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Separating Cue Encoding From Target Processing in the Explicit Task-Cuing Procedure: Are There "True" Task Switch Effects?

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Six experiments were conducted to separate cue encoding from target processing in explicitly cued task switching to determine whether task switch effects could be separated from cue encoding effects and to determine the nature of the representations produced by cue encoding. Subjects were required to respond to the cue, indicating which cue was presented (Experiments 1, 3a, and 4a) or which task was cued (Experiments 2, 3b, and 4b), before performing the cued task on the target. Cue encoding was successfully separated from target processing when the cue response indicated which task was cued but not when it indicated which cue was presented. Task switch effects were found when this separation was successful, suggesting that there are "true" task switch effects independent of cue encoding. Analysis of the conditions required for successful separation suggested that cue encoding results in a semantic categorical representation of the task to be performed rather than verbal or phonological representations of individual cues. Implications for the authors' past modeling of task-switching performance are discussed.

Keywords: cue encoding, cue representations, target processing, task switching, explicit task-cuing procedure

Task-switching procedures have become popular methods for studying executive control in recent years (Monsell, 2003). The *explicit task-cuing procedure* (Meiran, 1996; Sudevan & Taylor, 1987) is especially popular because it provides close control over the timing of critical processes. Subjects are given a cue on each trial indicating which task to perform on a subsequent target, and they typically perform more slowly and less accurately when tasks alternate on successive trials than when tasks repeat. These *switch costs* tend to decrease as the time between the cue and the target increases, suggesting that some of the processing involved in switching tasks can occur during this preparation interval (e.g., Logan & Bundesen, 2003; Meiran, 1996; Monsell & Mizon, 2006; cf. Altmann, 2004).

Many researchers have interpreted switch costs and their reduction during preparation intervals as evidence for reconfiguration processes that change the task set on switch trials (Meiran, 1996; Monsell & Mizon, 2006; Rogers & Monsell, 1995). Many different components of reconfiguration have been proposed, including shifting spatial or dimensional attention, retrieving goals or stimulus–response mapping rules, adjusting speed–accuracy criteria, and inhibiting prior task sets (for a review, see Monsell, 2003). Some of these components are thought to be endogenous, occurring within the preparation interval, whereas others are thought to be exogenous, occurring only after the target appears. Other researchers have challenged the idea of reconfiguration, interpreting the same results as evidence for priming effects in the processes involved in encoding the cue, suggesting there is no endogenous or exogenous reconfiguration in the explicit task-cuing procedure (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Schneider & Logan, 2005). The resolution of this controversy depends on researchers' ability to separate cue encoding benefits from task switch costs empirically. The present article presents a new variation of the explicit task-cuing procedure that is designed to accomplish this goal.

Previous Findings With the Explicit Task-Cuing Procedure

Switch costs in many explicit task-cuing experiments are difficult to interpret because cue repetition is confounded with task repetition and cue switching is confounded with task switching. Until 2003, all explicit task-cuing experiments used only one cue per task, and with this procedure, the cue repeated whenever the task repeated and the cue changed whenever the task changed. Switch costs could reflect benefits in encoding repeated cues, costs from switching tasks, or both. Logan and Bundesen (2003) and Mayr and Kliegl (2003) addressed this confound by using two cues for each task. This procedural modification results in three transitions across trials: *cue repetitions*, in which the cue and task repeat; *task repetitions*, in which the cue switches and the task repeats; and *task alternations*, in which the cue and task both switch. Previous explicit task-cuing experiments included only cue repetitions and task alternations. This new procedure includes task repetitions,

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which allow cue encoding to be separated from task switching. Logan and Bundesen (2003) found large response time (RT) differences between cue repetitions and task repetitions (*cue switch effects*) and much smaller differences between task repetitions and task alternations (*task switch effects*).[1] Mayr and Kliegl (2003) found substantial cue switch effects, but unlike Logan and Bundesen, they also found substantial task switch effects. Their procedure differed from Logan and Bundesen's in several respects, and subsequent research has shown that task switch effects are larger with arbitrary cues than with meaningful ones (Logan & Bundesen, 2004; Logan & Schneider, 2006a) and are larger when task alternations are rare than when they are frequent (Monsell & Mizon, 2006; Schneider & Logan, 2006).

Logan and Bundesen (2003) interpreted cue switch effects as cue encoding benefits that resulted from repeating the cue on cue-repetition trials. Other researchers have agreed with this interpretation (Arrington & Logan, 2004; Brass & von Cramon, 2004; Mayr & Kliegl, 2003; Monsell & Mizon, 2006). However, there is sharp disagreement over the interpretation of task switch effects. Mayr and Kliegl (2003), Brass and von Cramon (2004), and Monsell and Mizon (2006) interpreted task switch effects as "true" switch costs, which they take as evidence for reconfiguration. We interpret task switch effects as cue encoding benefits from semantic or associative priming and suggest there is no endogenous or exogenous reconfiguration in the explicit task-cuing procedure (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Logan, Schneider, & Bundesen, in press; Schneider & Logan, 2005). Schneider and Logan noted that meaningful word cues that refer to the same task (e.g., *magnitude* and *high–low*) are necessarily related to each other semantically and associatively by virtue of their reference to the same task and so should prime each other when they occur on successive trials. Logan and Schneider (2006b) manipulated the semantic relatedness between cues associated with the same task or different tasks and found clear evidence that semantic associations speeded cue encoding.

Our interpretation of cue switch and task switch effects is articulated in a formal model of performance in explicit task-cuing experiments (Schneider & Logan, 2005), in which subjects perform all of the tasks in the experiment with a single task set. We assume that subjects encode the cue and the target and then put them together to form a compound retrieval cue, which they use to retrieve an appropriate response from memory. For example, if the cue was *odd–even* and the target was *7*, subjects would encode the cue as meaningful words and the target as a meaningful digit and then combine them to form a compound retrieval cue and use it to probe semantic memory. The compound cue would retrieve *odd,* and subjects would execute the response associated with *odd*. We assume that this same task set—encode the cue, encode the target, form a compound retrieval cue, and respond with what it pulls from memory—is used on every trial, so there is no need to switch task sets when tasks change. We assume that cue encoding is affected by repetition priming, which produces cue switch effects, and semantic or associative priming, which produces task switch effects, and we suggest that these priming effects are sufficient to explain task-transition effects in the explicit task-cuing procedure. No reconfiguration, endogenous or exogenous, is required (see also Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Logan & Schneider, 2006a, 2006b; Schneider & Logan, 2005, 2006).

Our interpretation may be sufficient to account for cue switch and task switch effects in the explicit task-cuing procedure, but it is not unique. Mayr and Kliegl (2003) interpreted task switch effects as evidence of exogenous reconfiguration, and Monsell and Mizon (2006) interpreted them as evidence of endogenous reconfiguration (but see Logan et al., in press). The existing data cannot decide between our interpretation and theirs (though our model provides precise quantitative accounts, whereas its competitors provide only qualitative accounts). Thus, one purpose of the present experiments is to develop a new procedure that allows us to separate cue encoding from target processing to determine whether there are task switch effects in target processing that cannot be accounted for in terms of cue encoding. Our interpretation suggests that task switch effects will appear only in cue processing and not in target processing. Mayr and Kliegl's and Monsell and Mizon's interpretations suggested that some task switch effects will also appear in target processing.

Another purpose of the experiments is to determine what is involved in cue encoding. Our model assumes that cue encoding results in a representation that can be used as part of a compound retrieval cue. The compound cue is used to retrieve response categories from semantic or episodic memory (Arrington & Logan, 2004; Schneider & Logan, 2005), so cue encoding must produce a semantic representation. Other theoretical perspectives also predict that cue encoding results in abstract representations. Sohn and Anderson (2001, 2003) assumed that cue encoding produces representations of task goals, which are combined with the target to retrieve appropriate responses. Mayr and Kliegl (2000, 2003) assumed that cue encoding results in retrieval of task rules, which are applied to the target to produce appropriate responses. Our experiments address these predictions by distinguishing between different levels at which cues may be represented and between specific representations of each cue and abstract representations of the judgments or tasks.

Separating Cue Encoding From Target Processing

Explicit task-cuing experiments that use two cues per task allow researchers to separate cue encoding from target processing by subtraction—the difference between cue repetitions and task repetitions measures cue switch effects, and the difference between task repetitions and task alternations measures task switch effects. The subtraction separates the processes logically or theoretically, but not empirically. The RTs that are subtracted include the effects of cue encoding and the effects of target processing, and assumptions are required to motivate the subtraction that separates these processes. Logan and Bundesen (2003) provided another way to separate cue encoding from target processing in their models of the

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[1] We use the terms *cue switch effect* and *task switch effect* throughout this article to describe the contrast between cue repetitions and task repetitions and the contrast between task repetitions and task alternations, respectively. We chose these terms because they are theoretically neutral, describing the results of experimental manipulations (changing the cue or changing the task). Specifically, we do not interpret switch costs as direct evidence for task-set reconfiguration; many other interpretations that do not require task-set reconfiguration are available in the literature, and other evidence beyond the mere observation of task switch effects is necessary to distinguish among them.

time-course functions in explicitly cued task-switching performance, which are produced by varying the preparation interval (stimulus onset asynchrony; SOA) between the cue and the target. According to their analysis,

$$RT = RT_{Base} + \mu\exp(-SOA/\mu), \quad (1)$$

where RT_{Base} is the time to encode the target and to retrieve and produce the response, and μ is cue encoding time, which is modeled separately for cue repetitions, task repetitions, and task alternations. However, like the contrasts between cue repetitions, task repetitions, and task alternations, this analysis separates cue encoding from target processing only logically and theoretically, and not empirically. According to Equation 1, the single RT that is measured includes both cue encoding time and target processing time.

In the present research, we took a more direct approach to separating cue encoding from target processing. We required subjects to respond to the cue before the target was presented and then to respond separately to the target after it appeared. Separate responses to the cue and the target allow us to isolate cue encoding from target processing. Our method exploits the common assumption in the explicit task-cuing procedure that cue processing and target processing are serial. This assumption was made explicit in Logan and Bundesen's (2003) modeling of time-course functions, in the additive relationship between cue encoding time (μ) and RT_{Base} in Equation 1. Our method attempts to carve the explicit task-cuing procedure at its joints, enforcing serial processing by interposing a response when cue encoding purportedly finishes and before target processing begins. For the present, we will assume that enforced serial processing does not alter the normal processing involved in the explicit task-cuing procedure much beyond the extra time required to generate an overt response to the cue. We will return to this issue in the General Discussion.

We will use the transition effects associated with each response to determine whether we have succeeded in separating cue processing from target processing. If we separated cue processing from target processing, then cue RTs should be affected by factors that influence cue encoding and target RTs should be affected by factors that affect target processing. This scenario is illustrated in Panel A of Figure 1. If we failed to separate cue processing from target processing, then cue encoding should "spill over" into the target response and target RTs should be affected by factors that influence cue encoding as well as factors that affect target processing. This scenario is illustrated in Panel B of Figure 1.

Cue switch effects (differences between cue repetitions and task repetitions) are most diagnostic of successful separation because there seems to be consensus in the literature that they reflect cue encoding (i.e., repetition priming from repeated cues; Arrington & Logan, 2004; Brass & von Cramon, 2004; Logan & Bundesen, 2003, 2004; Logan & Schneider, 2006a; Mayr & Kliegl, 2003; Monsell & Mizon, 2006; Schneider & Logan, 2005, 2006). If separation is successful, then cue switch effects should occur in cue RTs but not in target RTs. Significant cue switch effects in target RTs would indicate a failure to separate cue encoding from target processing. Task switch effects could occur with either response. Small task switch effects in cue RTs could reflect semantic or associative priming from related cues (Logan & Schneider, 2006b; Schneider & Logan, 2005, 2006). Task switch effects in target RTs could reflect true switch costs, separate from cue encoding effects. However, task switch effects in target RTs can be interpreted as true switch costs that are independent of cue encoding effects only if there are no cue switch effects in the target RTs.

