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The Target of Task Switching

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Task switching involves processing target stimuli in accordance with a frequently changing series of tasks. An outstanding issue is whether this processing is tailored to the perceptual or categorical representation of targets. To address this issue, the authors compared switch costs in responding to targets that were perceptually distinct (words and images) but associated with the same categories (colors and shapes). In four experiments that varied the degree to which words and images were mixed together, no differences in switch costs were observed. These results support the idea that categorical target representations are central to task switching.

Keywords: task switching, switch cost, categorical representation, target encoding

Task switching involves processing target stimuli in accordance with a frequently changing series of tasks. How this feat is accomplished is a matter of debate, but there are models of task switching (e.g., Altmann & Gray, 2008; Gilbert & Shallice, 2002; Meiran, Kessler, & Adi-Japha, 2008; Schneider & Logan, 2005, 2009; Sohn & Anderson, 2001) that specify not only how task switching occurs, but also how tasks are performed (i.e., how targets are processed to generate responses).

An important issue concerns the level at which targets should be represented in a model. In this article we distinguish between two levels of representation: perceptual and categorical. A perceptual representation is one in which the model codes for the perceptual attributes of the target. For example, the perceptual representation of a colored shape target would be coded in terms of chromatic and geometric properties. A categorical representation is one in which the model codes for the task categories associated with the target. For example, the categorical representation of a colored shape target would be coded in terms of color and shape categories (e.g., blue and circle).

Existing models of task switching assume that targets are represented categorically (e.g., Altmann & Gray, 2008; Gilbert & Shallice, 2002; Meiran et al., 2008; Schneider & Logan, 2005, 2009; Sohn & Anderson, 2001). This assumption is a virtue in that it allows these models to be applied to different target types. However, this virtue may be a vice if task switching is actually tailored to the perceptual representation of targets. In this case, models would lose considerable generality because they would have to be specialized for different target types. Thus, determining the nature of the target representation involved in task switching is important for assessing the generality of models.

How can one distinguish between perceptual and categorical target representations? One way is to compare task-switching performance for target types that are perceptually distinct but associated with the same categories. The performance measure used in the present study was switch cost—slower performance for task switches than for task repetitions. We compared switch costs when switching between color (red, green, or blue) and shape (circle, triangle, or square) tasks for two target types: words and images. Examples of each target type are shown in Figure 1. Word targets were pairs of words denoting colors and shapes (e.g., *red triangle*). Image targets were irregularly shaped color patches beside white-outlined shapes. Each task was signaled by one of two cues, enabling three types of task transitions across trials: task switches (cue and task both switch), task repetitions (cue switches but task repeats), and cue repetitions (cue and task both repeat). We define switch cost as the difference between task switches and task repetitions to avoid confounding task switching with cue switching (Logan & Bundesen, 2003; Schneider & Logan, 2005, 2007).

We predicted different patterns of switch costs depending on whether targets are represented perceptually or categorically for the purposes of task-switching performance. If perceptual representations are used and task switching is tailored to those representations, then switch costs should differ between word and image targets. This prediction is based on the assumption that for image targets, the cognitive system would have to be set to process chromatic properties when switching to the color task and geometric properties when switching to the shape task, whereas for word targets, the system would have to be set to process orthography regardless of the task. If it takes time to switch between chromatic and geometric target representations, then switch cost is likely to be larger for images than for words. In contrast, if categorical representations are central to task switching, then switch costs should be the same for word and image targets because they involve the same categories (colors and shapes). The cognitive system would not have to be set to process different kinds of representations because task switching would be focused

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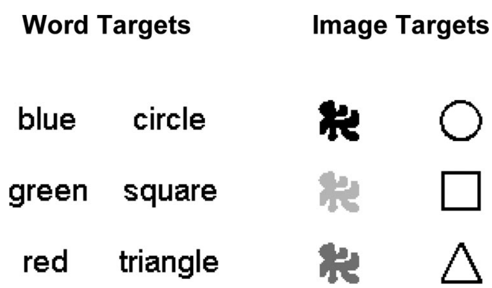

Figure 1. Examples of word and image targets used in the present study. For the color patches of image targets, different colors are represented by different shades of grey.

on the same kind of representation (e.g., color categories) regardless of the target type.

