Journal of Experimental Psychology:
Learning, Memory, and Cognition
2016, Vol. 42, No. 7, 1112–1126

0278-7393/16/$12.00 http://dx.doi.org/10.1037/xlm0000232

Perceptual and Conceptual Priming of Cue Encoding in Task Switching

Darryl W. Schneider
Purdue University

Transition effects in task-cuing experiments can be partitioned into task switching and cue repetition effects by using multiple cues per task. In the present study, the author shows that cue repetition effects can be partitioned into perceptual and conceptual priming effects. In 2 experiments, letters or numbers in their uppercase/lowercase or word/numeral forms, respectively, served as cues for perceptual categorization tasks (e.g., the letters *B*, *b*, *E*, and *e* were cues for a color judgment and the letters *D*, *d*, *G*, and *g* were cues for a shape judgment). Some cues represented the same concept but had different percepts, allowing nominal repetitions to occur across trials (e.g., *d* followed by *D*). Conceptual priming effects were measured by comparing relational repetitions (e.g., *G* followed by *D*) with nominal repetitions, whereas perceptual priming effects were measured by comparing nominal repetitions with physical repetitions (e.g., *D* followed by *D*). Large conceptual and perceptual priming effects on response time were observed. Implications of the results for understanding cue encoding in task switching situations are discussed.

Keywords: task switching, cue repetition, cue encoding, priming, memory

Many stimuli in the environment serve as cues to switch tasks. For example, imagine a professor sitting in an office and writing a manuscript. The sound of a ringing telephone is a cue to answer the telephone and engage in conversation. An e-mail alert on the computer screen is a cue to read a new message. The appearance of a student at the office door is a cue to close the door (just kidding). In each case, the cue indicates that a different task than manuscript writing is to be performed, giving it an important role in guiding behavior.

Cues are prominent in research on task switching (for reviews, see Kiesel et al., 2010; Vandierendonck, Liefooghe, & Verbruggen, 2010), where they are often used to indicate when subjects should repeat or switch tasks. For example, the words *color* and *shape* might serve as cues for color and shape judgments, respectively, of visual target stimuli. In the typical task-cuing procedure (see Meiran, 2014), cues are selected randomly across trials, resulting in some trials involving task switches (e.g., the color task followed by the shape task) and other trials involving task repetitions (e.g., the shape task followed by the shape task). In addition, the cue is usually presented before the target on each trial, with the time between stimulus onsets referred to as the cue–target interval (CTI). A common finding is that response time (RT) is longer for task switches than for task repetitions, and this transition effect tends to decrease with a longer CTI (e.g., Logan & Bundesen, 2003; Meiran, Chorev, & Sapir, 2000; Monsell & Mizon, 2006; Schneider & Logan, 2011).

Transition effects are important because they provide insight regarding how the cognitive system enables flexible task switching behavior. A critical question is whether transition effects reflect task switching, cue switching, or both. Early studies involving the task-cuing procedure used one cue per task (e.g., Meiran, 1996; Sudevan & Taylor, 1987), as in the example of using *color* and *shape* to cue color and shape tasks, respectively. However, a 1:1 cue–task mapping confounds task switching with cue switching: a task switch always involves a cue switch (e.g., *color* followed by *shape*), whereas a task repetition always involves a cue repetition (e.g., *shape* followed by *shape*). The confound is problematic because the relative contributions of task switching and cue switching to transition effects cannot be determined.

A solution to the problem is to use two cues per task (Logan & Bundesen, 2003; Mayr & Kliegl, 2003), such as the words *color* and *hue* as cues for the color task and the words *shape* and *form* as cues for the shape task. A 2:1 cue–task mapping partially deconfounds task switching and cue switching by allowing three types of transitions: task switches (task and cue both switch; e.g., *color* followed by *shape*), task repetitions (task repeats but cue switches; e.g., *form* followed by *shape*), and cue repetitions (task and cue both repeat; e.g., *shape* followed by *shape*). A task switching effect can be calculated as the difference between task switches and task repetitions (both involve switching cues), and a cue repetition effect can be calculated as the difference between task repetitions and cue repetitions (both involve repeating tasks). Researchers have observed both task switching and cue repetition effects (e.g., Mayr & Kliegl, 2003; Monsell & Mizon, 2006; Schneider & Logan, 2011), indicating there are at least two components of the overall transition effect (the difference between task switches and cue repetitions with either a 1:1 or 2:1 cue–task mapping).

Researchers have used 2:1 cue–task mappings to dissociate task switching and cue repetition effects in behavioral, electrophysiological, and neuroimaging studies (for a review, see Jost, De

This article was published Online First January 14, 2016.
I thank Katie Allsop, Jamie Colton, Stephanie Kielgas, Harlow Ladd, Moses Lee, Erin Moorman, Ambry Roberson, Serina Thottichira, and Phillip Urbanczyk for assistance with data collection.
Correspondence concerning this article should be addressed to Darryl W. Schneider, Department of Psychological Sciences, Purdue University, 703 Third Street, West Lafayette, IN 47907. E-mail: dws@purdue.edu

Baene, Koch, & Brass, 2013). A major aim has been to show that task switching effects cannot be attributed solely to cue-related processing. For example, Monsell and Mizon (2006) demonstrated that task switching effects—not just overall transition effects—tend to decrease with a longer CTI (especially when task switches are infrequent), which they interpreted as evidence of task-set reconfiguration during the CTI. Cue repetition effects have received less attention, even though they are sometimes larger than task switching effects (see Logan, Schneider, & Bundesen, 2007) and can be used to investigate aspects of cue-related processing. For example, Arrington, Logan, and Schneider (2007) used a double-response procedure (respond to the cue, then perform the cued task on the target) to determine that cue encoding had been separated from target processing when cue repetition effects were restricted to RT for the cue response. However, research aimed at understanding cue repetition effects has been limited, and some authors have proposed that task switching research would be simpler if cue repetitions were avoided altogether by having the cue switch on every trial (Monsell & Mizon, 2006). In contrast, Meiran (2014, p. 63) suggested "that 'cue repetition effects' may reflect important aspects of cognitive control," in which case it would be wise to study them in more detail.

Theoretical Accounts of Cue Repetition Effects

The focus of the present study is on cue repetition effects, which are hypothesized to reflect priming of either cue encoding or cue-based retrieval from long-term memory (LTM; Logan & Bundesen, 2003; Mayr & Kliegl, 2003). Regarding the latter hypothesis, Mayr and Kliegl (2003) suggested cue repetition effects arise from cue-based retrieval of task rules from LTM into working memory, building on their earlier idea that working memory can represent the rules for only one task at a time (Mayr & Kliegl, 2000). According to this view, cue repetitions are faster than task repetitions due to priming of retrieval that occurs when a repeated cue uses a recently activated pathway into LTM.

Priming of cue-based retrieval is a plausible explanation of cue repetition effects, although the consequence of retrieval—holding the rules for only one task in working memory—is difficult to reconcile with evidence of multiple task representations being concurrently active or interfering with each other. For example, task repetitions are slower in mixed-task blocks than in pure-task blocks, a finding known as mixing cost (e.g., Koch, Prinz, & Allport, 2005; Marí-Beffa & Kirkham, 2014; Rubin & Meiran, 2005; see also Los, 1996). If one set of task rules were retrieved into working memory on the previous trial, then it is unclear why a task repetition on the current trial (for which the relevant task rules are already in working memory) would be affected by the block context. As another example, performance is worse when a target is associated with different responses across tasks (incongruent) than with the same response (congruent), a finding known as the response congruency effect (e.g., Kiesel, Wendt, & Peters, 2007; Meiran & Kessler, 2008; Schneider & Logan, 2009). If one set of task rules were present in working memory, then response congruency effects could not occur for nonrepeated targets, contrary to recent findings (Schneider, 2015a, 2015b).

A different hypothesis was proposed by Logan and Bundesen (2003), who suggested cue repetition effects arise from cue encoding—the process of forming an internal representation of the cue to guide subsequent cognitive processing. According to this view, cue repetitions are faster than task repetitions due to priming of cue encoding that occurs when a trace of a repeated cue is active in short-term memory (STM). Logan and Bundesen (2003) construed cue encoding as a race between two comparison processes. One process involves comparing the current cue with LTM representations of learned cues. The other process involves comparing the current cue with a STM representation of the cue from the immediately preceding trial. A cue is encoded when either of the comparison processes yields a match, with cue encoding time determined by whichever process finishes first. The rate of each comparison process is proportional to the similarity between the current cue and representations in memory, such that higher similarity results in faster cue encoding.

Logan and Bundesen (2003; see also Schneider & Logan, 2005) argued that priming of cue encoding occurs when the previous cue (represented in STM) is similar to the current cue, facilitating encoding of the latter. Similarity is highest when the current cue is identical to the previous cue, as in the case of a cue repetition (e.g., *shape* followed by *shape*, returning to the examples used to illustrate a 2:1 cue–task mapping), resulting in a short cue encoding time. Similarity is lower when the current cue differs from the previous cue, as in the case of a task repetition (e.g., *form* followed by *shape*) or a task switch (e.g., *color* followed by *shape*), resulting in longer cue encoding times. If cue encoding time contributes to RT, which is likely at short and medium CTIs, then RT will be shorter for cue repetitions than for task repetitions, yielding a cue repetition effect. A formal model of this cue encoding hypothesis was developed by Logan and Bundesen (2003) and shown to account for empirical cue repetition effects in several studies (e.g., Arrington & Logan, 2004; Logan & Bundesen, 2004; Logan & Schneider, 2006b; Schneider & Logan, 2005, 2006, 2011).