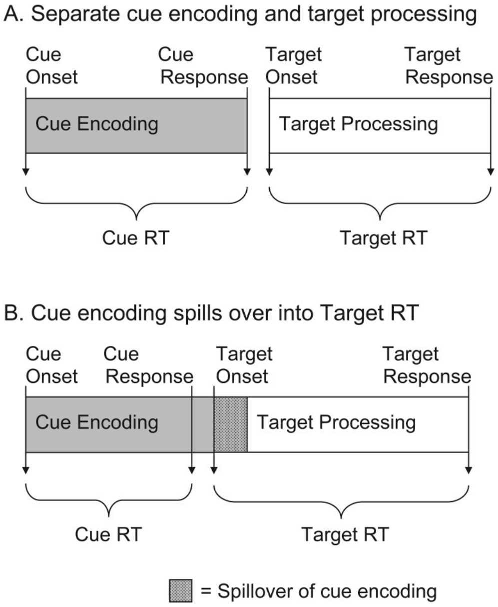

Figure 1. Illustration of cue encoding and target processing stages with their corresponding responses. A: Separate cue encoding and target processing when the cue response occurs at the end of cue encoding. B: Cue encoding spills over into target response time (RT) when the cue response occurs before cue encoding has finished.

The first goal of the present experiments was to separate cue processing from target processing and determine whether there were any task switch effects in target processing. If cue and target processing can be separated successfully, then a task switch effect in target RT would be evidence against Schneider and Logan's (2005; Logan & Schneider, 2006b) priming account of task switch effects. It would falsify the strong claim we made that all transition effects—cue switch effects and task switch effects—reflect priming and that there are no "true" task switch effects in the explicit task-cuing procedure. However, the observation of true task switch effects would not in itself distinguish between reconfiguration accounts (e.g., Mayr & Kliegl, 2000, 2003; Meiran, 1996; Monsell & Mizon, 2006) and accounts that interpret switch costs in terms of positive and negative priming effects induced by the target (Allport & Wylie, 2000; Waszak, Hommel, & Allport, 2003). Further research would be needed to distinguish between those accounts, but at least we would have provided a procedure that can isolate true task switch effects so their causes can be discovered.

On the other hand, if there are no true switch costs when cue and target processing are successfully separated—if cue switch and task switch effects occur only in cue RT processing and not in target RT—then the popular idea that true switch costs can be measured in the explicit task-cuing procedure would be falsified. Such a result would support the strong interpretation of our priming theory and contradict the predictions of endogenous and exogenous reconfiguration theories (e.g., Mayr & Kliegl, 2000, 2003; Meiran, 1996; Monsell & Mizon, 2006) and theories that attribute switch costs to positive and negative priming effects induced by the target (Allport & Wylie, 2000; Waszak et al., 2003).

The second goal of the present experiments was to use our new procedure to examine the nature of cue encoding. Across experiments, we manipulated cue processing by varying the type of response that subjects made to the cue. If the explicit response to the cue requires the same representation that is required for target processing (i.e., compound-cue retrieval; Schneider & Logan, 2005), then cue encoding will be complete before target processing begins. All of the cue encoding processes will be captured in the cue RT, and none of them will spill over into target RT (see Panel A of Figure 1). However, if the explicit response to the cue requires a different representation than the one that is required for target processing, cue encoding will not be complete when the cue response occurs and some of the cue encoding effects will spill over into the target RTs (see Panel B of Figure 1). We assessed the level of representation produced by cue encoding by varying the nature of the response to the cue, ranging from reading the cue aloud, which requires at least a verbal or phonological representation, to pressing arbitrary keys, which requires a second level of representation beyond verbally naming the cue. We varied the cue–response mapping to determine whether cue encoding resulted in a specific representation of each cue or a general representation for each judgment or task. Some experiments required a separate response to each cue (1:1 mapping), and other experiments required a separate response for each judgment or task (2:1 mapping).

Experiment 1: Vocal Cue Responses With 1:1 Cue–Response Mapping

All of the experiments used magnitude (greater or less than 5) and parity (odd or even) judgments of single digits. The cues were meaningful words that either named the task or gave the response mapping: *parity, even–odd, magnitude,* and *high–low*. The first experiment required a simple response to the cue: reading it aloud. This response requires subjects to form a verbal or phonological representation of the cue, which is likely to be part of the natural response to the cue in standard explicit task-cuing experiments. Other representations (lexical, semantic) are likely to be activated as well, but cue RT will depend most strongly on the time required to form a verbal or phonological representation. Emerson and Miyake (2003) showed that articulatory suppression interfered with explicit task-cuing, especially with arbitrary cues, and Goschke (2000) showed that naming a day of the week impaired task-switching performance relative to naming the task to be performed. Thus, a verbal or phonological representation may be a necessary part of cue encoding. In Experiment 1, we asked whether it was sufficient. If it was, then cue switch effects should appear only in cue RTs and not in task RTs. If it was necessary but not sufficient, cue encoding would have to continue after the cue response, spilling over into target processing and prolonging target RT. Reading the cue aloud may also activate lexical and semantic representations of the cue, so Experiment 1 tests the sufficiency of these representations as well. If something beyond phonological, lexical, and semantic representations of individual cue words is required for cue encoding (e.g., retrieving the task associated with the words or forming a compound retrieval cue), then cue switch effects may spill over into target RTs.

Experiment 1 required a unique response for each cue, so there was a 1:1 cue–response mapping. If cue encoding normally results in a specific representation of each cue, then cue switch effects should not appear in target RTs. However, if cue encoding normally results in a general representation of the judgment or task, then cue encoding will not be finished when the unique representation is generated, so cue encoding effects (cue switch effects and, possibly, task switch effects) should spill over into target RTs.

Method

Subjects. Sixteen volunteers from Vanderbilt University participated in Experiment 1 in exchange for course credit or $10. All subjects reported normal or corrected-to-normal vision.

Apparatus and stimuli. The presentation of stimuli and recording of responses were controlled by E-Prime 1.1 software (Psychology Software Tools, 2002) running on a Dell Dimension computer with a Sony Trinitron monitor. Cue responses were made vocally, and RT was recorded with a voice key apparatus produced by Psychology Software Tools. Target responses were made on a standard keyboard with the *j* and *k* keys. Four cues were used, with two cues for each task: *parity, even–odd* (or *odd–even*), *magnitude*, and *high–low* (or *low–high*, with the response label cues spatially compatible with the response keys). The cues were lowercase words, each 9 mm tall and 50 to 73 mm wide. The target stimuli were the digits 1, 2, 3, 4, 6, 7, 8, and 9, each 9 mm tall and 6 mm wide. The cue was presented directly above the center of the screen and the target directly below, with 6 mm separating the two stimuli. All stimuli were presented in black on a light gray background.

Design. Two different timing intervals were manipulated: the time from the response to the target on the previous trial to the onset of the cue on the current trial (the response–cue interval; RCI) and the time from the response to the cue on the current trial and the onset of the target (the response–target interval; RTI). There were four values for each of the timing intervals: 100, 400, 700, and 1,000 ms. Three different task transitions were defined on the basis of the cues presented on trials $n - 1$ and n: cue repetitions, task repetitions, and task alternations. All variables were manipulated within-subjects and within-blocks.

Procedure. Subjects were tested individually in small experimental rooms. The subjects were seated in front of a computer, and viewing distance was not controlled. The experiment began with subjects receiving written and verbal instructions and 20 practice trials for each task individually and, then, for the task-switching procedure. After these practice trials, the experimental trials began.

Each trial involved the presentation of two stimuli and the performance of two responses. Each trial began with the presentation of the cue stimulus. Subjects responded to the cue by reading it aloud. Thus, a unique response was made for each cue, resulting in a 1:1 cue–response mapping. The experimenter was present in the room throughout the experimental session to record the vocal response so that the accuracy of the cue response could be determined. The cue response initiated the RTI, after which time the target appeared below the cue. Both target and cue remained onscreen until the target response was made with the index or middle finger of the right hand. Following the target response, the screen was cleared and remained blank for the appropriate RCI, after which the next trial began. Trials were performed in eight blocks of 64 trials, with self-paced breaks between blocks. The trials were drawn at random without replacement from a pool of 512 trials, generated by crossing the four timing intervals for both RCI and RTI with the four cues and eight targets.

Results

Trials were categorized as cue repetitions, task repetitions, or task alternations. The first trial of each block was excluded because it lacked any transition status. Mean RTs were calculated for cue and target responses as a function of task transition and timing interval, after removing error trials and trials following an error, and all trials on which cue RT or target RT was less than 150 ms or greater than 3,000 ms. RT trimming resulted in the removal of < 1% of the trials. Overall, accuracy was high for both cue (99.6%) and target (97.1%) responses, and there was no evidence of a speed–accuracy tradeoff for either response. Throughout this article, we focus on RT data because the accuracy data were always consistent with the RTs. To simplify presentation of the data, we collapsed across RCI and RTI, which did not produce any informative interactions with task transition in any analysis. Analyses of RCI and RTI effects are presented in Appendix A.

Cue RTs. The mean cue RTs are shown as a function of task transition in Figure 2. Cue RTs were fast overall and showed a cue switch effect. Subjects responded slightly faster to cue repetitions ($M = 588$ ms) than to task repetitions ($M = 611$ ms) and task alternations ($M = 618$ ms). A one-way repeated-measures analysis of variance (ANOVA) showed a significant effect of task transition, $F(2, 30) = 8.7$, $p < .05$, $MSE = 464.8$. Least significant difference (LSD) comparisons showed that the 23-ms difference between cue repetitions and task repetitions was significant, but the 7-ms difference between task repetitions and task alternations was not. These transition effects are small compared with those observed in other experiments using two cues per task (cf. Logan & Bundesen, 2003).

Target RTs. The mean target RTs are shown in Figure 2 as a function of task transition. Target RT was substantially faster to cue repetitions ($M = 707$ ms) than to task repetitions ($M = 807$ ms) and task alternations ($M = 828$ ms). A one-way repeated-measures ANOVA showed a significant effect of task transition, $F(2, 30) = 19.4$, $p < .05$, $MSE = 3{,}429.2$. LSD comparisons showed that the 100-ms difference between cue repetitions and task repetitions was significant but the 21-ms difference between task repetitions and task alternations was not.

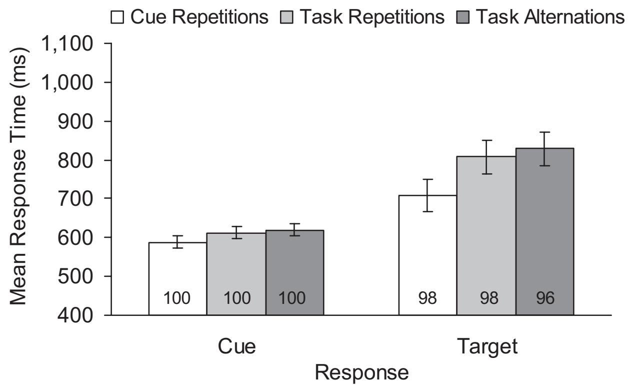

Figure 2. Mean cue and target response times for each task transition in Experiment 1. Error bars represent Fisher's least significant difference for $\alpha = .05$. Mean accuracy is inset within each bar.