To test these predictions at global (block-wise) and local (trial-wise) levels, our experiments progressed from blocking the target types to intermixing them within a trial. In Experiments 1 and 2, words and images were judged in separate blocks. In Experiment 3, they were mixed within every block, but a given trial included only words or only images. In Experiment 4, half of the blocks replicated Experiment 3, whereas the other half involved trials on which part of the target was a word and the other part was an image (e.g., a color patch beside a shape word). All experiments yielded similar data, so they will be considered together.

Method

Subjects

A total of 128 students (32 per experiment) from Vanderbilt University participated for course credit or $12.

Stimuli

Stimuli were displayed on a monitor with a black background and viewed at a distance of about 50 cm. The cues were *COLOR* and *HUE* for the color task and *SHAPE* and *FORM* for the shape task, each 6 × 17–28 mm. There were two target types (see Figure 1). Word targets consisted of a color word (*red*, *green*, or *blue*) and a shape word (*circle*, *triangle*, or *square*), each 7 × 14–32 mm. Image targets consisted of an irregularly shaped color patch (red, green, or blue) and a white-outlined shape (circle, triangle, or square), each 13 × 13 mm. When each target was displayed, the color and shape parts appeared on the left and right, respectively (separated by 40 mm), except in Experiment 2.

Procedure

Each trial began with a central fixation cross (5 × 5 mm). After 500 ms, the cross was replaced by a cue. After a cue–target interval (CTI), a target appeared 22 mm below the cue. The CTIs were 0, 100, 200, 400, and 800 ms, except in Experiments 2 and 4, where the 100-ms CTI was omitted. Cue and target remained onscreen until the subject responded by pressing a key on the numeric keypad (*1* for green or triangle; *2* for red or square; *3* for blue or circle). A reminder of the response mappings appeared below the screen. After a response, the screen was blank for 500 ms, then the next trial commenced. The cue, CTI, and target for each trial were randomly selected.

Experiment 1 involved judging words and images in separate blocks; target type alternated between blocks. Subjects were informed of the target type at the start of each block. Half of the subjects started with words and half started with images. There were two 45-trial practice blocks and eight 90-trial experimental blocks.

Experiment 2 was identical to Experiment 1 except the left—right spatial positioning of the color and shape parts of each target was randomized such that the task-relevant part of the target appeared in the same position (spatial repetition) or different positions (spatial switch) across trials. There were two 48-trial practice blocks and 10 96-trial experimental blocks.

Experiment 3 involved judging words and images in every block, with the target presented on each trial composed of only words or only images. The number of blocks was the same as in Experiment 1.

Experiment 4 involved judging targets in two types of blocks. Pure-trial blocks were identical to the blocks in Experiment 3. In mixed-trial blocks, the target on each trial consisted of a word and an image (e.g., the word *red* beside an outlined triangle). For analysis, the target type for mixed trials was classified with respect to the task-relevant part of the target (e.g., if the shape task was cued and the target was *red* beside an outlined triangle, the target type would be an image). Subjects were informed of the block type at the start of each block. Half of the subjects started with pure-trial blocks and half started with mixed-trial blocks; block type alternated between blocks. The number of blocks was the same as in Experiment 2.

Results

Practice blocks, the first trial of each block, and trials with response time (RT) exceeding 3,000 ms (1.5% of trials) were excluded. Error trials were excluded from the RT analysis. Mean RT and error rate data were submitted to repeated-measures analyses of variance (ANOVAs) with target type, task transition, CTI, spatial transition (for Experiment 3 only), and block type (for Experiment 4 only) as factors. There were no consistent interactions between target type and CTI; therefore, we focus on results collapsed over CTI. Unless indicated otherwise, all means appearing in parentheses refer to Experiments 1–4, respectively.