A general hypothesis consistent with the views of Mayr and Kliegl (2003) and Logan and Bundesen (2003) is that cue repetition effects reflect priming of cue-related processing, with the specific mechanism (cue-based retrieval of task rules or cue encoding) open to debate. Even critics of cue-based priming accounts of task switching acknowledge "that priming of cue encoding contributes to performance" (Monsell & Mizon, 2006, p. 514), citing cue repetition effects as supporting evidence. However, existing theoretical accounts of cue repetition effects are limited because they do not distinguish between different types of priming. Cue repetitions might be faster than task repetitions because encoding of the current cue is primed by residual activation of perceptual features in STM (e.g., the orientation of the lines making up the letters in the cue word *shape*) or a perceptual processing pathway (e.g., visual encoding mechanisms for orientation and other features) associated with the previous cue. Alternatively, priming might arise from residual activation of conceptual features in STM (e.g., the meaning of the cue word *shape*) or a conceptual processing pathway (e.g., retrieval mechanisms for accessing word meaning in LTM). These types of priming are not mutually exclusive, but it is unknown whether and to what extent they might underlie cue repetition effects. Investigations of matching-task phenomena raise the possibility that cue repetition effects can be partitioned into components associated with perceptual and conceptual priming of cue encoding.

Investigations of Matching-Task Phenomena

Matching tasks were used extensively from the 1960s through the early 1980s to investigate human information processing (for reviews, see Farell, 1985; Nickerson, 1978; Posner, 1978; Proctor, 1981). The matching-task procedure involves judging whether two stimuli (e.g., letters), presented either simultaneously or successively, are the same or different. Instructions determine whether a match should be based on physical identity (e.g., *B* and *B* are the same), nominal identity (e.g., *B* and *b* are letters with the same name), or categorical identity (e.g., *B* and *D* belong to the same category: consonants).

Two matching-task phenomena are relevant in the present context. First, when judgments are based on nominal matching instructions, "same" responses are faster to physically identical stimuli (physical-same trials; e.g., *BB*) than to nominally identical stimuli (name-same trials; e.g., *Bb*), a phenomenon known as the name–physical disparity (Posner, Boies, Eichelman, & Taylor, 1969; Posner & Mitchell, 1967; Proctor, 1981). Second, when judgments are based on categorical matching instructions (e.g., vowels vs. consonants), "same" responses tend to be faster to nominally identical stimuli than to categorically identical stimuli (category-same trials; e.g., *BD*), a phenomenon I will label the category–name disparity (Posner, 1970; Posner & Mitchell, 1967). Name–physical disparities observed with naming tasks (in which the second stimulus is named rather than explicitly matched against the first stimulus; Eichelman, 1970; Proctor, 1981) are similar to stimulus repetition effects observed with choice reaction tasks involving many-to-one stimulus–response mappings, where responses are faster to physically identical stimulus repetitions than to successive stimuli that are different but mapped to the same response (e.g., Bertelson, 1965; Campbell & Proctor, 1993; Kornblum, 1973; Pashler & Baylis, 1991; Rabbitt, 1968).

Disparities in the matching-task procedure suggest different levels of processing that form a temporal hierarchy (Posner, 1978; Posner & Mitchell, 1967). Posner (1969) suggested that processing may involve abstraction from the physical stimulus level to the nominal and categorical levels, depending on the task context. Abstraction could occur in multiple ways, involving serial or parallel processes and shared or separate mechanisms (Posner, 1978). Empirical disparities between conditions, especially with sequential matching, can be explained by assuming the first stimulus activates or primes pathways in the cognitive system, facilitating encoding of the second stimulus (Eichelman, 1970; Posner & Snyder, 1975; Proctor, 1981). Applied to the name–physical disparity, responding is faster on physical-same trials than on name-same trials because encoding of the second stimulus is facilitated by priming of a perceptual pathway that processes visual characteristics of the stimuli (e.g., determining the visual percept of *B*). Applied to the category–name disparity, responding is faster on name-same trials than on category-same trials because encoding of the second stimulus is facilitated by priming of a conceptual pathway that processes nominal characteristics of the stimuli (e.g., determining that *B* and *b* have the same name and represent the same letter concept). From this perspective, the name–physical and category–name disparities can be linked to perceptual and conceptual priming of stimulus encoding, respectively. Similar hypotheses about speedups in perception and categorization have been considered for repetition effects observed with choice reaction tasks (Pashler & Baylis, 1991).

Matching-task phenomena are relevant to cue repetition effects because the combined effect of the name–physical and category–name disparities in the matching-task procedure resembles the cue repetition effect in the task-cuing procedure. Using the previous examples of letter stimuli and task cues, the faster condition in both cases involves two stimuli or cues that are physically identical: physical-same trials in the matching-task procedure (e.g., *B* followed by *B*) and cue repetitions in the task-cuing procedure (e.g., *shape* followed by *shape*). The slower condition in both cases involves two stimuli or cues that are physically and nominally different, but related by association with a category or a task: category-same trials in the matching-task procedure (e.g., *B* followed by *D*, both being consonants) and task repetitions in the task-cuing procedure (e.g., *form* followed by *shape*, both cuing a shape judgment). The analogy is not perfect because the matching-task procedure involves responding to the current stimulus by comparing it with the previous stimulus, whereas the task-cuing procedure involves responding to the target in the context of the current cue without needing any comparison with the previous cue. That said, the analogy can be used to motivate a closer look at cue repetition effects.

Perceptual and Conceptual Components of Cue Repetition Effects

Given that the name–physical and category–name disparities in the matching-task procedure can be attributed to perceptual and conceptual priming of stimulus encoding, respectively, there is a possibility that cue repetition effects in the task-cuing procedure can be partitioned into components associated with perceptual and conceptual priming of cue encoding. This partitioning would enable refinement of existing hypotheses about the mechanisms underlying cue repetition effects (Logan & Bundesen, 2003; Mayr & Kliegl, 2003). However, the potential contributions of perceptual and conceptual priming to cue repetition effects are unclear from previous research.

Extant evidence for perceptual priming of cue encoding is mixed. Grange and Houghton (2010) investigated whether cue repetition effects reflect perceptual priming of cue encoding. In their Experiment 1, the relevant visual property (slant, fill, or border) for a target detection task was cued by either icons depicting the visual properties or words describing the properties (e.g., *slanted*, *filled*, *border*), with two cues for each property. A cue repetition effect was found with words cues but not with iconic cues. In their Experiment 2, which involved only the iconic cues, no cue repetition effect was found again when the cues matched the visual properties of the targets, whereas a cue repetition effect emerged when the same cues mismatched the targets. Grange and Houghton interpreted their results as evidence against perceptual priming of cue encoding, arguing instead that cue repetition effects reflect priming of control processes involved in forming task representations in working memory. When cues are maximally transparent by depicting the visual properties to be judged, then task representations are unnecessary and cue repetition effects do not occur.

Schneider and Logan (2007) investigated whether sequence repetition effects associated with repeating and switching task

sequences were partly due to perceptual priming of cue encoding. In their experiment, subjects memorized two task sequences (labeled *alpha* and *beta*) and then were randomly cued on each trial to perform the task associated with a serial position in a sequence (e.g., *alpha two* indicated the second task in the alpha sequence was to be performed). The visual form of the sequence-position cues was manipulated such that each cue appeared in either word form (e.g., *alpha two*) or letter-digit form (e.g., α *2*). A sequence repetition effect was found (sequence repetitions were faster than sequence switches), but there was also a small form repetition effect (form repetitions were faster than form switches), though only for sequence repetitions. Schneider and Logan (2007) interpreted their results as evidence of perceptual priming of cue encoding because a sequence repetition with a form repetition involved the same percept across trials (e.g., *alpha* followed by *alpha*), whereas a sequence repetition with a form switch involved different percepts for the same concept (e.g., α followed by *alpha*). However, given that the cues were for sequence positions rather than for tasks per se, the results do not speak directly to cue repetition effects in the typical task-cuing procedure.

Extant evidence for conceptual priming of cue encoding is limited. Logan and Schneider (2006b) investigated whether semantically related cues assigned to the same task yield priming of cue encoding on task repetition trials. In their experiment, pairs of associated words (e.g., *king–queen* and *salt–pepper*) were used as task cues, with the words in each pair assigned to either the same task or different tasks. Task repetitions were faster when semantically related cues were assigned to the same task (producing task repetitions such as *king* followed by *queen*) than when the cues were assigned to different tasks (producing task repetitions such as *king* followed by *salt*). Logan and Schneider (2006b) interpreted their results as evidence of semantic or associative priming of cue encoding, but as a partial explanation of task switching effects rather than cue repetition effects.

The Present Study

In the present study, I used an experimental manipulation that enabled me to determine whether cue repetition effects reflect perceptual priming, conceptual priming, or both. Inspired by the matching-task literature, I exploited the fact that some concepts can be represented by different visual forms that have the same name. For example, letters of the alphabet have uppercase and lowercase forms, such that *D* and *d* differ perceptually but have the same name and meaning. As another example, numbers can be represented as words or as numerals, such that *three* and *3* differ perceptually but have the same name and meaning. I conducted experiments in which letters (*B*/*b*, *D*/*d*, *E*/*e*, and *G*/*g*) or numbers (*one*/*1*, *two*/*2*, *three*/*3*, and *four*/*4*), each in their uppercase/lowercase or word/numeral forms, respectively, served as arbitrary cues for perceptual categorization tasks (color and shape judgments of visual targets).[1] An example of cue–task mappings involving letters would be using *B*, *b*, *E*, and *e* as cues for the color task, and *D*, *d*, *G*, and *g* as cues for the shape task. An example of cue–task mappings involving numbers would be using *one*, *1*, *four*, and *4* as cues for the color task, and *two*, *2*, *three*, and *3* as cues for the shape task.