Discussion

The effects of task transition in the cue RTs and target RTs suggest that we failed to separate cue encoding from target processing in this experiment. Cue switch effects and task switch effects were both smaller in the cue RTs than in the target RTs. Moreover, there were strong cue switch effects in the target RTs, which should not have occurred if cue encoding finished before the cue response was executed and target processing began. This result suggests that there is more to cue encoding than simply reading the cue. Forming a verbal or phonological representation of the cue may be part of cue encoding, but processes beyond forming a verbal or phonological representation seem to underlie cue switch effects. Reading the cue aloud may have activated lexical and semantic representations of the individual words in the cues, but the data suggest that these representations are not sufficient to account for cue switch effects. The remaining experiments required subjects to respond to the cue in different ways to determine what cue encoding involves beyond forming phonological, lexical, or semantic representations of individual cue words.

Experiment 2: Vocal Cue Responses With 2:1 Cue–Response Mapping

Experiment 2 used the same procedure as Experiment 1 except that subjects named the task associated with each cue instead of reading it aloud. For example, some subjects responded to the cues *parity* and *even–odd* by saying the word "parity," and responded to the cues *magnitude* and *high–low* by saying the word "magnitude." This procedure required subjects to map the two cues for each task onto a single vocal response, which is a 2:1 cue–response mapping instead of the 1:1 mapping in Experiment 1. This cue response may result in a representation that subjects can combine with the target representation to form a compound retrieval cue that retrieves an appropriate response from memory (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Schneider & Logan, 2005).

We used two different types of vocal responses, corresponding to the two types of cues: task names and response mappings. Half of the subjects were instructed to say the task names (*parity* and *magnitude*), and half of the subjects were instructed to say the response mappings (*even–odd* or *high–low*; the exact responses depended on the spatial organization of the response mappings).

Method

Subjects. Subjects were drawn from the same pool and met the same criteria as in Experiment 1. Nineteen subjects participated in Experiment 2. Data from 3 subjects were removed because of failure to meet a 90% accuracy criterion.

Apparatus, stimuli, and procedure. Apparatus and stimuli for Experiment 2 were identical to Experiment 1. The procedure was the same except for the vocal responses that were made to the cue. There were two responses for the four cues, producing a 2:1

cue–response mapping. Half of the subjects responded by saying the task name (i.e., *parity* or *magnitude*), and half of the subjects responded by saying the response mapping (i.e., *even–odd* or *low–high*).

Results

Trials were sorted by transition and included in the analyses with the same procedure as in Experiment 1. RT trimming resulted in the removal of < 1% of the trials. Again, accuracy was high for cue (98.8%) and target (97.9%) responses, and there was no evidence of a speed–accuracy tradeoff for either response, leading us to focus on the RT data. Analyses of RCI and RTI effects are presented in Appendix B.

Cue RTs. Figure 3 shows the mean cue RTs as a function of transition. Cue RTs were longer than in Experiment 1, perhaps because of the 2:1 cue–response mapping. Task transition had a large effect on cue RT. Cue repetitions (M = 632 ms) were much faster than task repetitions (M = 778 ms) and task alternations (M = 763 ms). Finding that task repetitions are slower than task alternations is unusual (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Logan & Schneider, 2006a, 2006b; Monsell & Mizon, 2006; Schneider & Logan, 2005, 2006). It suggests that subjects found it hard to repeat a vocal response when the cue changed from the previous trial. This reversal will be considered more fully below. The cue RT data were analyzed in a one-way repeated-measures ANOVA, yielding a significant task-transition effect, $F(2, 30) = 85.7$, $p < .05$, $MSE = 1{,}200.1$. LSD comparisons showed that the 146-ms difference between cue repetitions to task repetitions was significant, but the 15-ms difference between task repetitions and task alternations was not.

Target RTs. Figure 3 also shows the mean target RTs as a function of transition. As before, cue repetitions (M = 700 ms) were faster than task repetitions (M = 732 ms) and task alternations (M = 817 ms), but the pattern was different from Experiment 1. The cue switch effect in Experiment 2 was much smaller than the cue switch effect in Experiment 1, suggesting that we were successful in isolating cue encoding effects in the cue responses. Target RTs were analyzed in a one-way repeated-measures ANOVA, which revealed a significant effect of task transition, $F(2, 30) = 59.8$, $p < .05$, $MSE = 4{,}151.3$. LSD comparisons showed that the 32-ms difference between cue repetitions and task repetitions was not significant but the 85-ms difference between task repetitions and task alternations was significant.

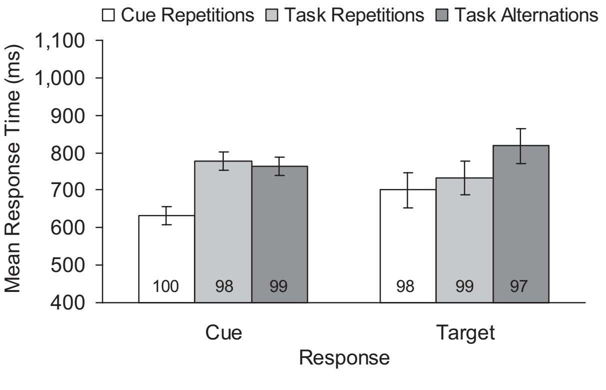

Figure 3. Mean cue and target response times for each task transition in Experiment 2. Error bars represent Fisher's least significant difference for $\alpha = .05$. Mean accuracy is inset within each bar.

Cue–response compatibility effects. The design of Experiment 2 allowed us to evaluate the compatibility of the mapping between cues and cue responses. Subjects either named the task or the response mapping. Thus, subjects could simply read one of the cues for each task (a *compatible* response), but they had to recode the other cue to produce an appropriate response (an *incompatible* response). For example, subjects who named tasks could simply read *magnitude* but would have to recode *high–low* to say "magnitude." We found that cue RT was dramatically affected by cue–response compatibility. RT was substantially faster for compatible responses (M = 640 ms) than for incompatible responses (M = 812 ms), and compatibility interacted with task transition. For compatible responses, cue RTs were faster for cue repetitions (M = 597 ms) than for task repetitions (M = 659 ms) and task alternations (M = 663 ms), which did not differ from each other. However, for incompatible responses, cue RTs remained fast for cue repetitions (M = 668 ms), but task repetitions (M = 903 ms) were slower than task alternations (M = 863 ms). These effects were assessed in a 2 (cue–response compatibility: compatible, incompatible) × 3 (task transition: cue repetition, task repetition, and task alternation) repeated-measures ANOVA. Compatibility had a significant main effect, $F(1, 15) = 99.3$, $p < .05$, $MSE = 7{,}160.2$; and interacted significantly with task transition, $F(2, 30) = 56.7$, $p < .05$, $MSE = 1{,}160.7$.

The cue–response compatibility effects also allow us to determine how successful we were in separating cue encoding from target processing. If we were successful, then cue–response compatibility should affect cue RT but not target RT. The data suggest we were successful. A 2 (cue–response compatibility: compatible, incompatible) × 3 (task transition: cue repetition, task repetition, and task alternation) repeated-measures ANOVA on the target RT data showed no significant main effect of cue–response compatibility, $F(1, 15) = 2.9$, $p > .1$, $MSE = 4{,}110.8$; and no interaction with task transition, $F(2, 30) < 1$, $MSE = 1{,}806.1$.

Comparisons with Experiment 1. Experiments 1 and 2 differed only in terms of the responses to the cue. Subjects in Experiment 1 simply read the cues, whereas subjects in Experiment 2 had to map the cues onto a single cue response. The cue and target RTs in Figures 2 and 3 show that this small change in procedure had a marked effect on performance. In Experiment 1, cue switch and task switch effects were both small for cue responses, and cue switch effects were large for target responses. In Experiment 2, there was a large cue switch effect and a small task switch effect for cue responses, and a small cue switch effect and a large task switch effect for target responses. We evaluated these differences in 2 (experiments: 1 vs. 2) × 3 (task transition: cue repetition, task repetition, and task alternation) mixed-measures ANOVAs for cue and target RTs. For cue RTs, experiment had a significant main effect, $F(1, 30) = 12.6$, $p < .05$, $MSE = 26{,}843.8$; and interacted significantly with task transition, $F(2, 60) = 41.0$, $p < .05$, $MSE = 832.4$. For target RTs, experiment did not have a significant main effect, $F(1, 30) = 0.26$, $p > .6$, $MSE = 87{,}969.8$; but it interacted significantly with task transition, $F(2, 60) = 5.1$, $p < .05$, $MSE = 2{,}245.6$.

Discussion

Task transitions had different effects on cue RTs and target RTs. Cue switch effects were large in cue RTs and small in target RTs, suggesting that we had better success in isolating cue encoding in cue responses than we had in Experiment 1. Task switch effects were small in cue RTs and larger in target RTs, suggesting that there are true switch costs independent of cue encoding effects (cf. Schneider & Logan, 2005).

This pattern of results was significantly different from the pattern in Experiment 1, in which cue switch and task switch effects were both weak in cue RTs and cue switch effects were strong in target RTs. We attribute these differences to differences in the responses to the cues. Experiment 2 required a semantic representation that mapped both cues onto one response. Experiment 1 required a phonological representation (and perhaps a lexical and semantic representation) of each cue, which may be a necessary but insufficient step toward forming the semantic representation of the task required for processing the target. Further processing may have been necessary to generate the required semantic representation. Another possibility is that Experiment 1 required a separate, specific representation of each cue (i.e., a 1:1 mapping), which may not have been general enough to enable target processing. Further processing may have been necessary to generate a more abstract representation that encompasses both cues. A third possibility is that both factors were responsible for producing the difference in results. Experiments 3a and 3b were designed to distinguish between these alternatives.

Experiments 3a and 3b: Manual Cue Responses

Experiments 3a and 3b replicated the first two experiments with keypress cue responses instead of vocal cue responses. Experiment 3a was like Experiment 1: Subjects identified the cue by pressing a separate key for each cue (i.e., 1:1 cue–response mapping). Experiment 3b was like Experiment 2: Subjects identified the task indicated by the cue, pressing one key for one task and another key for the other task (i.e., 2:1 cue–response mapping). The contrast between Experiments 3a and 3b allowed us to distinguish between levels of representation (verbal or phonological vs. semantic) and the specificity of representation (specific for 1:1 mapping; general for 2:1 mapping) as explanations of the differences between Experiments 1 and 2. If specificity of representation was the critical factor, then Experiment 3a should produce results like Experiment 1 because both used a 1:1 mapping, and Experiment 3b should produce results like Experiment 2 because both used a 2:1 mapping. However, if the level of representation required to respond to the cue was the critical factor, then both Experiments 3a and 3b should produce results like Experiment 2 because neither experiment allows subjects to respond after forming a simple verbal or phonological representation of the cue. Both sets of cue responses are arbitrary and so require more abstract representations.

Method

Subjects. Subjects were drawn from the same pool and met the same criteria as Experiment 1. Eighteen volunteers participated in Experiment 3a, with data from 2 subjects discarded because they failed to meet the 90% accuracy cutoff; 17 volunteers participated in Experiment 3b, with data from 1 subject discarded for low accuracy.

Apparatus, stimuli, and procedure. The stimuli were the same as in the previous experiments. The voice key apparatus was no longer used, and the procedure was altered slightly from the previous experiments. The responses to cues and targets were both made on a standard keyboard with the home row (*a, s, d, f, j, k, l,* and ;). Responses to cues and targets were made with different hands. In Experiment 3a, the cue–response mapping was 1:1: Each of the four cues was mapped onto one of the four keys to be pressed with the fingers of the left or right hand. For half of the subjects, the two responses for the two cues for a single task (e.g., *parity* and *even–odd*) were mapped to adjacent keys; for half of the subjects, they were mapped to nonadjacent keys. In Experiment 3b, the cue–response mapping was 2:1: The two cues for each task were mapped onto a single key.