Mean RT appears as a function of target type and task transition in Figure 2. There was a main effect of target type in each experiment, all Fs > 102.4, ps $< .001$. RT was longer for words (1,096; 1,092; 1,040; and 1,016 ms) than for images (983; 891; 939; and 954 ms), consistent with previous findings (e.g., Smith & Magee, 1980). In Experiment 4, this difference was smaller for mixed trials (8 ms) than for pure trials (115 ms), $F(1, 31) = 54.8$, $p < .001$. There was a main effect of task transition in each experiment, all Fs > 119.3, ps $< .001$. RT was longer for task switches (1,182; 1,079; 1,102; and 1,079 ms) than for task repetitions (1,030; 981; 978; and 974 ms), which were slower than cue repetitions (908; 914; 890; and 902 ms).

The critical results are whether switch costs differed between words and images. They did not. As shown in Figure 2, differences in switch costs did not exceed 7 ms in any experiment, all Fs < 1. The progressive mixing of target types indicated that it did not

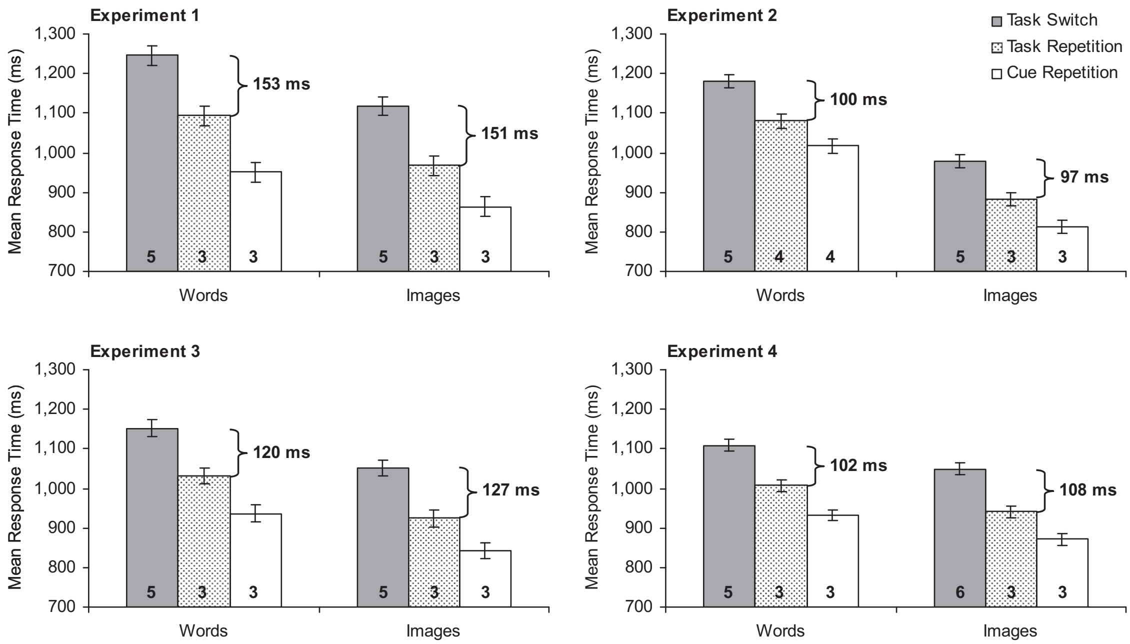

Figure 2. Mean response time as a function of target type and task transition. Bracketed bold values indicate switch costs. Inset bold values indicate error rates. Error bars represent 95% confidence intervals.

matter whether words and images were experienced in separate blocks (Experiments 1 and 2), in the same block on different trials (Experiment 3), or in the same block on different trials or on the same trial (Experiment 4).