An advantage of using these cues and mappings is that they allow four types of transitions, defined here (with examples for the aforementioned letter cue–task mappings) and summarized in Table 1:

- **Task switches (e.g., *B* followed by *D*).** The cues indicate different tasks across trials, represent different concepts (*B* and *D* do not refer to the same letter), and have different percepts (*B* and *D* are not physically identical). Task switches in the present context are the same as in previous research involving 1:1 and 2:1 cue–task mappings.
- **Relational repetitions (e.g., *G* followed by *D*).** The cues indicate the same task across trials (which is what makes them related), but they represent different concepts and have different percepts. Relational repetitions correspond to "task repetitions" in previous research involving 2:1 cue–task mappings.
- **Nominal repetitions (e.g., *d* followed by *D*).** The cues indicate the same task and they represent the same concept (*d* and *D* refer to the same letter) across trials, but they have different percepts. Nominal repetitions do not correspond to any transition in previous research involving 2:1 cue–task mappings, but they are analogous to sequence repetitions with form switches in Schneider and Logan's (2007) experiment.
- **Physical repetitions (e.g., *D* followed by *D*).** The cues indicate the same task, represent the same concept, and have the same percept (*D* and *D* are physically identical) across trials. Physical repetitions correspond to "cue repetitions" in previous research involving 1:1 and 2:1 cue–task mappings.

Table 1 indicates which property of the cue (task, concept, or percept) is the same or different across trials for each transition, in addition to providing a second set of examples (for the aforementioned number cue–task mappings). Three of the four transitions (task switches, relational repetitions, and physical repetitions) correspond to transitions that occur with a 2:1 cue–task mapping, enabling calculation of the same transition effects mentioned earlier:

- **Task switching effect.** The difference between task switches and relational repetitions, which differ only with respect to whether the cues indicate different tasks or the same task across trials. Any difference in performance would reflect task switching processes that could not be reduced entirely to processes related to a change of cues.
- **Cue repetition effect.** The difference between relational and physical repetitions, both of which involve task repetitions, but which differ with respect to whether the cues are associated with different concepts and percepts or with the same concept and percept across trials. Any difference in performance would reflect priming of cue encoding, but it would not distinguish between different types of priming.

The inclusion of a fourth transition (nominal repetitions) in the present study allows one to fractionate the cue repetition effect into

[1] Arbitrary cues—which have no pre-existing associations with the tasks to which they are assigned—have been used in several task switching studies (e.g., Brass & von Cramon, 2004; Gade & Koch, 2007; Koch, 2003; Logan & Schneider, 2006b; Mayr & Kliegl, 2003; Monsell, Sumner, & Waters, 2003; Schneider & Logan, 2011; Sohn & Anderson, 2001).

Table 1
Classification of Transitions (With Examples for Letter and Number Cues)

Transition	Cue property across trials[a]			Letter cue examples[b]		Number cue examples[b]	
	Task	Concept	Percept	Previous trial	Current trial	Previous trial	Current trial
Task switch	Different	Different	Different	*B*, *b*, *E*, or *e*	*D*	*one*, *1*, *four*, or *4*	*3*
Relational repetition	Same	Different	Different	*G* or *g*	*D*	*two* or *2*	*3*
Nominal repetition	Same	Same	Different	*d*	*D*	*three*	*3*
Physical repetition	Same	Same	Same	*D*	*D*	*3*	*3*

[a] *Task* refers to whether the cues indicate the same task or different tasks across trials. *Concept* refers to whether the cues represent the same concept or different concepts across trials. *Percept* refers to whether the cues have the same percept or different percepts across trials. [b] Letter cue examples assume *B*, *b*, *E*, and *e* are mapped to one task, and *D*, *d*, *G*, and *g* are mapped to the other task. Number cue examples assume *one*, *1*, *four*, and *4* are mapped to one task, and *two*, *2*, *three*, and *3* are mapped to the other task. All possible cue–task mappings were used. The transitions that actually occurred in the experiments are not limited to these examples.

components and calculate effects associated with conceptual and perceptual priming:

- **Conceptual priming effect.** The difference between relational and nominal repetitions, both of which involve task repetitions and different percepts, but differ with respect to whether the cues represent different concepts (*G* followed by *D*) or the same concept (*d* followed by *D*) across trials. Any difference in performance would reflect conceptual priming associated with accessing the same name and meaning of the cue on nominal repetition trials.
- **Perceptual priming effect.** The difference between nominal and physical repetitions, both of which involve task repetitions and the same concept, but differ with respect to whether the cues have different percepts (*d* followed by *D*) or the same percept (*D* followed by *D*) across trials. Any difference in performance would reflect perceptual priming associated with processing the same visual form of the cue on physical repetition trials.

To determine whether the transition effects are modulated by the time available for processing the cue in advance of the target, multiple CTIs ranging from 100 ms to 900 ms were used in each experiment. As noted earlier, there is evidence that transition effects tend to decrease with a longer CTI (Logan & Bundesen, 2003; Meiran et al., 2000; Monsell & Mizon, 2006; Schneider & Logan, 2011). If the transition effects are associated with different time-course functions, then further insight might be provided into the nature of the cognitive mechanisms engaged during the transitions.

The crux of the present study is that the introduction of nominal repetitions enables partitioning of cue repetition effects into perceptual and conceptual priming effects, analogous to how the introduction of relational repetitions with a 2:1 cue–task mapping in previous research enabled partitioning of overall transition effects into task switching and cue repetition effects. One can determine whether distinct perceptual and conceptual priming effects exist and measure their unique contributions to cue repetition effects. This partitioning of cue repetition effects would represent an important and novel advance in understanding priming of cue encoding. It would inform existing hypotheses about cue repetition effects (Logan & Bundesen, 2003; Mayr & Kliegl, 2003) and theories of task switching in general, because a comprehensive account of cued task switching would need to explain how cues are represented and processed.

Experiment 1

In Experiment 1, the uppercase/lowercase forms of the letters *B*/*b*, *D*/*d*, *E*/*e*, and *G*/*g*, or the word/numeral forms of the numbers *one*/*1*, *two*/*2*, *three*/*3*, and *four*/*4*, served as cues for color (red or yellow) and shape (circle or triangle) tasks performed on visual target stimuli. Cue type (letters or numbers) was manipulated between subjects. The specific letters serving as cues were chosen for three reasons. First, the uppercase and lowercase forms of each cue letter are perceptually distinct and cannot be made identical through analog resizing (Posner & Mitchell, 1967). Second, the cue letters are phonologically similar, which may have motivated subjects to focus on the letters' distinct visual representations. Third, the cue letters did not correspond to the first letters of any task name (color or shape) or task category (red, yellow, circle, or triangle), precluding cue-related compatibility effects found in previous studies (Arrington et al., 2007; Logan & Schneider, 2006a; Schneider & Logan, 2005). The specific numbers serving as cues were chosen simply because they occur in sequence.

Two letters or numbers were mapped to each task, resulting in four types of transitions: task switches, relational repetitions, nominal repetitions, and physical repetitions (see Table 1). Unconstrained randomization of cues would be expected to yield unequal transition frequencies: 50% task switches, 25% relation repetitions, 12.5% nominal repetitions, and 12.5% physical repetitions. Given that previous research has shown that transition effects are sensitive to transition frequencies (Mayr, 2006; Mayr, Kuhns, & Rieter, 2013; Monsell & Mizon, 2006; Schneider & Logan, 2006), I constrained the randomization of cues such that each transition occurred on 25% of trials. Consequently, differences in the sizes of transition effects cannot be attributed to differences in transition frequencies.

Method

Subjects. Ninety-six students from Purdue University participated for course credit. Half of the subjects had letter cues and the other half had number cues. All subjects in the present study

reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, tasks, stimuli, and responses. The experiment was conducted on Dell OptiPlex 7010 computers that displayed stimuli on Dell UltraSharp 21.5" monitors and registered responses from QWERTY keyboards. Stimulus presentation and response registration were controlled with E-Prime (Version 2.0), using experiment and trial information generated in advance by a randomization algorithm programmed in MATLAB (Version R2013a). Stimuli were displayed on a black background at a viewing distance of approximately 50 cm. Target stimuli consisted of four colored shapes: red circle, red triangle, yellow circle, and yellow triangle. Each target measured 2.4 cm × 2.4 cm onscreen and was filled by its color. Two perceptual categorization tasks were performed on the targets. The color task involved categorizing the target color as red or yellow. The shape task involved categorizing the target shape as circle or triangle. Responses were made with the S and L keys on the keyboard. Same-task categories were mapped to different keys (e.g., red and circle categories were mapped to the S key; yellow and triangle categories were mapped to the L key). The four possible sets of category–response mappings were counterbalanced across subjects. Reminders of the category–response mappings were displayed throughout each trial at the bottom of the screen.

For subjects with letter cues, the tasks were cued by the uppercase/lowercase forms of the letters *B*/*b*, *D*/*d*, *E*/*e*, and *G*/*g*. The uppercase and lowercase forms of two letters were assigned as cues for each task. For example, the color task might be cued by *B*, *b*, *E*, or *e*, and the shape task might be cued by *D*, *d*, *G*, or *g*. For subjects with number cues, the tasks were cued by the word/numeral forms of the numbers *one*/*1*, *two*/*2*, *three*/*3*, and *four*/*4*. The word and numeral forms of two numbers were assigned as cues for each task. For example, the color task might be cued by *one*, *1*, *four*, or *4*, and the shape task might be cued by *two*, *2*, *three*, or *3*. All cues were displayed in white 24-point Arial font. All possible sets of cue–task mappings were counterbalanced across subjects. Each possible combination of cue–task and category–response mappings was used by two subjects.

Procedure. Subjects sat at computers in individual testing rooms after providing informed consent for a study protocol approved by the Purdue University Institutional Review Board. Instructions were presented onscreen and read aloud by the experimenter. During the instructions, subjects completed four example trials with accuracy feedback. The example trials included one instance of each conceptually distinct cue (e.g., *B*, *d*, *e*, and *G*, for subjects with letter cues) and one instance of each target. All example trials had a fixed CTI of 400 ms. Following the instructions, the experimenter left the testing room and the subject completed the experiment, which consisted of 10 blocks of 81 trials per block without accuracy feedback. The first block was treated as practice and excluded from analysis. Reminders of the cue–task mappings were displayed onscreen between blocks.

