memory representations for their completion of prime and probe tasks on previous trials. These previous experiences contained knowledge about the circumstances in which processes engaged during the prime event tend to be helpful and when they tend not to be helpful. In turn, this knowledge guided the degree that performance of the preceding prime task contributed to performance of the present probe task.

In our introduction, we described the types of exogenous influences that theorists have identified as being the most likely sources of impairment in task switching experiments. Specifically, we identified task-set activation/inhibition, task-cue priming, and episodic retrieval processes as potential exogenous sources of task switching costs. With our procedure, we can rule out a contribution of task-cue priming effects. The associations we created between probe display features and the requirement for participants to switch tasks were perfectly orthogonal to whether the prime and probe task cues were the same or different. Consequently, in the following sections, we will discuss the implications of our results for the remaining two approaches. Both of these approaches offer clues as to how knowledge acquired on previous trials could allow participants to rapidly modulate the contribution of the prime event during their performance of the probe task.

Implications for Task-Set Activation/Inhibition Influences on Task Switching Costs

A number of researchers have suggested that task switching costs arise from the combined influence of activation of the prime task set and inhibition of the task set associated with the probe task at the time of the prime event (Allport et al., 1994; Mayr, 2002; Meuter & Allport, 1999; Monsell et al., 2000; Yeung & Monsell, 2003). From this perspective, task switching costs provide a measure of the length of time it takes participants to overcome either prior interference from a previously activated task set or prior inhibition of the task set that must be engaged in order to correctly respond to the probe display. Our observation that probe identity and probe location can modulate the size of task switching costs represents an influence that is independent of the amount of task-set activation and inhibition that occurs at the time of the prime event.

To accommodate our results, adoption of a task-set activation/inhibition approach to task switch costs must allow for participants to rapidly modify the activation or inhibition of task-set representations "on the fly" when the probe display appears. Such flexible control over the underlying activation of task-set representations has been proposed elsewhere. For instance, in a recent study, Philipp and Koch (2006) manipulated whether or not task repetition could occur in a procedure designed to measure set alternation costs.

In the critical trials of experiments used for measuring set alternation costs (see also Arbuthnott & Woodward, 2002; Mayr, 2002; Mayr & Keele, 2000; Schuch & Koch, 2003), participants perform two different tasks in response to successive displays. In response to a third event (the probe task), participants would be required to perform the first task again or some other task that differs from the preceding two tasks. The typical finding in these studies is that, in comparison with no alternation trials in which participants perform three different tasks in succession, performance of the probe task is significantly slower when that task is the same as Task 1 (often referred to as *set alternation* trials). This result is frequently interpreted as being an instance of backward inhibition, in that participants must inhibit the task set associated with their response to the first display to facilitate their performance of a different task in response to the second display. As a consequence of this backward task-set inhibition, participants are impaired in their performance of T1 in response to the third display. Using this procedure, Philipp and Koch (2006) observed a reduction in the set alternation cost when it was possible for task repetitions to occur across an experimental session or within blocks of trials within an experimental session. In explaining these results, they suggested that participants modify the balance of activation and inhibition of a recently performed task set, depending on their likelihood of being required to perform the same task in response to the following display.

Note, however, that participants' imposition of a general, experiment-wide adjustment in the activation/inhibition of task-set representations cannot account for the results of the present study. In Experiment 1, the identity of the probe varied randomly across trials, as did the location of the probe display in Experiment 2. Thus, if probe-specific task switching costs reflect variations in the degree of activation or inhibition that participants apply to task-set representations, then these adjustments must rapidly occur after initiation of the probe event. Following a suggestion by Koch (2001), perhaps the pattern of switching costs observed in our study reflects the relative activation of our two alternative task sets and that the magnitude of switching costs depends on how much the irrelevant task must be inhibited before the relevant task can be performed. That is, a probe display that predicts the need to repeat the prime task might cause increased activation of the prime task set. The outcome would be enhanced performance on task repetition trials and particularly impaired performance on task switch trials. Conversely, a probe display that predicts the need to switch tasks might cause inhibition of the prime task set, contributing a source of impairment to performance on task repetition trials and a source of facilitation to performance on task switch trials.

Implications for Episodic Retrieval Influences on Task Switching Costs

Our observation that the magnitude of impairment on task switch trials can depend on processes exclusive to the probe event is quite consistent with episodic retrieval approaches to task switching costs in particular (Allport & Wylie, 2000; Leboe et al., 2005; Rothermund et al., 2005; Waszak et al., 2003, 2004, 2005; Wong & Leboe, in press; Wylie & Allport, 2000), and to immediate priming effects, more generally (Bodner & Masson, 1997, 2001; Hommel, 1998, 2004; Hommel et al., 2001; Joordens & Becker, 1997; Leboe et al., 2006; Leboe et al., 2005; Masson & Bodner, 2003; Milliken et al., 1998; Neill, 1997; Neill & Mathis, 1998; Ratcliff & McKoon, 1988; Tenpenny, 1995; Whittlesea & Jacoby, 1990). As it applies to the domain of task switching, impairment on task switch trials might originate from the retrieval of an episodic representation for the prime event at the time of the appearance of the probe display. Retrieval of the prime episode engages cognitive operations and/or responses associated with the prime event that are not appropriate for performance of a different probe task. The patterns of task switching costs observed in the present study are consistent with this theoretical perspective. For example, when the task is to judge an animal's habitat, the retrieval of processes associated with having just made an animal size judgment effectively leads people astray from their current goal.

Adopting an episodic retrieval approach to task switching costs, our experiments offer the possibility of a higher level of influence on the retrieval of processes engaged during the prime episode. They demonstrate that the degree of interference that occurs on task switch trials (or the amount of facilitation occurring on task repetition trials) can depend on a previously established contingency between an attribute of the probe display and the requirement to repeat versus switch tasks. That is, when the probe display appears, our experiments provide a demonstration that memory representations generated during preceding experimental trials may themselves be capable of either promoting or discouraging the retrieval of processes associated with the prime task.

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