Results

Trials were sorted into task-transition conditions and trials were excluded from RT analyses by the methods used in the earlier experiments. RT trimming resulted in the removal of $< 2\%$ of the trials in Experiment 3a and $< 3\%$ of the trials in Experiment 3b. Overall, accuracy was high for cue (97.9% and 97.8%) and target (97.5% and 97.7%) responses for Experiments 3a and 3b, respectively, and there was no evidence of a speed–accuracy tradeoff. Analyses of RCI and RTI effects are presented in Appendix C.

Experiment 3a: Cue RTs. The top panel of Figure 4 shows cue RTs as a function of task transition. Cue repetitions ($M = 620$ ms)

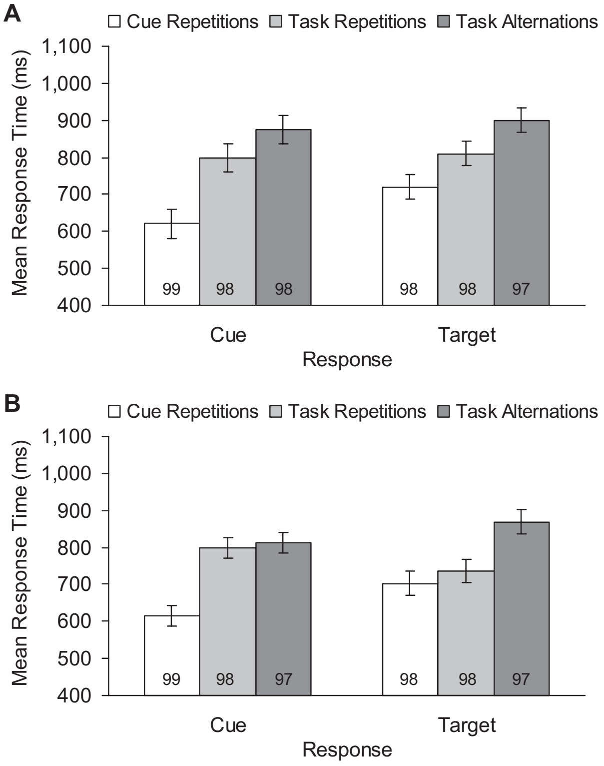

Figure 4. Mean cue and target response times for each task transition in Experiments 3a (Panel A) and 3b (Panel B). Error bars represent Fisher's least significant difference for $\alpha = .05$. Mean accuracy is inset within each bar.

were faster than task repetitions (*M* = 799), which were faster than task alternations (*M* = 876 ms). Cue RTs were analyzed in a one-way repeated-measures ANOVA, yielding a significant task-transition effect, $F(2, 30) = 98.2$, $p < .05$, $MSE = 2{,}807.8$. LSD comparisons showed that the 179-ms difference between cue repetitions and task repetitions and the 77-ms difference between task repetitions and task alternations were both significant.

Experiment 3a: Target RTs. The top panel of Figure 4 also shows target RTs as a function of task transition. The transition effects were similar to those in the cue RTs. Cue repetitions (*M* = 719 ms) were faster than task repetitions (*M* = 810 ms), which were faster than task alternations (*M* = 900 ms). A one-way repeated-measures ANOVA revealed a significant effect of task transition, $F(2, 30) = 64.1$, $p < .05$, $MSE = 2{,}036.5$. LSD tests showed that the 91-ms difference between cue repetitions and task repetitions and the 90-ms difference between task repetitions and task alternations were both significant. The significant cue switch effect on target RT suggests that the experiment did not succeed in separating cue encoding from target processing.

Experiment 3b: Cue RTs. The bottom panel of Figure 4 shows the mean cue RTs as a function of task transition. The transition effects differed from those in Experiment 3a. Cue repetitions (*M* = 613 ms) were substantially faster than task repetitions (*M* = 797 ms) and task alternations (*M* = 813 ms), but the difference between task repetitions and task alternations was small. A one-way repeated-measures ANOVA showed a significant effect of task transition, $F(2, 30) = 135.5$, $p < .05$, $MSE = 1{,}458$. LSD tests showed that the 184-ms difference between cue repetitions and task repetitions was significant, but the 16-ms difference between task repetitions and task alternations was not.

Experiment 3b: Target RTs. The bottom panel of Figure 4 also shows the target RTs as a function of task transition. The transition effects were different from Experiment 3a. Cue repetitions (*M* = 703 ms) were slightly faster than task repetitions (*M* = 735 ms), which were substantially faster than task alternations (*M* = 869 ms). A one-way repeated-measures ANOVA showed a significant effect of task transition, $F(2, 30) = 65.6$, $p < .05$, $MSE = 1{,}900.5$. LSD tests showed that the 31-ms difference between cue repetitions and task repetitions was on the cusp of significance (LSD = 31 ms) and the 166-ms difference between task repetitions and task alternations was highly significant.

Comparisons of Experiments 3a and 3b. The data in Figure 4 indicate that the two experiments produced different results. In the cue RTs, Experiment 3a (1:1 mapping) produced both cue switch and task switch effects, whereas Experiment 3b (2:1 mapping) produced only cue switch effects. These differences were assessed in a 2 (experiment: 3a vs. 3b) × 3 (task transition: cue repetition, task repetition, and task alternation) mixed-measures ANOVA with experiment as a between-subjects variable. The main effect of experiment was not significant, $F(1, 30) = 0.5$, $p = .48$, $MSE = 26{,}685.6$; but the interaction between experiment and task transition was significant, $F(2, 60) = 4.2$, $p < .05$, $MSE = 2{,}133.3$.

In the target RTs, Experiment 3a (1:1 mapping) produced both cue switch and task switch effects, whereas Experiment 3b (2:1 mapping) produced a small cue switch effect and a large task switch effect. Another mixed-measures ANOVA was conducted on the target RT data. A 2 (experiment: 3a vs. 3b) × 3 (task transition: cue repetition, task repetition, and task alternation) mixed-measures ANOVA showed that the main effect of experiment was not significant, $F(1, 30) = 1.1$, $p = .30$, $MSE = 35{,}060.8$; but the interaction between experiment and task transition was significant, $F(2, 60) = 3.8$, $p < .05$, $MSE = 1{,}968.5$.

Discussion

Experiments 3a and 3b produced results similar to the previous experiments, but there were important differences. Experiment 3a produced results that were similar to Experiment 1, which also required a separate response for each cue. The target RTs showed cue switch and task switch effects, which suggests that Experiment 3a did not separate cue processing from target processing. Some of the cue encoding process appears to have “spilled over” into the target RTs, suggesting that cue encoding normally produces abstract representations that are used to retrieve responses (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Schneider & Logan, 2005), goals (Sohn & Anderson, 2001, 2003), or mapping rules (Mayr & Kliegl, 2000, 2003). Experiment 3a also showed cue switch and task switch effects in cue RTs, unlike Experiment 1, which showed no such effects. This finding suggests that the keypress responses required in Experiment 3a required more abstract representations than the simple vocal responses (reading the cue aloud) in Experiment 1.

Experiment 3b produced results like Experiment 2, which also required a 2:1 cue–response mapping. Cue RTs showed large cue switch effects and small task switch effects, whereas target RTs showed small cue switch effects and large task switch effects. The small cue switch effects in the target RTs suggest that the experiment successfully separated cue processing from target processing. The response to the cue—the binary classification indicating which task was cued—appears to have required the same representation that was necessary to drive retrieval of responses, goals, or mapping rules after the target appeared. Moreover, the strong task switch effects in the target RTs suggest that there may be true switch costs in the explicit task-cuing procedure that are independent of cue encoding effects (cf. Schneider & Logan, 2005).

The results of Experiments 3a and 3b suggest that the differences in the specificity and levels of representation were both responsible for the differences in results between Experiments 1 and 2. A 1:1 mapping requires a separate representation of each cue, whereas a 2:1 mapping requires a common representation for different cues associated with the same task. The common representation seems necessary to drive the retrieval process that is engaged when the target appears, whether responses, goals, or mapping rules are retrieved. The experiments also suggest that the representation of the cue must be more abstract than a simple verbal or phonological representation. The representation must encompass all of the cues associated with a task, like a representation of a task name or a task goal.

Experiments 4a and 4b: Response Label Cues

Experiments 4a and 4b were designed to provide converging evidence that a 2:1 cue–response mapping produces a representation that is more abstract than a verbal or phonological representation of the cue. The experiments exploited a cue–target congruency effect observed by Schneider and Logan (2005) when cues name single response alternatives. Schneider and Logan used ODD, EVEN, HIGH and LOW as cues for parity and magnitude judgments of digits, and they found shorter RTs when cues and targets were congruent (e.g., ODD-3; HIGH-7) than when cues and targets were incongruent (e.g., EVEN-3; LOW-7). Logan and Schneider (2006a) used this congruency effect to determine when subjects retrieved names of response categories with arbitrary cues, finding stronger congruency effects when subjects were likely to retrieve the names of response categories than when they were unlikely to do so. Experiments 4a and 4b used the congruency effect in a similar manner to determine whether subjects were more likely to represent cues in terms of response categories with a 1:1 cue–response mapping than with a 2:1 cue–response mapping. We used *odd, even, high,* and *low* as cues and had subjects make separate responses to each cue (1:1 mapping) in Experiment 4a and separate responses for each task (2:1 mapping) in Experiment 4b. We expected strong cue–target congruency effects with the 1:1 mapping because the cue response requires subjects to encode each cue separately. If subjects formed a more abstract representation with the 2:1 mapping, as the previous experiments suggest, the cue–target congruency effects should be smaller.

Method

Subjects. The subjects were 17 (Experiment 4a) and 16 (Experiment 4b) volunteers from the same subject population as in Experiment 1 and met the same inclusion criteria. Data from 1 subject were removed from Experiment 4a for failure to meet the accuracy criterion. No subjects had participated in earlier experiments, and all were naive to the purpose of the experiment.

Stimuli, apparatus, design, and procedure. All experimental details were identical to those used in Experiments 3a and 3b, with the exception of the cues. The cues for the parity task were the words *even* and *odd* and the cues for the magnitude task were the words *low* and *high*, each 9 mm tall and 24–32 mm wide. This change to the cues resulted in a new variable in the design: cue–target congruency.

Results

Trials were sorted into task-transition conditions on the basis of the cues on trials $n - 1$ and n. Trials were excluded from RT analyses by the methods used in the earlier experiments. RT trimming resulted in the removal of $< 3\%$ of the trials for both experiments. As in the previous experiments, overall accuracy was high for cue (98.3% and 97.7%) and target (97.1% and 97.6%) responses for Experiments 4a and 4b, respectively. There was no suggestion of a speed–accuracy tradeoff. Analyses of RCI and RTI effects are presented in Appendix D.

Experiment 4a: Cue RTs. The top panel of Figure 5 shows the mean cue RTs as a function of task transition. The pattern of task-transition effects was similar to Experiment 3a, except for an overall slowing. Cue RT was fastest for cue repetitions ($M = 687$ ms), followed by task repetitions ($M = 852$ ms), and then task alternations ($M = 985$ ms). A one-way repeated-measures ANOVA showed a significant effect of task transition, $F(2, 30) = 136.1$, $p < .05$, $MSE = 2{,}626.9$. LSD comparisons showed that the 165-ms difference between cue repetitions and task repetitions and the 133-ms difference between task repetitions and task alternations were both significant.