Each experimental trial started with a fixation cross displayed in the center of the screen. After 500 ms, the fixation cross was replaced by a cue. After a CTI of 100, 200, 400, 600, or 900 ms, a target was displayed 2.2 cm below the cue (with the distance measured from the center of each stimulus). The stimuli remained onscreen until the subject responded, then the next trial started after a blank screen was displayed for 500 ms. Subjects were instructed to respond quickly and accurately. The first trial of each block involved a randomly selected task, cue, target, and CTI. The remaining 80 trials of each block were determined by random selection, subject to the constraints that each task, target, and correct response occurred equally often. Transitions and CTIs were randomized within each block such that each combination of transition and CTI occurred equally often. In addition, each of the eight cues of the relevant cue type was presented at least eight times per block. Due to the randomization constraints, each transition (task switch, relational repetition, nominal repetition, and physical repetition) occurred on 25% of trials. Each subject experienced 40 trials for each combination of transition and CTI.

Results

The first block and the first trial of each subsequent block were excluded. Trials with RTs more than three standard deviations above the mean in each condition for a given subject were excluded (2.5% of trials). Error trials were excluded from the RT analyses. Mean RTs and error rates for the 2 (cue type) × 4 (transition) × 5 (CTI) experiment design are presented in Figure 1. Analyses of variance (ANOVAs) based on the full design are not readily informative because transition effects would need to be analyzed further with multiple post hoc contrasts. For this reason, the data were analyzed separately from the outset for transition effects due to task switching, conceptual priming, and perceptual priming, as well as changes in transition effects with CTI. Following these analyses, partitioning of the overall transition effect (the performance difference between task switches and physical repetitions) into components is addressed. The data were also analyzed

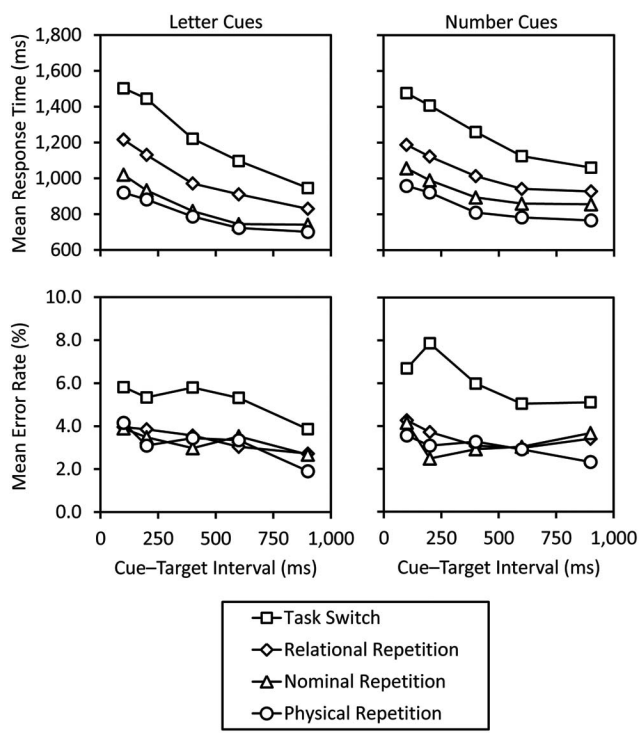

Figure 1. Mean response times and error rates as a function of cue type, transition, and cue–target interval in Experiment 1.

with respect to whether the form of the cue (uppercase or lowercase; word or numeral) repeated or switched across trials. Form transition analyses are reported in Appendix A.

Task switching analysis. The purpose of this analysis was to assess effects due to task switching by comparing performance for relational repetitions and task switches, which differ only with respect to whether the cues indicate the same task or different tasks across trials (see Table 1). Mean RTs and error rates were submitted to 2 (cue type) × 2 (transition: relational repetition or task switch) × 5 (CTI) mixed-factor ANOVAs, with the results summarized in Table 2. For all ANOVAs in the present study, cue type was a between-subjects factor, whereas transition and CTI were within-subjects factors.

Mean RT was longer for task switches (1,254 ms) than for relational repetitions (1,025 ms; see Figure 1), resulting in a 229-ms task switching effect and a significant main effect of transition. RT became shorter with a longer CTI, resulting in a significant main effect of CTI. The change in RT from the shortest to the longest CTI was greater with letter cues (472 ms) than with number cues (337 ms), resulting in a significant interaction between cue type and CTI. The task switching effect decreased from 288 ms to 124 ms from the shortest to the longest CTI, resulting in a significant interaction between transition and CTI.

Mean error rate was higher for task switches (5.7%) than for relational repetitions (3.5%; see Figure 1), resulting in a 2.2% task switching effect and a significant main effect of transition. Error rate decreased from 5.2% to 3.8% from the shortest to the longest CTI, resulting in a significant main effect of CTI.

Conceptual priming analysis. The purpose of this analysis was to assess effects due to conceptual priming by comparing performance for nominal and relational repetitions, which differ only with respect to whether the cues represent the same concept or different concepts across trials (see Table 1). Mean RTs and error rates were submitted to 2 (cue type) × 2 (transition: nominal or relational repetition) × 5 (CTI) mixed-factor ANOVAs, with the results summarized in Table 2.

Mean RT was longer for relational repetitions (1,025 ms) than for nominal repetitions (891 ms; see Figure 1), resulting in a 134-ms conceptual priming effect and a significant main effect of transition. RT became shorter with a longer CTI, resulting in a significant main effect of CTI. The change in RT from the shortest to the longest CTI was greater with letter cues (333 ms) than with number cues (230 ms), resulting in a significant interaction between cue type and CTI. The conceptual priming effect decreased from 164 ms to 81 ms from the shortest to the longest CTI, resulting in a significant interaction between transition and CTI.

Mean error rate was similar for relational repetitions (3.5%) and for nominal repetitions (3.3%). Error rate decreased from 4.1% to 3.1% from the shortest to the longest CTI, resulting in a significant main effect of CTI.

Perceptual priming analysis. The purpose of this analysis was to assess effects due to perceptual priming by comparing performance for physical and nominal repetitions, which differ only with respect to whether the cues have the same percept or different percepts across trials (see Table 1). Mean RTs and error rates were submitted to 2 (cue type) × 2 (transition: physical or nominal repetition) × 5 (CTI) mixed-factor ANOVAs, with the results summarized in Table 2.

Mean RT was longer for nominal repetitions (891 ms) than for physical repetitions (825 ms; see Figure 1), resulting in a 66-ms perceptual priming effect and a significant main effect of transition. RT became shorter with a longer CTI, resulting in a significant main effect of CTI. The perceptual priming effect was smaller with letter cues (48 ms) than with number cues (83 ms),

Table 2
Summary of Analyses of Variance for Experiment 1

			Response time			Error rate		
Analysis	Effect	*df*	*F*	*MSE*	η_p^2	*F*	*MSE*	η_p^2
Task switching	C	1,94	.20	792,352	<.01	.44	128	.01
	T	1,94	271.21*	46,414	.74	57.57*	21	.38
	I	4,376	227.49*	24,482	.71	5.61*	14	.06
	C × T	1,94	.02	46,414	<.01	2.10	21	.02
	C × I	4,376	5.86*	24,482	.06	1.36	14	.01
	T × I	4,376	10.58*	24,755	.10	1.16	12	.01
	C × T × I	4,376	.13	24,755	<.01	1.19	12	.01
Conceptual priming	C	1,94	1.21	572,444	.01	.00	92	<.01
	T	1,94	83.60*	51,639	.47	.80	9	.01
	I	4,376	132.49*	20,988	.59	3.31*	10	.03
	C × T	1,94	3.30	51,639	.03	.10	9	<.01
	C × I	4,376	3.72*	20,988	.04	1.59	10	.02
	T × I	4,376	2.69*	21,468	.03	.83	10	.01
	C × T × I	4,376	.42	21,468	<.01	.33	10	<.01
Perceptual priming	C	1,94	1.88	505,145	.02	.04	82	<.01
	T	1,94	63.21*	16,434	.40	.80	9	.01
	I	4,376	105.09*	17,589	.53	4.68*	9	.05
	C × T	1,94	4.48*	16,434	.05	.07	9	<.01
	C × I	4,376	1.57	17,589	.02	1.26	9	.01
	T × I	4,376	1.11	16,055	.01	1.67	9	.02
	C × T × I	4,376	.51	16,055	.01	.70	9	.01

Note. C = cue type; T = transition; I = cue–target interval.
* $p < .05$.

resulting in a significant interaction between cue type and transition.

Mean error rate was similar for nominal repetitions (3.3%) and for physical repetitions (3.1%). Error rate decreased from 3.9% to 2.6% from the shortest to the longest CTI, resulting in a significant main effect of CTI.

Partitioning of the overall transition effect. The preceding analyses indicate the overall transition effect on RT (the difference between task switches and physical repetitions) can be partitioned into components. For subjects with letter cues, the overall transition effect (439 ms) can be divided almost equally into a task switching effect (230 ms) and a cue repetition effect (209 ms). The cue repetition effect can be divided into a conceptual priming effect (161 ms) and a perceptual priming effect (48 ms). The conceptual priming effect was larger than the perceptual priming effect for 35 of the 48 letter-cue subjects ($p = .002$, sign test), resulting in a significant difference in the aggregate data, $t(47) = 3.99$, $SE = 28$, $p < .001$. For subjects with number cues, the overall transition effect (418 ms) can also be divided almost equally into a task switching effect (227 ms) and a cue repetition effect (191 ms). The cue repetition effect can be divided into a conceptual priming effect (108 ms) and a perceptual priming effect (83 ms). The conceptual priming effect was larger than the perceptual priming effect for only 27 of the 48 number-cue subjects ($p = .47$, sign test), resulting in a nonsignificant difference in the aggregate data, $t(47) = 0.90$, $SE = 27$, $p = .37$.