In Experiments 1 and 2, all trials involved target-type repetitions because target type was blocked. Consequently, these experiments allowed us to assess global effects of target type on switch costs, and we found no differences in switch costs between words and images. In Experiments 3 and 4, some trials involved target-type repetitions and others involved target-type switches. Consequently, these experiments allow us to assess local effects of target type on switch costs. To this end, we reanalyzed the data from Experiment 3 and the pure-trial data from Experiment 4 with target-type transition as an additional factor. There was a main effect of target-type transition in each experiment, both Fs > 6.7, ps $< .05$. RT was longer for target-type switches than for target-type repetitions in Experiment 3 (997 vs. 980 ms) and in Experiment 4 (994 vs. 959 ms). However, target-type transition did not interact with target type and task transition; for the three-way interaction, $F(2, 62) = 2.7$, $p = .07$, in Experiment 3, and $F < 1$, in Experiment 4. The marginally significant interaction in Experiment 3 reflects a pattern involving differences between task repetitions and cue repetitions that was not replicated in Experiment 4. These results do not provide strong evidence that any local effects of target type on switch costs differed from the global effects observed in Experiments 1 and 2.

In Experiments 1, 3, and 4, the color and shape parts of each target always appeared on the left and right, respectively, conforming to the order in which color and shape words are read in English (e.g., *red triangle* instead of *triangle red*). However, this design choice meant that task switching was correlated with spatial-attention shifting. In Experiment 2, the left—right positioning of the color and shape parts was randomized, allowing us to assess the potential role of spatial-attention shifting. Although there was a cost of shifting spatial attention, $F(1, 31) = 44.6$, $p < .001$, it did not differ significantly between words (41 ms) and images (22 ms), $F(1, 31) = 2.8$, $p = .10$. Moreover, there were still switch costs when spatial transition was held constant and they did not differ significantly between words and images: For spatial repetitions, switch costs were 124 and 101 ms for words and images, respectively, $F(1, 62) = 2.0$, $p = .16$. For spatial switches, switch costs were 75 and 91 ms for words and images, respectively, $F < 1$. These results suggest that the switch costs in the other experiments are not merely spatial-attention shifting effects.

This conclusion receives support from a supplemental experiment in which 32 subjects judged image targets for which the color and shape parts were attributes of different objects (as in Experiments 1–4) or the same object (e.g., a red-filled triangle). In the different-object condition, task switching involved spatial-attention shifting, whereas in the same-object condition, there was no spatial-attention shifting. Switch cost was larger in the different-object condition (130 ms) compared with the same-object condition (65 ms), $F(1, 62) = 42.3$, $p < .001$, indicating a cost of spatial-attention shifting. However, the switch cost in the same-object condition—which can only be attributed to task switching—was significant, $F(1, 62) = 84.6$, $p < .001$, indicating a task-switching effect above and beyond a spatial-attention shifting effect, consistent with the results of Experiment 2.

Mean error rate appears as a function of target type and task transition in Figure 2. There was a main effect of task transition in each experiment, all Fs > 19.6, ps $< .001$. Error rate was higher for task switches (5%) compared with task repetitions and cue repetitions (both 3%). Error rate did not vary consistently in any other way and there was no evidence of speed–accuracy tradeoffs.

Discussion

Four experiments revealed no differences in switch costs between word and image targets, supporting the idea that categorical (rather than perceptual) target representations are central to task switching. Before elaborating on this conclusion, we address some interpretive considerations pertaining to our data.

The argument for categorical target representations is based on null effects. However, the logic of null-hypothesis significance testing is such that a nonsignificant effect—no matter how small—only indicates a failure to reject the null hypothesis; it does not allow one to accept the null hypothesis of no difference. At best, one can conclude that the null hypothesis remains tenable, but this conclusion is not satisfying because the null hypothesis has theoretical importance here.