Experiment 4a: Target RTs. The top panel of Figure 5 also shows the mean target RTs as a function of task transition. Target RT was fastest for cue repetitions ($M = 773$ ms), followed by task repetitions ($M = 861$ ms), and then task alternations ($M = 976$ ms). A one-way repeated-measures ANOVA showed a significant effect of task transition, $F(2, 30) = 50.2$, $p < .05$, $MSE = 3{,}312.5$. LSD comparisons showed that the 88-ms difference between cue repetitions and task repetitions and the 115-ms difference between task repetitions and task alternations were both significant. The large cue switch effect indicates that this experiment was not successful in isolating cue processing in the cue response. Some cue encoding spilled over into the target responses.

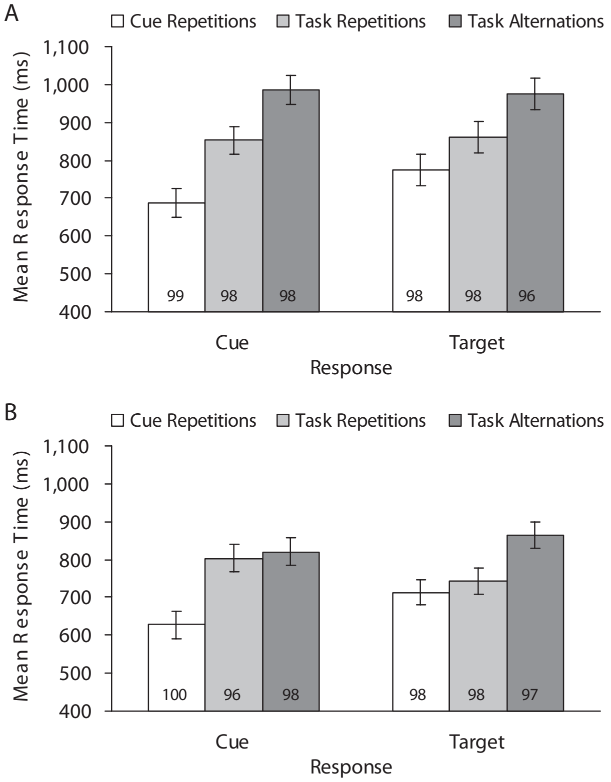

Figure 5. Mean cue and target response times for each task transition in Experiments 4a (Panel A) and 4b (Panel B). Error bars represent Fisher's least significant difference for $\alpha = .05$. Mean accuracy is inset within each bar.

The novel contribution of this experiment was to examine cue–target congruency effects to determine the nature of the cue representation that subjects formed. Table 1 contains the mean target RTs for congruent and incongruent trials for each task transition. Following Schneider and Logan (2005; Logan & Schneider, 2006a), cue–target congruency had a large effect with task repetitions (64 ms) and task alternations (74 ms) but not with cue repetitions (–6 ms). These results suggest that subjects formed representations of the individual cues to respond to the cue, and these representations persisted to facilitate or interfere with target processing (Schneider & Logan, 2005) after the cue response. A 2 (cue–target congruency: congruent and incongruent) × 3 (task transition: cue repetition, task repetition, and task alternation) repeated-measures ANOVA revealed a significant main effect of cue–target congruency, $F(1, 15) = 19.9$, $p < .05$, $MSE = 2{,}359.7$; and a significant interaction between congruency and task transi-

Table 1

Target Response Times (ms) as a Function of Cue–Target Congruency and Task Transition in Experiments 4a and 4b

		Task transition					
		Cue repetition		Task repetition		Task alternation	
Experiment	Cue–target congruency	*M*	*SE*	*M*	*SE*	*M*	*SE*
4a	Incongruent	770	28	893	36	1,014	47
	Congruent	775	37	829	38	940	48
4b	Incongruent	716	25	763	28	885	34
	Congruent	711	25	724	26	846	33

tion, $F(2, 30) = 9.8$, $p < .05$, $MSE = 1{,}464.1$ (see Schneider & Logan, 2005, pp. 352–353, for a detailed explanation of this interaction).

Experiment 4b: Cue RTs. The bottom panel of Figure 5 shows the mean cue RTs as a function of task transition. Cue RT was fastest for cue repetitions ($M = 627$ ms), followed by task repetitions ($M = 803$ ms) and task alternations ($M = 821$ ms). A one-way repeated-measures ANOVA revealed a significant effect of task transition, $F(2, 30) = 76.6$, $p < .05$, $MSE = 2{,}396.1$. LSD tests showed that the 176-ms difference between cue repetitions and task repetitions was significant, but the 18-ms difference between task repetitions and task alternations was not significant.

Experiment 4b: Target RTs. The bottom panel of Figure 5 shows the mean target RTs as a function of task transition. As in Experiment 3b, cue repetitions were fastest ($M = 713$ ms), followed closely by task repetitions ($M = 743$ ms). Task alternations were substantially slower than cue repetitions and task repetitions ($M = 864$ ms). A one-way repeated-measures ANOVA showed a significant effect of task transition, $F(2, 30) = 45.5$, $p < .05$, $MSE = 2{,}255.1$. LSD tests indicated that the 30-ms difference between cue repetitions and task repetitions was not significant, but the 121-ms difference between task repetitions and task alternations was significant.

The effects of cue–target congruency are presented in Table 1. Again, cue–target congruency affected target RTs for task repetitions (39 ms) and task alternations (39 ms) but not for cue repetitions (5 ms); however, the congruency effect was smaller than the one seen in Experiment 4a. A 2 (cue–target congruency: congruent and incongruent) × 3 (task transition: cue repetition, task repetition, and task alternation) repeated-measures ANOVA revealed a significant main effect of cue–target congruency, $F(1, 15) = 27.1$, $p < .05$, $MSE = 694.4$; and a significant interaction between congruency and transition, $F(2, 30) = 6.3$, $p < .05$, $MSE = 480.9$.

Comparison of Experiments 4a and 4b. The cue RTs were analyzed in a 2 (experiment: 4a vs. 4b) × 3 (task transition: cue repetition, task repetition, and task alternation) mixed-measures ANOVA with experiment as a between-subjects factor. The main effect of experiment was significant, $F(1, 30) = 4.7$, $p < .05$, $MSE = 42{,}504.9$, indicating slower responding in Experiment 4a (1:1 mapping; $M = 842$ ms) than in Experiment 4b (2:1 mapping; $M = 750$ ms). Experiment interacted significantly with task transition, $F(2, 60) = 12.9$, $p < .05$, $MSE = 2{,}511.5$, reflecting the different task switch effects in the two experiments.

Target RTs were also analyzed in a 2 (experiment: 4a vs. 4b) × 3 (task transition: cue repetition, task repetition, and task alternation) mixed-measures ANOVA. The main effect of experiment was significant, $F(1, 30) = 4.4$, $p < .05$, $MSE = 50{,}191.9$, with slower responding in Experiment 4a ($M = 870$ ms) than in Experiment 4b ($M = 774$ ms). The interaction between experiment and task transition approached significance, $F(2, 60) = 2.9$, $p = .06$, $MSE = 11{,}255.9$.

The most critical analysis compared cue–target congruency effects between experiments. A 2 (experiment: 4a vs. 4b) × 2 (cue–target congruency: congruent and incongruent) × 2 (task transition: task repetition and task alternation) mixed-measures ANOVA was conducted to evaluate the differences. This ANOVA included only task repetitions and task alternations because they were the only transitions that produced substantial cue–target congruency effects. The critical interaction between experiment and cue–target congruency was significant, $F(1, 30) = 4.6$, $p < .05$, $MSE = 1{,}480.5$, indicating smaller congruency effects with the 2:1 mapping.

Discussion

Experiments 4a and 4b produced results like Experiments 3a and 3b. Experiment 4a produced results like Experiment 3a, finding significant cue switch and task switch effects in both cue RTs and target RTs, which suggests that the experiment did not successfully isolate cue processing in the cue RTs. Experiment 4b produced results like Experiment 3b and Experiment 2. The cue RTs showed significant cue switch effects but no significant task switch effects. The target RTs showed a small nonsignificant cue switch effect and a much larger significant task switch effect, which suggests successful separation of cue processing from target processing.

The novel contribution of Experiments 4a and 4b was to use Schneider and Logan's (2005) cue–target congruency effect to determine the nature of the representations subjects generated to respond to the cues. Experiment 4a showed strong cue–target congruency effects, suggesting that subjects formed representations of the individual cues, which persisted to influence target processing. Experiment 4b showed significantly smaller cue–target congruency effects, suggesting that subjects formed more abstract representations to respond to the cue. Taken together with the nonsignificant cue switch effects in the target RTs in Experiment 4b, these results suggest that cue encoding in the typical explicit task-cuing procedure with two cues per task involves forming a representation of the cue that is more abstract than a simple verbal or phonological representation, which is then used to retrieve responses (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Schneider & Logan, 2005), goals (Sohn & Anderson, 2001, 2003), or mapping rules (Mayr & Kliegl, 2000, 2003).

General Discussion

We had two major goals in conducting the present experiments: To determine whether true task switch effects could be observed in the explicit task-cuing procedure and to discover the representations that were created by cue encoding processes. Achievement of both of these goals required separating cue processing from target processing and isolating the factors that affected them in cue RTs and target RTs, respectively. The experiments that used a 1:1 cue–response mapping generally failed to achieve this separation. There were substantial cue switch effects in target RTs in Experiments 1, 3a, and 4a ($M = 93$ ms). The experiments that used a 2:1 cue–response mapping generally succeeded in separating cue encoding from target processing. The cue switch effects in target RTs were small in Experiments 2, 3b, and 4b ($M = 31$ ms) and were (barely) significant only in Experiment 3b.

Did Responding to the Cue Disrupt Normal Processing?

The present experiments differed from typical explicit task-cuing experiments in that they required subjects to respond overtly to the cue. Before discussing the implications of the results, it is important to determine whether this extra requirement disrupted normal processing enough to limit generalization from the present experiments to more typical ones. To address this issue, we calculated the mean target RT collapsed over transitions in each experiment (*M*s = 781, 750, 810, 769, 870, and 774 ms for Experiments 1, 2, 3a, 3b, 4a, and 4b, respectively) and compared them with the mean RT at the longest SOA collapsed over transitions in our previous experiments with the same cues and digit tasks (*M*s = 811, 912, 891, 791, and 733 ms for Logan & Bundesen, 2003, Experiment 3, 900-ms SOA; Logan & Bundesen, 2004, Experiment 1, 900-ms SOA; Schneider & Logan, 2005, Experiments 1, 2, and 3, 800-ms SOA, respectively). The mean target RT across the present experiments (792 ms) was slightly faster than the mean RT at the longest SOA in our previous experiments (828 ms), suggesting that the requirement to respond to the cue did not disrupt target processing substantially.

At first glance, the conclusion that responding to the cue did not disrupt target processing substantially is surprising: Subjects had to switch between responding to the cue and responding to the target, and switching between tasks usually produces large costs. On reflection, the lack of substantial costs could have been anticipated from previous experiments. Jersild (1927) found no switch costs when subjects alternated between tasks that required different responses to different classes of stimuli (adding 3 to numbers and producing antonyms of words). Switch costs are also reduced when response set overlap is minimized, being smaller with 1:1 response–key mappings than with 2:1 response–key mappings (e.g., Meiran, 2000b). Given that there was no overlap between the responses to the cues and the responses to the targets, switching between cue and target responses should not be expected to produce large switch costs.

Are the Estimates of Cue Encoding Time Valid?