Discussion

There were three main findings from the RT data in Experiment 1. First, a task switching effect was found, replicating the results of previous studies in which 2:1 cue–task mappings were used to dissociate task switching and cue repetition effects (e.g., Mayr & Kliegl, 2003; Monsell & Mizon, 2006; Schneider & Logan, 2011). The task switching effect was similar across cue types and decreased reliably with a longer CTI. Second, a conceptual priming effect was found, indicating that cue encoding was influenced by whether the cues on successive trials represented the same concept (nominal repetition) or different concepts (relational repetition), even though the cues in both cases indicated task repetitions. Third, a perceptual priming effect was found, indicating that cue encoding was influenced by whether the cues on successive trials had the same percept (physical repetition) or different percepts (nominal repetitions), even though the cues in both cases referred to the same concept (e.g., the same letter). Together, the conceptual and perceptual priming effects constitute a cue repetition effect, which is analogous to the cue repetition effects obtained in previous studies involving 2:1 cue–task mappings. For subjects with letter cues, the majority of the cue repetition effect reflected conceptual priming (with a nontrivial contribution of perceptual priming), whereas for subjects with number cues, the cue repetition effect reflected conceptual and perceptual priming in similar proportions.

Experiment 2

The purpose of Experiment 2 was to replicate Experiment 1, but with different transition frequencies. As noted earlier, unconstrained randomization of cues would be expected to yield 50% task switches, which is common in task-cuing experiments. Task switches occurred on 25% of trials in Experiment 1 because cue randomization was constrained such that all transitions occurred equally often. To assess effects of task switch frequency, I changed how randomization was constrained in Experiment 2. Task switches occurred on 50% of trials, whereas each type of repetition (relational, nominal, and physical) occurred on 16.7% (one-sixth) of trials. As in Experiment 1, the relative frequencies of the repetitions remained equal in Experiment 2 to ensure that the relative contributions of conceptual and perceptual priming effects to cue repetition effects cannot be attributed to differences in those transition frequencies.

Method

Subjects. Ninety-six students from Purdue University participated for course credit. Half of the subjects had letter cues and the other half had number cues. None of them had participated in Experiment 1.

Apparatus, tasks, stimuli, and responses. These aspects of the experiment were identical to those of Experiment 1.

Procedure. The procedure was identical to that of Experiment 1, except for changes to accommodate different transition frequencies. The experiment consisted of 11 blocks of 73 trials per block, resulting in a total (803 trials) similar to that of Experiment 1 (810 trials). Three of the five CTIs from Experiment 1 were used: 100, 400, and 900 ms. Trial randomization was constrained in the same manner as in Experiment 1, but with two changes. First, task switches occurred on 50% of trials, whereas relational, nominal, and physical repetitions each occurred on 16.7% (one-sixth) of trials. Each transition occurred equally often with each CTI. Second, each of the eight cues of the relevant cue type was presented at least seven times per block. By reducing the frequency of each repetition but also reducing the number of CTIs, each subject experienced 44 trials for each combination of repetition and CTI, and 132 task switches per CTI.

Results

Data trimming was identical to that of Experiment 1 (2.4% of trials were RT outliers) and the data were analyzed in a similar manner. Mean RTs and error rates for the 2 (cue type) × 4 (transition) × 3 (CTI) experiment design are presented in Figure 2. Form transition analyses are reported in Appendix A.

Task switching analysis. Mean RTs and error rates were submitted to 2 (cue type) × 2 (transition: relational repetition or task switch) × 3 (CTI) mixed-factors ANOVAs, with the results summarized in Table 3.

Mean RT was longer for task switches (1,319 ms) than for relational repetitions (1,197 ms; see Figure 2), resulting in a 122-ms task switching effect and a significant main effect of transition. RT became shorter with a longer CTI, resulting in a significant main effect of CTI. RT was longer with letter cues (1,352 ms) than with number cues (1,164 ms), resulting in a significant main effect of cue type. The change in RT from the shortest to the longest CTI was greater with letter cues (420 ms) than with number cues (363 ms), resulting in a significant interaction between cue type and CTI.

Mean error rate was higher for task switches (6.0%) than for relational repetitions (4.4%; see Figure 2), resulting in a 1.6% task

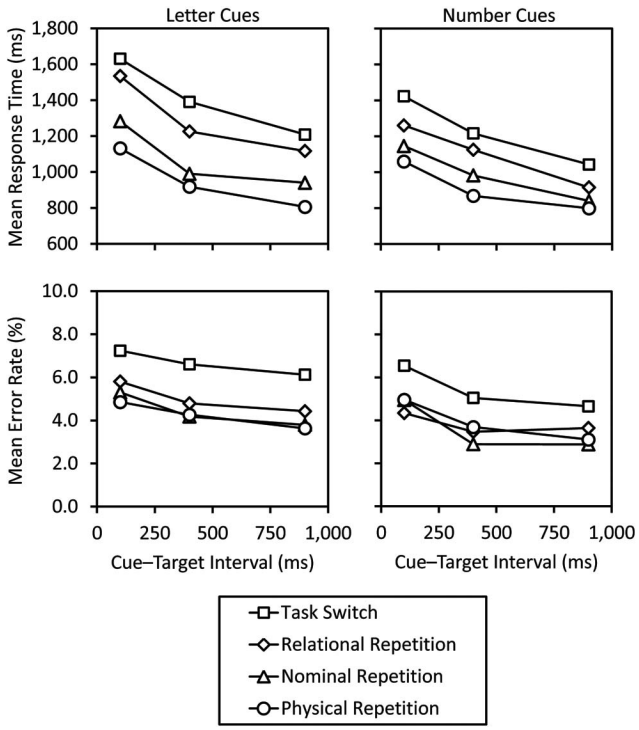

Figure 2. Mean response times and error rates as a function of cue type, transition, and cue–target interval in Experiment 2.

switching effect and a significant main effect of transition. Error rate decreased from 6.0% to 4.7% from the shortest to the longest CTI, resulting in a significant main effect of CTI.

Conceptual priming analysis. Mean RTs and error rates were submitted to 2 (cue type) × 2 (transition: nominal or relational repetition) × 3 (CTI) mixed-factors ANOVAs, with the results summarized in Table 3.

Mean RT was longer for relational repetitions (1,197 ms) than for nominal repetitions (1,030 ms; see Figure 2), resulting in a 167-ms conceptual priming effect and a significant main effect of transition. The conceptual priming effect was larger with letter cues (222 ms) than with number cues (112 ms), resulting in a significant interaction between cue type and transition. RT became shorter with a longer CTI, resulting in a significant main effect of CTI. RT was longer with letter cues (1,182 ms) than with number cues (1,045 ms), resulting in a significant main effect of cue type. The change in RT from the shortest to the longest CTI was greater with letter cues (380 ms) than with number cues (327 ms), resulting in a significant interaction between cue type and CTI.

Mean error rate was similar for relational repetitions (4.4%) and for nominal repetitions (4.0%). Error rate decreased from 5.1% to 3.7% from the shortest to the longest CTI, resulting in a significant main effect of CTI.

Perceptual priming analysis. Mean RTs and error rates were submitted to 2 (cue type) × 2 (transition: physical or nominal repetition) × 3 (CTI) mixed-factors ANOVAs, with the results summarized in Table 3.

Mean RT was longer for nominal repetitions (1,030 ms) than for physical repetitions (930 ms; see Figure 2), resulting in a 100-ms perceptual priming effect and a significant main effect of transition. RT became shorter with a longer CTI, resulting in a significant main effect of CTI.

Mean error rate was similar for nominal repetitions (4.0%) and for physical repetitions (4.1%). Error rate decreased from 5.0% to 3.4% from the shortest to the longest CTI, resulting in a significant main effect of CTI.

Partitioning of the overall transition effect. For subjects with letter cues, the overall transition effect (458 ms) can be divided into a task switching effect (117 ms) and a cue repetition effect (341 ms). The cue repetition effect can be divided into a conceptual priming effect (222 ms) and a perceptual priming effect (119 ms). The conceptual priming effect was larger than the perceptual priming effect for 38 of the 48 letter-cue subjects ($p <$ .001, sign test), resulting in a significant difference in the aggregate data, $t(47) = 2.73$, $SE = 38$, $p = .009$. For subjects with number cues, the overall transition effect (318 ms) can also be divided into a task switching effect (126 ms) and a cue repetition effect (192 ms). The cue repetition effect can be divided into a conceptual priming effect (112 ms) and a perceptual priming effect (80 ms). The conceptual priming effect was larger than the perceptual priming effect for only 29 of the 48 number-cue subjects ($p = .19$, sign test), resulting in a nonsignificant difference in the aggregate data, $t(47) = 0.70$, $SE = 45$, $p = .49$.

Discussion

There were three main findings from the RT data in Experiment 2. First, a task switching effect was found. However, the effect was noticeably smaller in Experiment 2 (122 ms) than in Experiment 1 (229 ms), and did not decrease reliably with a longer CTI. These results suggest an effect of task switch frequency (25% in Experiment 1 vs. 50% in Experiment 2), which was investigated in combined experiment analyses reported in Appendix B. Second, a conceptual priming effect was found, indicating that memory for the conceptual representations of letters or numbers affected cue encoding. Third, a perceptual priming effect was found, indicating that memory for the perceptual representations of letters or numbers affected cue encoding. Together, the conceptual and perceptual priming effects constitute a cue repetition effect. As in Experiment 1, for subjects with letter cues, the majority of the cue repetition effect reflected conceptual priming (with a sizable contribution of perceptual priming), whereas for subjects with number cues, the cue repetition effect reflected conceptual and perceptual priming in similar proportions.