We addressed this issue in four ways (see Table 1). First, we computed 95% confidence intervals for the mean differences in switch costs between words and images. All intervals include zero and none of the bounds exceed ± 32. Second, using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) we calculated the effect sizes for the differences in switch costs. None of the effect sizes exceed .11 and they are smaller than a "small" effect size of .20 (Cohen, 1988). Third, we calculated likelihood ratios (Glover & Dixon, 2004) by comparing the fits of two models of the data to determine which one was more likely. The additive model assumed main effects of target type and task transition, whereas the interactive model assumed an additional interaction effect (i.e., a difference in switch costs). To account for the interactive model having one more parameter than the additive model, we adjusted each likelihood ratio using the small-sample approximation to the Akaike Information Criterion (see Glover & Dixon, 2004). The likelihood ratios indicate that the fit of the additive model is about 2–3 times more likely than that of the interactive model. Fourth, we computed Bayes factors (Rouder, Speckman, Sun, Morey, & Iverson, 2009) to compare the probability of the data under the null hypothesis of no difference with the probability of the data under the alternative hypothesis of some difference. The Bayes factors indicate that the null hypothesis is 6–7 times more probable than the alternative hypothesis for each experiment. Collectively, the confidence intervals, effect sizes, likelihood ratios, and Bayes factors favor the conclusion that there were no differences in switch costs between words and images.

This empirical support for a categorical target representation is consistent with other work implicating categorical representations in task switching. Arrington and Logan (2004) reported evidence that cues and targets are used to retrieve information from semantic memory to enable task performance. Categorical representations are more conducive to this kind of retrieval than perceptual representations because semantic memory stores categorical information. Arrington, Logan, and Schneider (2007) suggested that the process of cue encoding results in a semantic, categorical representation of the task indicated by the cue. We suggest that the process of target encoding results in a semantic, categorical representation of the target.

We think this conclusion generalizes to most other task-switching experiments because they often involve tasks of a categorical nature, with multiple targets in each category (e.g., judging numbers as odd or even, classifying letters as consonants or vowels, etc.). Given that there was only one target per category in our experiments (e.g., a single exemplar of the circle category), one could argue that our experimental design worked against finding evidence of categorical target representations because subjects could have mapped each target to a response without categorizing it. From that perspective, our results implicating categorical representations are all the more compelling.

We suggest that if the tasks are primarily categorical, then targets are likely to be represented categorically for the purposes of task-switching performance, consistent with existing models (Altmann & Gray, 2008; Gilbert & Shallice, 2002; Meiran et al., 2008; Schneider & Logan, 2005, 2009; Sohn & Anderson, 2001). However, the target representations used for noncategorical tasks and more distinct target types (e.g., targets presented in different modalities) are unclear, suggesting that the present study is merely a first step toward a deeper understanding of representational issues in task switching.

Table 1
Summary Statistics for Evaluating Differences in Switch Costs Between Words and Images

Experiment	M_{Diff}	CI_{Lower}	CI_{Upper}	d	λ	B
1	2	–28	32	.02	3.0	7.2
2	4	–19	26	.06	2.9	6.9
3	–6	–30	17	.11	2.8	6.3
4	–6	–32	20	.08	2.7	6.6
All	–2	–14	11	.03	2.7	13.8

Note. M_{Diff} = mean difference in switch costs between words and images; CI_{Lower} and CI_{Upper} = lower and upper bounds, respectively, of the 95% confidence interval around the mean difference; d = effect size; λ = likelihood ratio; B = Bayes factor.

Résumé

L'alternance de tâche implique de traiter des stimuli dans une série de tâches qui alternent fréquemment. Un enjeu important est de savoir si ce processus est associé à la représentation perceptuelle ou catégorielle des stimuli. Pour étudier cette question, les auteurs ont comparé les coûts d'alternance lorsqu'on répond à des cibles qui sont distinctes sur le plan perceptuel (mots et images), mais associées à une même catégorie (couleurs et formes). Dans quatre expériences où le mélange entre les mots et les images était variable, aucune différence de coût d'alternance n'a été observée. Ces résultats appuient l'idée selon laquelle les représentations catégorielles de la cible sont centrales pour l'alternance de tâche.

Mots-clés : alternance de tâche, coût d'alternance, représentation catégorielle, encodage d'une cible

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