A second way to assess whether the data from the present experiments are comparable with data from more typical explicit task-cuing experiments is to compare estimates of cue encoding time. If the response to the cue taps into normal cue processing, then estimates of cue encoding time and differences in cue encoding time between transitions should be similar to estimates from more typical experiments. To address this issue, we estimated cue encoding times in previous experiments with the same cues and tasks (Logan & Bundesen, 2003, Experiment 3; Logan & Bundesen, 2004, Experiment 1; Schneider & Logan, 2005, Experiments 1–3) by fitting Equation 1 to the time-course functions. The fits allowed a separate cue encoding time (μ) for cue repetitions, task repetitions, and task alternations but required a common value of base RT (RT_{Base}). Measures of goodness of fit and values of RT_{Base} parameters are reported in the original articles.[2] The estimates of cue encoding time for cue repetitions, task repetitions, and task alternations are presented in Table 2. The mean fitted cue encoding times, across experiments, were 278, 439, and 502 ms for cue repetitions, task repetitions, and task alternations, respectively. By contrast, the mean cue RTs in Experiments 2, 3b, and 4b were 624, 793, and 799 ms for cue repetitions, task repetitions, and task alternations, respectively. Because cue encoding was separated successfully from target processing in these experiments, we interpret these cue RTs as *measured cue encoding times*, with the caveat that they include response selection and execution time as well as cue encoding time.

Averaged over transition, the measured cue encoding times were 333 ms longer than the fitted cue encoding times. This difference is reasonable in two respects. First, the measured cue encoding times include response selection and execution time as well as cue encoding time, whereas the fitted cue encoding times do not require response selection and execution. Second, in the measured cue encoding times, response selection and execution may be prolonged by "concurrence costs" that are often observed in dual-task experiments that require subjects to execute separate responses to two separate stimuli (Pashler, 1994). RT to the first of two stimuli is often substantially longer than RT to the same stimulus in single-task conditions. For example, Logan and Gordon (2001) found a difference of 179 ms between performing magnitude judgments of digits in single-task conditions and performing the same judgment as the first of two responses in dual-task conditions. Subtracting this difference from the 333-ms difference between the measured and fitted cue encoding times yields

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[2] The cue encoding times in Table 2 were taken from the fits of the priming model to the data from Schneider and Logan's (2005) experiments. In essence, the priming model fits Equation 1 to the data with RT_{Base} constrained to be the same for different transitions. The cue encoding times for Logan and Bundesen's (2003, 2004) experiments were estimated from new fits, which allowed separate cue encoding times for each transition. The goodness of fit was better than or equal to the goodness of fit for Model 2 in those articles, which constrained cue encoding time to be equal for task repetitions and task alternations and allowed cue encoding time to be faster for cue repetitions. Model 2 is nested in our new model, so our new model cannot fit worse than Model 2. The estimates of goodness of fit of Model 2 in Logan and Bundesen (2003, 2004) represent the lower limits of the goodness of fit of our new model.

Table 2

Estimates of Cue Encoding Time (ms) Derived From Equation 1 for 15 Conditions From Previously Published Experiments

Experiment	CR	TR	TA
Logan & Bundesen, 2003, Experiment 3	242	482	525
Logan & Bundesen, 2004, Experiment 1	278	556	562
Schneider & Logan, 2005, Experiment 1	256	372	453
Schneider & Logan, 2005, Experiment 2	283	357	481
Schneider & Logan, 2005, Experiment 3	332	404	513
Mean	278	439	502

Note. The estimates from Logan and Bundesen (2004) are for the word cues in their word-first conditions. CR = cue repetitions; TR = task repetitions; TA = task alternations.

an estimated response selection and execution time of 154 ms, which seems to be a reasonable value.

The transition effects in fitted and measured cue encoding times were very similar. To illustrate the agreement between the estimates, we plot Figure 6 by using the fitted cue encoding times and the measured cue encoding times, with 333 ms subtracted to remove the time required for response selection and execution. Cue switch effects were almost identical (169 ms for measured; 161 ms for fitted), but task switch effects differed somewhat (6 ms for measured; 63 ms for fitted). Overall, the agreement between the measured and fitted values is quite close, suggesting that differences between transitions in cue RTs can provide valid estimates of differences between cue encoding times. More generally, the agreement between measured and fitted values suggests that interposing a cue response in the explicit task-cuing procedure does not disrupt normal cue processing.

The discrepancy between measured and fitted task switch effects deserves comment. On the one hand, the larger task switch effects in the fitted values may reflect contamination in the model fits, whereby true task switch effects contributed to estimates of cue encoding time. It is possible that the effects we attributed to priming of cue encoding, especially in the Schneider and Logan (2005) data, were partly due to task switch effects in target processing. Indeed, the parameters that accounted for cue encoding in the Schneider and Logan (2005) fits were constrained such that they also accounted for cue–target congruency effects on target processing. The present Experiments 4a and 4b confirmed the assumption that cue–target congruency effects reflect target processing; they appeared only in target RTs in those experiments. This possibility challenges Schneider and Logan's (2005) interpretation of task switch effects in cue encoding times as evidence for their priming model. However, Logan and Schneider (2006b) found evidence of priming independent of model fits. They used arbitrary cues (*Day, Night, Noun, Verb, Salt, Pepper, King,* and *Queen*) to cue parity and magnitude judgments and found larger task switch effects—arising from faster task repetition RTs—when the two cues for a given task were semantically related words (e.g., *Day* and *Night* cued magnitude judgments; *Noun* and *Verb* cued parity judgments) than when the two cues for a given task were semantically unrelated words (e.g., *Day* and *Noun* cued magnitude judgments; *Salt* and *Queen* cued parity judgments). Model fits suggested that related words primed cue encoding on task repetition trials. These data support Schneider and Logan's (2005) claim that cue encoding can benefit from semantic or associative priming, but the boundary conditions on these effects remain to be demonstrated.

On the other hand, it is possible that the measured cue encoding times overestimate the true cue encoding times for task repetition trials. Subjects typically respond more slowly when they have to give the same response they just executed to a different stimulus. Many researchers interpret these results as positive effects of repeating the same stimulus and response across trials, but Hommel (2004) and colleagues (e.g., Waszak et al., 2003) have interpreted them as negative effects of having to unbind the response from the previous stimulus and re-bind it to the current one. They argued that unbinding and re-binding are not necessary when stimuli and responses both change because these stimuli and responses were not bound recently in the past. Thus, it is possible that unbinding and re-binding are necessary on task repetition trials but not on task alternation trials, and this difference in processing requirements counteracts the positive effects of semantic or associative priming on cue encoding, resulting in small differences between task repetitions and task alternations in measured cue encoding times. This account is speculative, but it draws attention to the need for further research to specify the processing that underlies cue RTs in experiments like the present ones.

Observing "True" Task Switch Effects

The experiments suggest that true task switch effects can be observed if cue encoding is separated from target processing. Successful separation requires separate responses to the cues and the targets, and the cue responses must indicate the task to be performed (2:1 mapping) rather than the cue that was presented (1:1 mapping). The experiment must also include a manipulation that selectively affects cue encoding, like using two cues per task to separate cue repetitions from task repetitions. Separation is successful only if cue switch effects do not appear in target RTs.

Experiments 2, 3b, and 4b met these criteria for successful separation. Averaged across experiments, the task switch effect in target RT was 124 ms. These task switch effects in target RTs

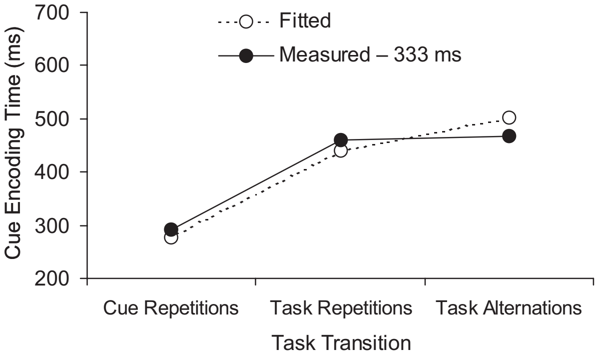

Figure 6. Estimates of cue encoding time from cue-response times in Experiments 2, 3b, and 4b (measured) and from fits of Equation 1 to previously published data (fitted) from Arrington and Logan (2004), Logan and Bundesen (2003, 2004), and Schneider and Logan (2005). Three hundred thirty-three milliseconds have been subtracted from the measured cue encoding times (cue-response times) to remove the time required for response selection and execution.

falsify the conclusion from our previous work that task-transition effects are entirely due to cue encoding (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Schneider & Logan, 2005). In our previous work, we tried to account for transition effects in standard explicit task-cuing experiments by fitting models based on Equation 1 to time-course functions produced by varying the SOA between the cue and the target. These models assumed that RT_{Base} was constant across conditions, so all of the variation in task-transition effects was due to variation in the cue encoding parameters (μ). Schneider and Logan's (2005) priming model allowed separate values of μ for each transition, explaining cue switch effects as repetition priming and task switch effects as semantic or associative priming. The task switch effects in the present target RT data suggest that this model is not sufficient. Arrington and Logan (2004) and Logan and Bundesen (2004) anticipated the present data by proposing a different model (Model 3) that allowed RT_{Base} to be slower for task alternations than for task repetitions and cue repetitions. These effects could be accommodated in Schneider and Logan's priming model by allowing prior associations with responses and response categories to affect the compound-cue retrieval process that begins when the target appears (cf. Allport & Wylie, 2000; Waszak et al., 2003). Further research will be necessary to determine the range of phenomena that can be accounted for by such extensions of the model. For example, Schneider and Logan (2007) developed a version of their model that dealt successfully with time-course functions and sequential effects in a transition cuing experiment in which subjects were instructed to switch or repeat tasks (using the cues *Repeat, Again, Switch,* and *Change*). They included separate RT_{Base} parameters for different transitions as well as parameters for mediator retrieval, assuming that the transition cues led subjects to retrieval of task names.

The task switch effects in target RTs suggest that something beyond cue encoding produces task switch effects. What that is, however, remains unclear. It is tempting to suggest that endogenous reconfiguration is responsible for the task switch effects, consistent with claims by Meiran (1996, 2000a) and Monsell and Mizon (2006), among others. Indeed, much of the appeal of task-switching experiments is the possibility that they measure endogenous reconfiguration. However, the failure to find significant reductions in transition effects over cue–response/target intervals of 100 to 1,000 ms in any experiment (see Appendixes A–D) seems more consistent with exogenous reconfiguration (Mayr & Kliegl, 2000, 2003; Rogers & Monsell, 1995) or negative priming effects (Allport, Styles & Hsieh, 1994; Allport & Wylie, 2000; Waszak et al., 2003) triggered by target onset. Nevertheless, endogenous reconfiguration cannot be ruled out entirely. Some endogenous reconfiguration could occur between the time the cue is encoded and the response to the cue is executed. The comparisons of measured and fitted cue encoding times reported above suggest that this interval may be on the order of 300 ms, which may be long enough to complete a substantial amount of reconfiguration. Moreover, most researchers assume that endogenous reconfiguration is a voluntary process, which raises the possibility that some experimental conditions may invite subjects to postpone endogenous reconfiguration until the target appears. This possibility is consistent with De Jong's (2000) failure-to-engage hypothesis and with empirical demonstrations that reductions in transition effects with preparation interval may be different when the preparation interval is blocked or randomized (Altmann, 2004; Rogers & Monsell, 1995). The present experiments provide no basis for distinguishing between these interpretations; our observation of task switch effects is consistent with endogenous reconfiguration, exogenous reconfiguration, and negative priming that begins with target onset. Further research will have to be done to distinguish between these interpretations, and that research will have to do more than demonstrate task switch effects. Ideally, that research would include manipulations that are uniquely diagnostic of each interpretation (e.g., see Schneider & Logan, in press). Our experiments set the stage for this future research by providing a method for separating cue encoding from target processing that allows researchers to measure true task switch effects. The play that will unfold on the stage remains to be seen.

What Representations Are Produced by Cue Encoding?