General Discussion

The purpose of the present study was to achieve insight regarding cue repetition effects in task switching performance, which are hypothesized to reflect priming of cue-related processing. Inspired by the matching-task literature, I focused on determining whether cue repetition effects reflect perceptual or conceptual priming of cue encoding (or both). I conducted two experiments in which letters or numbers in their uppercase/lowercase or word/numeral forms, respectively, were used as cues for perceptual categorization tasks. The fact that some cues represented the same concept but had different percepts (e.g., *d* and *D*) allowed me to assess performance for four types of transitions: task switches, relational

Table 3
Summary of Analyses of Variance for Experiment 2

Analysis	Effect	*df*	Response time *F*	Response time *MSE*	Response time η_p^2	Error rate *F*	Error rate *MSE*	Error rate η_p^2
Task switching	C	1,94	9.10*	557,286	.09	1.77	121	.02
	T	1,94	48.01*	44,702	.34	38.25*	10	.29
	I	2,188	219.35*	33,770	.70	9.35*	9	.09
	C × T	1,94	.07	44,702	<.01	.01	10	<.01
	C × I	2,188	3.77*	33,770	.04	.20	9	<.01
	T × I	2,188	.17	31,847	<.01	.42	7	<.01
	C × T × I	2,188	2.03	31,847	.02	1.02	7	.01
Conceptual priming	C	1,94	5.60*	483,385	.06	1.57	96	.02
	T	1,94	76.60*	52,231	.45	2.05	12	.02
	I	2,188	138.06*	44,488	.60	10.87*	11	.10
	C × T	1,94	8.40*	52,231	.08	.34	12	<.01
	C × I	2,188	6.26*	44,488	.06	.28	11	<.01
	T × I	2,188	1.67	35,026	.02	.85	9	.01
	C × T × I	2,188	.19	35,026	<.01	.58	9	.01
Perceptual priming	C	1,94	1.59	352,600	.02	.62	83	.01
	T	1,94	31.57*	45,320	.25	.13	8	<.01
	I	2,188	196.84*	24,486	.68	16.21*	9	.15
	C × T	1,94	1.20	45,320	.01	1.23	8	.01
	C × I	2,188	2.88	24,486	.03	.95	9	.01
	T × I	2,188	.55	24,233	.01	.50	11	.01
	C × T × I	2,188	2.50	24,233	.03	.03	11	<.01

Note. C = cue type; T = transition; I = cue–target interval.
* $p < .05$.

repetitions, nominal repetitions, and physical repetitions (see Table 1). I obtained large RT differences between transitions in each experiment (see Figures 1 and 2) attributable to task switching, conceptual priming, and perceptual priming.[2] Together, the conceptual and perceptual priming effects constituted robust cue repetition effects. Combined experiment analyses revealed that task switching effects were smaller when task switches were more frequent (see Appendix B). Collectively, the novel results of the present study indicate that cue repetition effects are more complex than previously thought.

The partitioning of cue repetition effects into conceptual and perceptual priming effects suggests cue-related processing in existing theoretical accounts can be split into multiple stages. Given that priming of cue encoding is the dominant account in the task switching literature (Jost et al., 2013; Logan & Bundesen, 2003; Schneider & Logan, 2005), I will discuss how cue encoding can be reinterpreted as consisting of three stages, using Logan and Bundesen's (2003) view as a framework. Even though the stages are discussed in a specific order, I make no strong claims about their independence or whether they occur in series or in parallel. For example, cue encoding might involve a series of discrete stages, with the finished output of one stage becoming the input for the next stage. Alternatively, each stage might represent a different level of cue encoding achieved by processes that work in parallel and pass partial information to each other in a cascaded manner (McClelland, 1979). A more detailed account of cue encoding that distinguishes between these possibilities requires additional data and computational modeling beyond the scope of the present study.

The first stage of cue encoding likely involves forming a perceptual representation of the cue (e.g., a visual percept of the letter *D*). As hypothesized by Logan and Bundesen (2003), this process may involve comparing the current cue to a STM representation of the previous cue and to LTM representations of learned cues. The rate of each comparison process is proportional to the similarity between the current cue and representations in memory, such that higher similarity results in faster cue encoding. For this stage, similarity would be defined in terms of the match between the visual form of the cue and perceptual representations in memory. A physical repetition (*D* followed by *D*) would yield a strong match because there is complete perceptual overlap, whereas a nominal repetition (*d* followed by *D*) would yield a weak match because there is little perceptual overlap. The mismatch for nominal repetitions would be salient with number cues because of differences in length (*three* vs. *3*), which might explain why the perceptual priming effect represented a larger percentage of the cue repetition effect for number cues than for letter cues. The higher similarity for physical repetitions than for nominal repetitions would lead to faster cue encoding for the former than for the latter, consistent with the observed perceptual priming effects.

The second stage of cue encoding likely involves forming a conceptual representation of the cue (e.g., the meaning of the letter *D*). Drawing on Logan and Bundesen's (2003) hypothesis, this process might also involve similarity-based comparisons with representations in STM and LTM. For this stage, similarity would be defined in terms of the match between the meaning of the cue and conceptual representations in memory. A nominal

[2] Changes in the transition effects with CTI were modest. The task switching and conceptual priming effects decreased reliably across CTI in Experiment 1, whereas all other transition effects decreased numerically across CTI. These results do not suggest clear differences in the time-course functions for the different transition effects.

repetition (*d* followed by *D*) would yield a strong match because there is complete conceptual overlap, whereas a relational repetition (*G* followed by *D*) would yield a weaker match because there is less conceptual overlap—both cues refer to letters, resulting in some conceptual overlap, but they represent different letters. The mismatch for relational repetitions would be sensitive to preexisting conceptual associations between cues, consistent with Logan and Schneider's (2006b) finding that relational repetitions were faster when semantically related cues were assigned to the same task than when they were assigned to different tasks. The higher similarity for nominal repetitions than for relational repetitions would lead to faster cue encoding for the former than for the latter, consistent with the observed conceptual priming effects.

The third stage of cue encoding—or a distinct stage following cue encoding—likely involves using the cue to retrieve a task representation from memory based on learned cue–task mappings.[3] The task representation could take the form of a task set (Mayr & Kliegl, 2000; Rogers & Monsell, 1995), a task-name mediator (Logan & Schneider, 2006a), or a task goal (Rubinstein, Meyer, & Evans, 2001). This process might be sensitive to the history of retrieving a specific task representation, being faster for a more recently cued task. A relational repetition (*G* followed by *D*, where both cues indicate the same task) would yield fast processing because the relevant task representation was retrieved on the immediately preceding trial, whereas a task switch (*B* followed by *D*, indicating different tasks) would yield slow processing because a different task representation has to be retrieved from memory. The result would be faster processing for relational repetitions than for task switches, consistent with the observed task switching effects.[4] In addition, if retrieval is more difficult for task switches than for repetitions in general, then it would explain why error rate was higher for task switches than for all repetitions in the present study (see Figures 1 and 2).

This third stage might also be sensitive to the strength of the cue–task associations underlying retrieval. Meaningful or transparent cues that directly indicate the relevant task (e.g., the word *color* for a color judgment) arguably have stronger task associations than do arbitrary or nontransparent cues that bear no obvious relation to the relevant task (e.g., the cues used in the present study). Previous studies have shown that task switching effects (or overall transition effects) tend to be smaller with transparent cues than with nontransparent cues (e.g., Arbuthnott & Woodward, 2002; Logan & Bundesen, 2004; Mayr & Kliegl, 2000; Miyake, Emerson, Padilla & Ahn, 2004; Schneider & Logan, 2011). This finding is consistent with the hypothesis that the third stage of cue encoding (or a subsequent stage) involves retrieving a task representation based on cue–task mappings.

This characterization of the stages of cue encoding fits well with the results of the present study. However, the nature of the cue representation in memory and the processing hypothesized for each stage need to be explored further and formalized in a computational model. Experimental manipulations that involve varying the perceptual or conceptual similarity of cues might provide data for testing a more sophisticated model of cue encoding in task switching situations. The main contribution of the present study has been to show that a more detailed picture of cue encoding can be obtained by partitioning cue repetition effects into conceptual and perceptual priming effects. Future research addressing these effects will likely fill in additional details and draw more attention to the role served by cues in guiding behavior.

[3] Arrington, Logan, and Schneider (2007) argued that the product of cue encoding is a semantic representation of the task to be performed, which would make retrieval of the task representation a part of cue encoding. However, one could argue that the retrieval stage is qualitatively distinct from the other two stages and reflects processing that is separate from cue encoding.

[4] The finding that task switching effects are larger when subjects are instructed about cue–task mappings than when they are not (Forrest, Monsell, & McLaren, 2014) is also consistent with the idea of cue-based retrieval of a task representation from memory.