In theory, cue encoding results in a representation that is used to select the appropriate response to the target. In principle, the cue may be represented at several different levels, ranging from visual features to semantic categories, and the representation at each level may be specific to the individual cue or may be more general, encompassing all of the cues assigned to a task. The cue may be represented at several levels as cue encoding unfolds, eventually resulting in a final representation that is used to select the appropriate response to the target. The present experiments allow us to assess the final representation by requiring subjects to respond overtly to the cue, and the assessment depends on our ability to separate cue encoding from target processing: We know that the cue response has tapped the final representation when all of the cue encoding effects appear in cue RT and none of the cue encoding effects appear in target RT (see Figure 1). The critical cue encoding effects in the present experiments were cue switch effects, which reflect a cue encoding benefit for repeated cues (Logan & Bundesen, 2003; Mayr & Kliegl, 2003). By this criterion, Experiments 2, 3b, and 4b captured the final cue representation because they successfully separated cue encoding from target processing. The contrasts between the successful experiments (2, 3b, and 4b) and the unsuccessful ones (1, 3a, and 4a) suggest that cue encoding produces a symbol that represents the task to be performed instead of an individual representation of each cue and that the representation is semantic or categorical and not just phonological.

The conclusion that cue encoding results in a categorical, semantic representation of the task is consistent with our theory of explicit task-cuing. We assume that the cue representation is combined with the target to form a compound retrieval cue that probes semantic memory for an appropriate response (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Schneider & Logan, 2005), so a semantic representation of the cue would be a very appropriate product of cue encoding. The conclusion is also consistent with Sohn and Anderson's (2001, 2003) theory of task switching, in which cue encoding produces a goal representation that is used in response selection. Other approaches to task switching have assumed that more elaborate representations result from cue encoding. Mayr and Kliegl (2000, 2003) assumed that the cue retrieves mapping rules, which are then applied to the target to produce a response (but see Schneider & Logan, 2005). Meiran (2000a) assumed that cue encoding produces a stimulus task set and a response task set, which are represented as weights for distributing attention across dimensions. Monsell and Mizon (2006; see also Rogers & Monsell, 1995) assumed that cue encoding produces a specific configuration of perceptual, attentional, cognitive, and motor processes that is necessary to perform the cued task. The present results do not distinguish between these alternatives. Further research will be required to determine whether simpler or more elaborate representations are necessary to account for the patterns of effects observed in explicitly cued task-switching performance.

What Has and Has Not Been Falsified?

It is important to be clear about the parts of our previous work that have and have not been falsified by the present results. The present results have falsified the conclusion we drew in several articles that cue encoding effects are responsible for all cue- and task-transition effects in explicit task-cuing experiments. The task switch effects in target RTs in Experiments 2, 3b, and 4b show that our conclusion is false. Experiments 2, 3b, and 4b separated cue encoding from target processing, so the task switch effects we observed in target RTs cannot be due to cue encoding. A more conservative conclusion may be that the present experiments falsify the general conclusion that cue encoding is responsible for all cue- and task-transition effects, but they need not falsify the specific conclusions we drew about the results of particular experiments. Task switch effects were very small in some of Logan and Bundesen's experiments (e.g., Experiments 3 and 4 of their 2003 article and the word-cue conditions in their 2004 article), and it may be true that cue encoding is sufficient to account for cue- and task-transition effects in those experiments. However, the present results suggest that there may be many conditions under which cue encoding does not provide a sufficient account of cue- and task-transition effects (see also Schneider & Logan, 2007). Future research may identify boundary conditions under which cue encoding provides a sufficient explanation.

The present experiments do not falsify our models of cue encoding effects (Arrington & Logan, 2004; Logan & Bundesen, 2003, 2004; Schneider & Logan, 2005). Our models provide estimates of cue encoding times and explain the ways in which cue encoding may benefit from repetition and semantic or associative priming. The present experiments show that there are effects in task-switching experiments beyond cue encoding effects. They speak to limitations or boundary conditions on our models rather than the truth or falsehood of the models. The present experiments do not show that the estimates of cue encoding times from our models are invalid—indeed, the close agreement between measured and fitted cue encoding times in Figure 6 supports the validity of the estimates—and they do not falsify our models' explanations of the effects of repetition and semantic priming on cue encoding. A major contribution of the present experiments and our previous ones is to demonstrate that there are strong cue encoding effects in the explicit task-cuing procedure. Other researchers will need to account for these cue encoding effects when they develop explanations of reconfiguration and retrieval in the explicit task-cuing procedure. Whereas the methodology of the present experiments may have provided researchers with a way of isolating cue encoding effects empirically, our models provide them with a way of isolating them theoretically and estimating their duration (see Model 3 in Arrington & Logan, 2004, and Logan & Bundesen, 2004; see also Schneider & Logan, 2007).

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Appendix A

We examined RCI effects in the RT and accuracy data in the cue responses in Experiment 1, collapsing over RTI to obtain stable data. The means across subjects appear in Table A1. Mean cue switch effects and task switch effects also appear in the table. A 3 (transition: cue repetition, task repetition, task alternation) × 4 (RCI: 100, 400, 700, 1,000 ms) ANOVA on the RT data yielded a significant main effect of RCI, $F(3, 45) = 32.6$, $p < .01$, $MSE = 3{,}710.9$; and a nonsignificant interaction between transition and RCI, $F(6, 90) = 1.0$, $p > .1$, $MSE = 411.0$. An ANOVA with the same design on the accuracy data revealed a main effect of RCI that approached significance, $F(3, 45) = 2.3$, $p < .1$, $MSE = 0.0001$; and a nonsignificant interaction between transition and RCI, $F(6, 90) = 1.6$, $p > .1$, $MSE = 0.0001$. Thus, it is appropriate to collapse across RCI in the analyses of cue RTs and accuracies that are reported in the main text.

Table A1

Mean Response Time (RT) and Accuracy (Acc) as a Function of Response to Cue Interval for Cue Responses and Response to Target Interval for Target Responses in Experiment 1

		100		400		700		1,000	
Response		*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Response to cue interval for cue responses									
Cue repetition	RT	660	35	589	24	552	23	547	21
	Acc	99.2	0.4	99.0	0.4	99.8	0.2	99.8	0.2
Task repetition	RT	686	33	615	29	579	25	574	23
	Acc	100	0.0	99.3	0.3	99.5	0.4	99.8	0.2
Task alternation	RT	680	32	630	27	587	25	577	26
	Acc	99.8	0.1	99.6	0.2	99.2	0.4	99.8	0.1
Cue switch effect	RT	26		26		27		27	
	Acc	0.8		0.3		−0.4		0.0	
Task switch effect	RT	−6		15		8		3	
	Acc	−0.2		0.3		−0.3		0.0	
Response to target interval for target responses									
Cue repetition	RT	801	40	710	42	658	42	652	36
	Acc	97.8	0.6	97.6	0.7	96.8	1.1	98.9	0.4
Task repetition	RT	917	52	817	61	747	49	745	54
	Acc	98.3	0.6	97.9	0.7	98.6	0.6	97.1	1.2
Task alternation	RT	957	61	828	58	788	56	748	51
	Acc	96.7	0.8	96.0	0.9	95.3	1.3	97.7	0.6
Cue switch effect	RT	116		107		89		93	
	Acc	0.5		0.3		1.8		−1.8	
Task switch effect	RT	40		11		41		3	
	Acc	−1.5		−1.9		−3.3		0.6	

We examined the RTI effects in the RT and accuracy data in the target responses, collapsing over RCI to obtain stable data. The means across subjects also appear in Table A1. Mean cue switch effects and task switch effects also appear in the table. A 3 (transition: cue repetition, task repetition, task alternation) × 4 (RTI: 100, 400, 700, 1,000 ms) ANOVA on the RT data yielded a significant main effect of RTI, $F(3, 45) = 85.9$, $p < .01$, $MSE = 3{,}570.9$; and a nonsignificant interaction between transition and RTI, $F(6, 90) = 1.3$, $p > .1$, $MSE = 2{,}311.2$. An ANOVA with the same design on the accuracy data revealed a nonsignificant main effect of RTI, $F(3, 45) = 1.6$, $p > .1$, $MSE = 0.0006$; and a nonsignificant interaction between transition and RTI, $F(6, 90) = 1.4$, $p > .1$, $MSE = 0.0009$. Thus, it is appropriate to collapse across RTI in the analyses of target RTs and accuracies that are reported in the main text.

Appendix B

We examined RCI effects in the RT and accuracy data in the cue responses in Experiment 2, collapsing across RTI. The means across subjects appear in Table B1. Mean cue switch effects and task switch effects also appear in the table. We conducted 3 (transition: cue repetition, task repetition, task alternation) × 4 (RCI: 100, 400, 700, 1,000 ms) ANOVAs on the RT and accuracy data. There was a significant effect of RCI for RT, $F(3, 45) = 32.1$, $p < .01$, $MSE = 31{,}051.5$; but not for accuracy, $F(3, 45) = 0.7$, $p > .1$, $MSE = 0.0003$. The interaction between transition and RCI was not significant for RT, $F(6, 90) = 1.5$, $p > .1$, $MSE = 1{,}299.2$; or for accuracy, $F(6, 90) = 1.2$, $p > .1$, $MSE = 0.0003$.

The target response data were analyzed by collapsing across RCI and conducting 3 (transition: cue repetition, task repetition, task alternation) × 4 (RTI: 100, 400, 700 or 1,000 ms) ANOVAs on the mean target RTs and accuracy scores. Means across subjects appear in Table B1. Mean cue switch effects and task switch effects also appear in the table. The ANOVAs showed significant effects of RTI for RT, $F(3, 45) = 39.7$, $p < .01$, $MSE = 4{,}856.0$; and for accuracy, $F(3, 45) = 3.5$, $p < .05$, $MSE = 0.0004$; but no significant interaction between transition and RTI for RT, $F(6, 90) = 1.1$, $p > .1$, $MSE = 2{,}519.3$; or for accuracy, $F(6, 90) = 1.1$, $p > .1$, $MSE = 0.0006$.

Table B1

Mean Response Time (RT) and Accuracy (Acc) as a Function of Response to Cue Interval for Cue Responses and Response to Target Interval for Target Responses in Experiment 2

		100		400		700		1,000	
Response		*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Response to cue interval for cue responses									
Cue repetition	RT	698	26	624	22	600	20	613	24
	Acc	99.8	0.2	100	0.0	99.6	0.3	99.7	0.2
Task repetition	RT	839	30	798	28	731	26	745	27
	Acc	96.4	1.1	97.7	0.7	97.8	0.6	97.8	0.6
Task alternation	RT	829	28	760	23	733	23	732	21
	Acc	99.3	0.3	99.0	0.2	98.8	0.5	99.1	0.3
Cue switch effect	RT	141		174		131		132	
	Acc	−3.4		−2.3		−1.8		−1.8	
Task switch effect	RT	−10		−38		2		−13	
	Acc	0.3		1.3		0.9		1.2	
Response to target interval for target responses									
Cue repetition	RT	786	42	688	32	664	37	653	35
	Acc	99.4	0.3	97.8	0.9	97.0	1.1	98.0	0.9
Task repetition	RT	833	49	725	41	684	36	686	37
	Acc	98.8	0.5	99.2	0.5	99.2	0.4	98.2	0.8
Task alternation	RT	896	36	841	45	768	38	769	41
	Acc	98.0	0.6	97.8	0.4	96.7	0.8	97.2	0.5
Cue switch effect	RT	47		37		20		33	
	Acc	−0.6		1.4		2.2		0.2	
Task switch effect	RT	63		116		84		83	
	Acc	−0.8		−1.4		−2.5		−1.0	

(*Appendixes continue*)

Appendix C

Experiment 3a

The mean cue RTs and accuracy scores, collapsed across RTI, appear in Table C1. Mean cue switch effects and task switch effects also appear in the table. ANOVAs evaluating the effects of transition (cue repetition, task repetition, task alternation) and RCI (100, 400, 700, 1,000 ms) found that the main effect of RCI was significant for RT, $F(3, 45) = 6.1$, $p < .01$, $MSE = 2{,}734.5$; but not for accuracy, $F(3, 45) = 0.8$, $p > .1$, $MSE = 0.0003$. The interaction between transition and RCI was not significant for RT, $F(6, 90) = 0.7$, $p > .1$, $MSE = 1{,}590.3$; but it was significant for accuracy, $F(6, 90) = 2.4$, $p < .05$, $MSE = 0.0002$.

The mean target RTs and accuracy scores, collapsed across RCI, appear in Table C1. Mean cue switch effects and task switch effects also appear in the table. Transition × RTI ANOVAs revealed a significant main effect of RTI for RT, $F(3, 45) = 19.0$, $p < .01$, $MSE = 4{,}211.4$; but not for accuracy, $F(3, 45) = 0.7$, $p > .1$, $MSE = 0.0003$. The interaction between transition and RTI was not significant for RT, $F(6, 90) = 1.2$, $p > .1$, $MSE = 2{,}727.1$; or for accuracy, $F(6, 90) = 1.2$, $p > .1$, $MSE = 0.0003$.

Experiment 3b

The data for Experiment 3b were analyzed in the same way as the data for Experiment 3a. The mean RTs and accuracy scores for cue responses and target responses are presented in Table C2. Mean cue switch effects and task switch effects also appear in the table. For cue responses, Transition × RCI ANOVAs revealed significant main effects of RCI for RT, $F(3, 45) = 2.9$, $p < .05$, $MSE = 5{,}130.5$; and for accuracy, $F(3, 45) = 3.0$, $p < .05$, $MSE = 0.00001$; but the interaction between transition and RCI was not significant for RT, $F(6, 90) = 1.9$, $p < .1$, $MSE = 1{,}917.9$; or for accuracy, $F(6, 90) = 1.8$, $p > .1$, $MSE = 0.0002$. For target responses, Transition × RTI ANOVAs revealed a significant main effect for RTI on RT, $F(3, 45) = 6.9$, $p < .01$, $MSE = 2{,}940.2$; but not for accuracy, $F(3, 45) = 0.8$, $p > .1$, $MSE = 0.0004$; and the interaction between transition and RTI was not significant for RT, $F(6, 90) = 1.2$, $p > .1$, $MSE = 1{,}633.6$; or for accuracy, $F(6, 90) = 0.4$, $p > .1$, $MSE = 0.0002$.

Table C1

Mean Response Time (RT) and Accuracy (Acc) as a Function of Response to Cue Interval for Cue Responses and Response to Target Interval for Target Responses in Experiment 3a

		100		400		700		1,000	
Response		*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Response to cue interval for cue responses									
Cue repetition	RT	655	22	609	19	604	19	615	20
	Acc	98.6	0.3	98.7	0.4	99.3	0.3	98.0	0.5
Task repetition	RT	822	31	799	24	780	31	797	36
	Acc	98.3	0.4	97.4	0.6	96.8	0.7	97.8	0.7
Task alternation	RT	895	27	887	29	853	32	870	36
	Acc	97.8	0.5	98.1	0.4	97.7	0.5	97.3	0.6
Cue switch effect	RT	167		190		176		182	
	Acc	−0.3		−1.3		−2.4		−0.2	
Task switch effect	RT	73		88		73		73	
	Acc	−0.6		0.7		0.8		−0.5	
Response to target interval for target responses									
Cue repetition	RT	767	21	717	29	695	26	696	23
	Acc	97.9	0.4	98.6	0.5	97.7	0.7	98.0	0.5
Task repetition	RT	865	33	795	35	780	37	799	32
	Acc	98.7	0.4	98.3	0.4	98.2	0.5	98.3	0.5
Task alternation	RT	974	33	898	38	879	36	851	44
	Acc	97.1	0.5	96.1	0.7	96.5	0.7	97.3	0.4
Cue switch effect	RT	98		78		85		103	
	Acc	0.8		−0.3		0.4		0.3	
Task switch effect	RT	109		103		99		52	
	Acc	−1.5		−2.3		−1.7		−1.0	

Table C2

Mean Response Time (RT) and Accuracy (Acc) as a Function of Response to Cue Interval for Cue Responses and Response to Target Interval for Target Responses in Experiment 3b

		100		400		700		1,000	
Response		*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Response to cue interval for cue responses									
Cue repetition	RT	636	23	595	21	601	21	622	21
	Acc	99.3	0.3	99.1	0.2	99.1	0.3	99.2	0.3
Task repetition	RT	823	41	800	28	789	30	775	23
	Acc	97.7	0.5	96.5	0.7	98.4	0.4	97.9	0.6
Task alternation	RT	840	34	831	27	789	27	797	23
	Acc	97.3	1.0	97.1	1.2	96.9	0.8	97.3	0.7
Cue switch effect	RT	187		205		188		153	
	Acc	−1.5		−2.6		−0.8		−1.3	
Task switch effect	RT	17		31		0		22	
	Acc	−0.5		0.6		−1.5		−0.6	
Response to target interval for target responses									
Cue repetition	RT	727	19	707	25	677	22	702	24
	Acc	98.3	0.5	98.2	0.5	97.4	0.8	98.4	0.4
Task repetition	RT	756	25	741	28	723	28	719	27
	Acc	98.2	0.6	97.9	0.7	97.5	0.7	98.2	0.7
Task alternation	RT	903	37	876	31	860	34	838	32
	Acc	97.7	0.5	97.9	0.7	97.6	0.6	97.5	0.6
Cue switch effect	RT	29		34		46		17	
	Acc	−0.1		−0.3		0.1		−0.1	
Task switch effect	RT	147		135		137		119	
	Acc	−0.5		0.0		0.1		−0.7	

Appendix D

Experiment 4a

The RT and accuracy data for cue and target responses were analyzed for effects of RCI and RTI, respectively, as in the previous experiments. The means across subjects appear in Table D1. Mean cue switch effects and task switch effects also appear in the table. For cue responses, 3 (transition: cue repetition, task repetition, task alternation) × 4 (RCI: 100, 400, 700, 1,000 ms) ANOVAs revealed a significant main effect of RCI for RT, $F(3, 45) = 4.0$, $p < .05$, $MSE = 4{,}117.3$; and for accuracy, $F(3, 45) = 4.8$, $p < .01$, $MSE = 0.0002$. The interaction between transition and RCI was not significant for RT, $F(6, 90) = 1.1$, $p > .1$, $MSE = 1{,}871.3$; or for accuracy, $F(6, 90) = 1.2$, $p > .1$, $MSE = 0.0002$. For target responses, Transition × RTI ANOVAs revealed significant main effects of RTI for RT, $F(3, 45) = 32.9$, $p < .01$, $MSE = 4{,}347.7$; and for accuracy, $F(3, 45) = 5.5$, $p < .01$, $MSE = 0.0002$. The interaction between transition and RTI was significant for RT, $F(6, 90) = 3.6$, $p < .01$, $MSE = 2{,}163.2$; but not for accuracy, $F(6, 90) = 1.5$, $p > .1$, $MSE = 0.0003$.

Experiment 4b

Cue and target responses in Experiment 4b were analyzed in the same way as in Experiment 4a. Means across subjects appear in Table D2. Mean cue switch effects and task switch effects also appear in the table. For cue responses, Transition × RCI ANOVAs revealed a significant main effect of RCI for RT, $F(3, 45) = 22.2$, $p < .01$, $MSE = 2{,}448.3$; but not for accuracy, $F(3, 45) = 2.2$, $p < .1$, $MSE = 0.0003$; and the interaction between transition and RCI was not significant for RT, $F(6, 90) = 0.9$, $p < .1$, $MSE = 2{,}503.9$; or for accuracy, $F(6, 90) = 1.7$, $p > .1$, $MSE = 0.0004$. For target responses, Transition × RTI ANOVAs revealed a significant main effect of RTI for RT, $F(3, 45) = 11.4$, $p < .01$, $MSE = 2{,}769.2$; but not for accuracy, $F(3, 45) = 0.7$, $p > .1$, $MSE = 0.0002$; and the interaction between transition and RTI was not significant for RT, $F(6, 90) = 1.0$, $p > .1$, $MSE = 2{,}027.8$; or for accuracy, $F(6, 90) = 0.6$ $p > .1$, $MSE = 0.0002$.

(*Appendixes continue*)

Table D1

Mean Response Time (RT) and Accuracy (Acc) as a Function of Response to Cue Interval for Cue Responses and Response to Target Interval for Target Responses in Experiment 4a

		100		400		700		1,000	
Response		*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Response to cue interval for cue responses									
Cue repetition	RT	724	35	680	31	672	30	670	26
	Acc	99.3	0.3	98.8	0.4	98.9	0.4	99.3	0.3
Task repetition	RT	865	33	852	30	832	31	863	39
	Acc	99.3	0.3	97.9	0.4	98.2	0.7	98.3	0.5
Task alternation	RT	1013	31	985	24	966	25	979	34
	Acc	98.1	0.5	97.4	0.7	97.6	0.6	98.6	0.4
Cue switch effect	RT	141		172		160		193	
	Acc	0.0		−0.9		−0.7		−1.0	
Task switch effect	RT	148		133		134		116	
	Acc	−1.2		−0.5		−0.5		0.3	
Response to target interval for target responses									
Cue repetition	RT	832	34	764	35	752	29	746	36
	Acc	97.2	0.7	98.6	0.3	98.8	0.3	98.3	0.5
Task repetition	RT	925	36	861	41	821	32	833	45
	Acc	97.8	0.5	98.0	0.5	98.1	0.6	97.7	0.5
Task alternation	RT	1086	49	984	49	924	46	915	48
	Acc	95.0	0.8	96.9	0.7	96.0	0.8	96.9	0.7
Cue switch effect	RT	93		97		69		87	
	Acc	0.6		−0.6		−0.7		−0.6	
Task switch effect	RT	161		123		103		82	
	Acc	−2.7		−1.0		−2.1		−0.8	

Table D2

Mean Response Time (RT) and Accuracy (Acc) as a Function of Response to Cue Interval for Cue Responses and Response to Target Interval for Target Responses in Experiment 4b

		100		400		700		1,000	
Response		*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Response to cue interval for cue responses									
Cue repetition	RT	677	33	612	27	588	25	630	31
	Acc	99.6	0.2	99.8	0.1	99.6	0.2	99.1	0.5
Task repetition	RT	843	44	808	46	766	38	796	36
	Acc	96.9	0.8	95.2	1.3	95.1	1.3	96.0	0.7
Task alternation	RT	874	38	809	32	801	32	800	35
	Acc	98.1	0.6	96.9	0.8	98.3	0.5	97.7	0.7
Cue switch effect	RT	166		196		178		166	
	Acc	−2.7		−4.6		−4.5		−3.1	
Task switch effect	RT	31		1		35		4	
	Acc	1.2		1.7		3.2		1.7	
Response to target interval for target responses									
Cue repetition	RT	749	26	711	25	682	26	716	29
	Acc	98.3	0.5	97.9	0.5	97.9	0.4	98.2	0.4
Task repetition	RT	772	30	744	28	724	27	732	29
	Acc	98.4	0.5	98.7	0.3	98.7	0.5	98.8	0.3
Task alternation	RT	912	33	851	35	851	35	843	35
	Acc	97.7	0.5	96.8	0.8	97.6	0.4	97.3	0.7
Cue switch effect	RT	23		33		42		16	
	Acc	0.1		0.8		0.7		0.6	
Task switch effect	RT	140		107		127		111	
	Acc	−0.7		−1.9		−1.0		−1.5	

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