References

Arbuthnott, K. D., & Woodward, T. S. (2002). The influence of cue-task association and location on switch cost and alternating-switch cost. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale, 56,* 18–29. http://dx.doi.org/10.1037/h0087382

Arrington, C. M., & Logan, G. D. (2004). Episodic and semantic components of the compound-stimulus strategy in the explicit task-cuing procedure. *Memory & Cognition, 32,* 965–978. http://dx.doi.org/10.3758/BF03196874

Arrington, C. M., Logan, G. D., & Schneider, D. W. (2007). Separating cue encoding from target processing in the explicit task-cuing procedure: Are there "true" task switch effects? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 484–502. http://dx.doi.org/10.1037/0278-7393.33.3.484

Bertelson, P. (1965). Serial choice reaction-time as a function of response versus signal-and-response repetition. *Nature, 206,* 217–218. http://dx.doi.org/10.1038/206217a0

Brass, M., & von Cramon, D. Y. (2004). Decomposing components of task preparation with functional magnetic resonance imaging. *Journal of Cognitive Neuroscience, 16,* 609–620. http://dx.doi.org/10.1162/089892904323057335

Campbell, K. C., & Proctor, R. W. (1993). Repetition effects with categorizable stimulus and response sets. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 1345–1362. http://dx.doi.org/10.1037/0278-7393.19.6.1345

Eichelman, W. H. (1970). Stimulus and response repetition effects for naming letters at two response-stimulus intervals. *Perception & Psychophysics, 7,* 94–96. http://dx.doi.org/10.3758/BF03210140

Farell, B. (1985). Same-different judgments: A review of current controversies in perceptual comparisons. *Psychological Bulletin, 98,* 419–456. http://dx.doi.org/10.1037/0033-2909.98.3.419

Forrest, C. L. D., Monsell, S., & McLaren, I. P. L. (2014). Is performance in task-cuing experiments mediated by task set selection or associative compound retrieval? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40,* 1002–1024. http://dx.doi.org/10.1037/a0035981

Gade, M., & Koch, I. (2007). Cue-task associations in task switching. *The Quarterly Journal of Experimental Psychology, 60,* 762–769. http://dx.doi.org/10.1080/17470210701268005

Grange, J. A., & Houghton, G. (2010). Cue-switch costs in task-switching: Cue priming or control processes? *Psychological Research, 74,* 481–490. http://dx.doi.org/10.1007/s00426-009-0270-y

Jost, K., De Baene, W., Koch, I., & Brass, M. (2013). A review of the role of cue processing in task switching. *Zeitschrift für Psychologie, 221,* 5–14. http://dx.doi.org/10.1027/2151-2604/a000125

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching—A

review. *Psychological Bulletin, 136,* 849–874. http://dx.doi.org/10.1037/a0019842

Kiesel, A., Wendt, M., & Peters, A. (2007). Task switching: On the origin of response congruency effects. *Psychological Research, 71,* 117–125. http://dx.doi.org/10.1007/s00426-005-0004-8

Koch, I. (2003). The role of external cues for endogenous advance reconfiguration in task switching. *Psychonomic Bulletin & Review, 10,* 488–492. http://dx.doi.org/10.3758/BF03196511

Koch, I., Prinz, W., & Allport, A. (2005). Involuntary retrieval in alphabet-arithmetic tasks: Task-mixing and task-switching costs. *Psychological Research, 69,* 252–261. http://dx.doi.org/10.1007/s00426-004-0180-y

Kornblum, S. (1973). Sequential effects in choice reaction time: A tutorial review. In S. Kornblum (Ed.), *Attention and performance IV* (pp. 259–288). New York, NY: Academic Press.

Logan, G. D., & Bundesen, C. (2003). Clever homunculus: Is there an endogenous act of control in the explicit task-cuing procedure? *Journal of Experimental Psychology: Human Perception and Performance, 29,* 575–599. http://dx.doi.org/10.1037/0096-1523.29.3.575

Logan, G. D., & Bundesen, C. (2004). Very clever homunculus: Compound stimulus strategies for the explicit task-cuing procedure. *Psychonomic Bulletin & Review, 11,* 832–840. http://dx.doi.org/10.3758/BF03196709

Logan, G. D., & Schneider, D. W. (2006a). Interpreting instructional cues in task switching procedures: The role of mediator retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 347–363. http://dx.doi.org/10.1037/0278-7393.32.3.347

Logan, G. D., & Schneider, D. W. (2006b). Priming or executive control? Associative priming of cue encoding increases "switch costs" in the explicit task-cuing procedure. *Memory & Cognition, 34,* 1250–1259. http://dx.doi.org/10.3758/BF03193269

Logan, G. D., Schneider, D. W., & Bundesen, C. (2007). Still clever after all these years: Searching for the homunculus in explicitly cued task switching. *Journal of Experimental Psychology: Human Perception and Performance, 33,* 978–994. http://dx.doi.org/10.1037/0096-1523.33.4.978

Los, S. A. (1996). On the origin of mixing costs: Exploring information processing in pure and mixed blocks of trials. *Acta Psychologica, 94,* 145–188. http://dx.doi.org/10.1016/0001-6918(95)00050-X

Marí-Beffa, P., & Kirkham, A. (2014). The mixing cost as a measure of cognitive control. In J. A. Grange & G. Houghton (Eds.), *Task switching and cognitive control* (pp. 74–100). New York, NY: Oxford University Press. http://dx.doi.org/10.1093/acprof:osobl/9780199921959.003.0004

Mayr, U. (2006). What matters in the cued task-switching paradigm: Tasks or cues? *Psychonomic Bulletin & Review, 13,* 794–799. http://dx.doi.org/10.3758/BF03193999

Mayr, U., & Kliegl, R. (2000). Task-set switching and long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 1124–1140. http://dx.doi.org/10.1037/0278-7393.26.5.1124

Mayr, U., & Kliegl, R. (2003). Differential effects of cue changes and task changes on task-set selection costs. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 362–372. http://dx.doi.org/10.1037/0278-7393.29.3.362

Mayr, U., Kuhns, D., & Rieter, M. (2013). Eye movements reveal dynamics of task control. *Journal of Experimental Psychology: General, 142,* 489–509. http://dx.doi.org/10.1037/a0029353

McClelland, J. L. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review, 86,* 287–330. http://dx.doi.org/10.1037/0033-295X.86.4.287

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1423–1442. http://dx.doi.org/10.1037/0278-7393.22.6.1423

Meiran, N. (2014). The task-cuing paradigm: A user's guide. In J. A. Grange & G. Houghton (Eds.), *Task switching and cognitive control* (pp. 45–73). New York, NY: Oxford University Press. http://dx.doi.org/10.1093/acprof:osobl/9780199921959.003.0003

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology, 41,* 211–253. http://dx.doi.org/10.1006/cogp.2000.0736

Meiran, N., & Kessler, Y. (2008). The task rule congruency effect in task switching reflects activated long-term memory. *Journal of Experimental Psychology: Human Perception and Performance, 34,* 137–157. http://dx.doi.org/10.1037/0096-1523.34.1.137

Miyake, A., Emerson, M. J., Padilla, F., & Ahn, J.-C. (2004). Inner speech as a retrieval aid for task goals: The effects of cue type and articulatory suppression in the random task cuing paradigm. *Acta Psychologica, 115,* 123–142. http://dx.doi.org/10.1016/j.actpsy.2003.12.004

Monsell, S., & Mizon, G. A. (2006). Can the task-cuing paradigm measure an endogenous task-set reconfiguration process? *Journal of Experimental Psychology: Human Perception and Performance, 32,* 493–516. http://dx.doi.org/10.1037/0096-1523.32.3.493

Monsell, S., Sumner, P., & Waters, H. (2003). Task-set reconfiguration with predictable and unpredictable task switches. *Memory & Cognition, 31,* 327–342. http://dx.doi.org/10.3758/BF03194391

Nickerson, R. S. (1978). On the time it takes to tell things apart. In J. Requin (Ed.), *Attention and performance VII* (pp. 77–88). Hillsdale, NJ: Erlbaum.

Pashler, H., & Baylis, G. (1991). Procedural learning: 2. Intertrial repetition effects in speeded-choice tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 33–48. http://dx.doi.org/10.1037/0278-7393.17.1.33

Posner, M. I. (1969). Abstraction and the process of recognition. In G. H. Bower & J. T. Spence (Eds.), *The psychology of learning and motivation* (Vol. 3, pp. 43–100). New York, NY: Academic Press.

Posner, M. I. (1970). On the relationship between letter names and superordinate categories. *The Quarterly Journal of Experimental Psychology, 22,* 279–287. http://dx.doi.org/10.1080/00335557043000221

Posner, M. I. (1978). *Chronometric explorations of mind*. Hillsdale, NJ: Erlbaum.

Posner, M. I., Boies, S. J., Eichelman, W. H., & Taylor, R. L. (1969). Retention of visual and name codes of single letters. *Journal of Experimental Psychology, 79,* 1–16. http://dx.doi.org/10.1037/h0026947

Posner, M. I., & Mitchell, R. F. (1967). Chronometric analysis of classification. *Psychological Review, 74,* 392–409. http://dx.doi.org/10.1037/h0024913

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition: The Loyola symposium* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Proctor, R. W. (1981). A unified theory for matching-task phenomena. *Psychological Review, 88,* 291–326. http://dx.doi.org/10.1037/0033-295X.88.4.291

Rabbitt, P. M. A. (1968). Repetition effects and signal classification strategies in serial choice-response tasks. *The Quarterly Journal of Experimental Psychology, 20,* 232–240. http://dx.doi.org/10.1080/14640746808400157

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207–231. http://dx.doi.org/10.1037/0096-3445.124.2.207

Rubin, O., & Meiran, N. (2005). On the origins of the task mixing cost in the cuing task-switching paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 1477–1491. http://dx.doi.org/10.1037/0278-7393.31.6.1477

Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 763–797. http://dx.doi.org/10.1037/0096-1523.27.4.763

Schneider, D. W. (2015a). Attentional control of response selection in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 41,* 1315–1324. http://dx.doi.org/10.1037/xhp0000091

Schneider, D. W. (2015b). Isolating a mediated route for response congruency effects in task switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41,* 235–245. http://dx.doi.org/10.1037/xlm0000049

Schneider, D. W., & Logan, G. D. (2005). Modeling task switching without switching tasks: A short-term priming account of explicitly cued performance. *Journal of Experimental Psychology: General, 134,* 343–367. http://dx.doi.org/10.1037/0096-3445.134.3.343

Schneider, D. W., & Logan, G. D. (2006). Priming cue encoding by manipulating transition frequency in explicitly cued task switching. *Psychonomic Bulletin & Review, 13,* 145–151. http://dx.doi.org/10.3758/BF03193826

Schneider, D. W., & Logan, G. D. (2007). Retrieving information from a hierarchical plan. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 1076–1091. http://dx.doi.org/10.1037/0278-7393.33.6.1076

Schneider, D. W., & Logan, G. D. (2009). Selecting a response in task switching: Testing a model of compound cue retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 122–136. http://dx.doi.org/10.1037/a0013744

Schneider, D. W., & Logan, G. D. (2011). Task-switching performance with 1:1 and 2:1 cue–task mappings: Not so different after all. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37,* 405–415. http://dx.doi.org/10.1037/a0021967

Sohn, M.-H., & Anderson, J. R. (2001). Task preparation and task repetition: Two-component model of task switching. *Journal of Experimental Psychology: General, 130,* 764–778. http://dx.doi.org/10.1037/0096-3445.130.4.764

Sudevan, P., & Taylor, D. A. (1987). The cuing and priming of cognitive operations. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 89–103. http://dx.doi.org/10.1037/0096-1523.13.1.89

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task switching: Interplay of reconfiguration and interference control. *Psychological Bulletin, 136,* 601–626. http://dx.doi.org/10.1037/a0019791

Appendix A

Form Transition Analyses

Task switches and relational repetitions are unique among the transitions in that they include both form repetitions (e.g., uppercase letter followed by uppercase letter; numeral followed by numeral) and form switches (e.g., lowercase letter followed by uppercase letter; word followed by numeral), as can be inferred from Table 1. In contrast, nominal repetitions include only form switches, and physical repetitions include only form repetitions. To assess effects of form transition, mean RTs and error rates were submitted to 2 (cue type: letters or numbers) × 2 (cue transition: relational repetition or task switch) × 2 (form transition: form repetition or form switch) mixed-factor ANOVAs for each experiment, collapsing over CTI to obtain an adequate number of observations per condition.

Experiment 1

The task switching effect was larger when the form switched (248 ms) than when it repeated (208 ms), resulting in a significant interaction between cue transition and form transition, $F(1, 94) = 5.17$, $MSE = 7{,}531$, $p = .03$, $\eta_p^2 = .05$. There were no other significant effects involving form transition. Means (RT; error rate) were as follows: task switch and form switch (1,265 ms; 5.7%); task switch and form repetition (1,241 ms; 5.7%); relational repetition and form switch (1,017 ms; 3.5%); relational repetition and form repetition (1,033 ms; 3.4%).

Experiment 2

There were no significant effects involving form transition. Means (RT; error rate) were as follows: task switch and form switch (1,319 ms; 5.9%); task switch and form repetition (1,318 ms; 6.2%); relational repetition and form switch (1,205 ms; 4.3%); relational repetition and form repetition (1,186 ms; 4.5%).

(*Appendices continue*)

Appendix B

Combined Experiment Analyses

Experiments 1 and 2 were designed to be similar, thereby affording the same analyses of task switching, conceptual priming, and perceptual priming effects. However, they differed with respect to an additional variable manipulated between subjects across experiments: task switch frequency was either 25% (Experiment 1) or 50% (Experiment 2).[5] To implement the task switch frequency manipulation while maintaining an adequate number of trials per condition, the number of CTIs decreased from five to three as task switch frequency increased from 25% to 50%. As a result, task switch frequency was confounded with the number of CTIs, although the range of CTIs (100 ms to 900 ms) remained constant across experiments.

I am not aware of any evidence that varying the number of CTIs within a given range affects task switching performance. However, there is evidence that performance is modulated by task switch frequency, which has been investigated in previous task-cuing studies. For example, Monsell and Mizon (2006) conducted an experiment with two cues per task in which they manipulated the relative frequencies of task switches and relational repetitions (there were no physical repetitions because the cue always changed across trials). They found that the task switching effect decreased from 120 ms to 70 ms to 31 ms as task switch frequency increased from 25% to 50% to 75%. Similar findings have been reported by other researchers (Mayr, 2006; Mayr et al., 2013; Schneider & Logan, 2006). Thus, performance differences between Experiments 1 and 2 seem more likely to reflect task switch frequency than the number of CTIs.

Task switch frequency was included as a between-subjects factor in combined experiment analyses to investigate its potential effects on task switching, conceptual priming, and perceptual priming. Based on previous research, I expected the task switching effect to decrease as task switch frequency increased. I did not expect much change in the conceptual and perceptual priming effects with task switch frequency because those effects are calculated from the three types of repetitions, which occurred equally often in each experiment. CTI was included as a within-subjects factor by analyzing the data from the three CTIs common to both experiments (100, 400, and 900 ms). To avoid redundancy with the analyses in the main text, only the significant effects ($p < .05$) involving task switch frequency are reported. There were no significant effects involving task switch frequency in the error data; therefore, the following analyses address only the RT data.[6]

Results

Task Switching Analysis

Mean RTs and error rates were submitted to 2 (cue type) × 2 (task switch frequency) × 2 (transition: relational repetition or task switch) × 3 (CTI) mixed-factor ANOVAs. Mean RT was longer when task switch frequency was 50% (1,258 ms) than when it was 25% (1,134 ms), resulting in a significant main effect of task switch frequency, $F(1, 188) = 8.46$, $MSE = 518{,}526$, $p = .004$, $\eta_p^2 = .04$. The task switch frequency effect on overall RT was larger with letter cues (238 ms) than with number cues (10 ms), resulting in a significant interaction between cue type and task switch frequency, $F(1, 188) = 7.19$, $MSE = 518{,}526$, $p = .008$, $\eta_p^2 = .04$. The task switching effect decreased from 221 ms to 122 ms as task switch frequency increased from 25% to 50%, resulting in a significant interaction between task switch frequency and transition, $F(1, 188) = 17.68$, $MSE = 39{,}292$, $p < .001$, $\eta_p^2 = .09$. The decrease in the task switching effect from the shortest to the longest CTI was greater when task switch frequency was 25% (288 ms to 124 ms; see Figure 1) than when it was 50% (129 ms to 110 ms; see Figure 2), resulting in a significant interaction between task switch frequency, transition, and CTI, $F(2, 376) = 4.43$, $MSE = 30{,}528$, $p = .013$, $\eta_p^2 = .02$.

[5] Overall repetition frequency also changed across experiments, but the three types of repetitions (relational, nominal, and physical) were constrained to have the same relative frequencies in each experiment: 25% (Experiment 1) or 16.7% (Experiment 2).

[6] A second set of combined experiment analyses was conducted to investigate target transition effects (immediate target repetitions occurred on approximately 25% of trials). Mean RTs and error rates were submitted to 2 (cue type) × 2 (task switch frequency) × 4 (cue transition) × 2 (target transition) mixed-factor ANOVAs, collapsing over CTI to obtain an adequate number of observations per condition. There were only two significant effects ($p < .05$) involving target transition, each occurring for both RT and error rate. First, target switches (1,092 ms for RT; 4.6% for error rate) were slower and more error-prone than were target repetitions (956 ms; 3.1%), resulting in significant main effects of target transition. Second, the target transition effect (target switches minus target repetitions) became larger as the cue transition became easier (task switches [61 ms; 0.4%]; relational repetitions [110 ms; 0.8%]; nominal repetitions [178 ms; 2.1%]; physical repetitions [196 ms; 2.6%]), resulting in significant interactions between target transition and cue transition.

(*Appendices continue*)

Conceptual Priming Analysis

Mean RTs and error rates were submitted to 2 (cue type) × 2 (task switch frequency) × 2 (transition: nominal or relational repetition) × 3 (CTI) mixed-factor ANOVAs. Mean RT was longer when task switch frequency was 50% (1,113 ms) than when it was 25% (961 ms), resulting in a significant main effect of task switch frequency, $F(1, 188) = 15.77$, $MSE = 425{,}501$, $p < .001$, $\eta_p^2 = .08$. The task switch frequency effect on overall RT was larger with letter cues (250 ms) than with number cues (56 ms), resulting in a significant interaction between cue type and task switch frequency, $F(1, 188) = 6.37$, $MSE = 425{,}501$, $p = .012$, $\eta_p^2 = .03$. The task switch frequency effect decreased from the shortest CTI (186 ms) to the longest CTI (114 ms), resulting in a significant interaction between task switch frequency and CTI, $F(2, 376) = 3.71$, $MSE = 33{,}778$, $p = .025$, $\eta_p^2 = .02$. The change in the task switch frequency effect from the shortest to the longest CTI was greater with number cues (82 ms to −15 ms) than with letter cues (291 ms to 244 ms), resulting in a significant interaction between cue type, task switch frequency, and CTI, $F(2, 376) = 3.81$, $MSE = 33{,}778$, $p = .023$, $\eta_p^2 = .02$.

Perceptual Priming Analysis

Mean RTs and error rates were submitted to 2 (cue type) × 2 (task switch frequency) × 2 (transition: physical or nominal repetition) × 3 (CTI) mixed-factor ANOVAs. Mean RT was longer when task switch frequency was 50% (980 ms) than when it was 25% (861 ms), resulting in a significant main effect of task switch frequency, $F(1, 188) = 12.76$, $MSE = 323{,}354$, $p < .001$, $\eta_p^2 = .06$. The task switch frequency effect decreased from the shortest CTI (166 ms) to the longest CTI (80 ms), resulting in a significant interaction between task switch frequency and CTI, $F(2, 376) = 9.08$, $MSE = 19{,}904$, $p < .001$, $\eta_p^2 = .05$.

Discussion

There were three main findings involving task switch frequency in the RT data. First, overall RT was longer when task switch frequency was 50% than when it was 25%, and this task switch frequency effect was generally larger with letter cues than with number cues (the relevant interaction was significant in two of the three analyses; $p = .07$ in the perceptual priming analysis). Second, the task switching effect—but neither the conceptual priming effect nor the perceptual priming effect—was affected by task switch frequency, being smaller when task switches were more frequent. Third, the task switching effect decreased substantially with CTI when task switch frequency was 25% but not when it was 50% (compare Figures 1 and 2). These results are consistent with previous findings related to manipulations of task switch frequency (Mayr, 2006; Mayr et al., 2013; Monsell & Mizon, 2006; Schneider & Logan, 2006), as well as Monsell and Mizon's observation that reliable reductions in task switching effects with CTI seem more likely to occur when task switches are infrequent.

Received September 7, 2015
Revision received November 27, 2015
Accepted December 1, 2015 ■