Task-Switch Costs: A Phenomenon of Retrieval or Inhibition?

by

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A Thesis submitted to the Faculty of Graduate Studies of
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Abstract

Research of task-switching costs reveals a ‘switch cost asymmetry’ in that switching from a difficult to an easy task results in higher switch costs than the reverse (Allport & Wylie, 2000). By an ‘episodic retrieval’ interpretation, responding to a difficult task generates a more retrievable memory representation that interferes with subsequent performance of the alternative task. Alternatively, by an ‘inhibition’ approach, irrelevant tasks are suppressed to the extent that they are easy, making them more difficult to perform immediately thereafter. To demonstrate asymmetric switch costs, Experiment 1 required participants to switch between an easy perceptual task and a more difficult conceptual task. During Experiment 2, participants either switched between two easy perceptual tasks or between two difficult conceptual tasks. Results suggest that switching between two difficult conceptual tasks leads to higher switch costs. Thus, switch costs result from retrieval engaged in during the prime task interfering with performance of a current task.

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CHAPTER 1

INTRODUCTION

Purpose of the Study

With repetition, tasks become well-rehearsed. The well known phrase, “practice makes perfect” appears to be true when thinking of initial attempts at parallel parking. It is only through practice that one becomes skilled at pulling smoothly into the parking space. In addition, it is not until repetitively striking a punching bag that one learns to strike harder and faster or through repeatedly throwing a baseball that one learns to pitch with better aim.

Repetition improves how proficient we are at carrying out a task. For example, typing skills are acquired by practicing how to type on a keyboard without looking at the keys. At first, typing seems awkward and sluggish but after repeatedly striking the keys, the typist learns the location of each letter on the keyboard and begins to type words accurately and quickly. Despite its obvious benefits, however, repetition does not always improve performance. For example, having repeatedly dated documents for the year 2006, one may accidentally continue to date cheques for that same year well into January of 2007. The purpose of this study is to explore how repetition can be both beneficial and costly to performance of a current task, and to investigate what theoretical approach best captures these influences on current performance. In order to gain insight into how performing some task influences performance of a subsequent task, the current study will rely on the methodology provided by immediate priming. A detailed discussion of the priming procedure, including a review of some of the research that has employed this methodology, is provided below.

Immediate Positive Priming Effects

The effect of repetition on our performance is often investigated using the priming methodology. Results of both immediate and long-term priming experiments indicate prior exposure to an identical or related stimulus during a ‘prime’ display makes that stimulus easier to perceive when it appears in a subsequent ‘probe’ display (e.g. Scarborough, Cortese & Scarborough, 1977; Scarborough, Gerard & Cortese, 1979; Tenpenny, 1995; Thapar & Rouder, 2001).

Long-term priming involves delaying the onset of the probe item for some amount of time. For instance, Kolers (1976) instructed participants to read passages of text presented in upside-down and inverted type. He then presented the passages to the same participants a year later, and found that they were significantly faster at re-reading those passages relative to the time required to read passages that were not encountered the year before. This is an extreme example demonstrating how priming may be observed over relatively long time delays. Nevertheless, the focus of the current study will be on measuring more immediate consequences of priming.

There is a long history of demonstrations of both repetition and associative (or semantic) priming using the immediate priming procedure, which entails presenting a probe item shortly after the prime (usually within a few seconds). Repetition priming experiments involve presenting an identical prime and probe pair in succession. The results of repetition priming studies suggest performance is enhanced when responding to an item or event on its second presentation. For instance, Posner and Snyder (1975) demonstrated that the response time to make a sameness judgment between two test stimuli is facilitated by the presentation of a matching prime. On each trial of their study, a single prime stimulus was presented briefly, consisting of either a letter or a fixation cross ('+'). The prime was then replaced by the probe display, which consisted of a pair of letters. The participants' task was to judge whether these two probe letters were the same or different. Although the probe letters were different on half of the trials, Posner and Snyder were most interested in the effect of priming when the probe letters were the same. On these trials, the prime could be either a valid cue, matching the letters appearing in the probe display (e.g., A followed by AA) or the prime might be an invalid cue, differing from the probe letters (e.g., B followed by AA). For one set of participants, when a letter appeared as the prime, 80% of trials were valid (high validity condition), while only 20% of trials were valid for another group (low validity condition).

Using this procedure, Posner and Snyder observed that response times in making same judgments were particularly fast in the high validity condition when the prime and probe letters were the same. Moreover, participants in the high validity group responded faster on valid trials relative to performance on valid trials in the low validity condition. Posner and Snyder attributed fast performance in the high validity condition to participants' use of a conscious expectation to prepare for presentation of the prime letter in the subsequent probe display. If on 80% of same trials the appearance of A as the prime was followed by the matching test items, AA, individuals should begin to regard the prime as a useful cue for presentation of matching probe letters. On the other hand, participants should not have the same expectation in the low validity condition. Surprisingly, even though a match between prime and probe rarely occurred in the low validity condition, participants were faster at making same judgments compared to response times after both non-identical primes (e.g., B followed by AA) and neutral primes (e.g., + followed by AA). Since valid trials only occurred 20% of the time, this effect cannot be explained by conscious expectation. Instead, this finding suggests that separate from conscious expectations, presentation of a prime automatically facilitates perception of an identical probe stimulus.

Similar to observations of repetition priming, presenting a related prime and probe in direct succession also decreases the amount of time it takes to generate a response to a probe stimulus. An early lexical decision experiment conducted by Meyer and Schvaneveldt (1971) involved presenting two strings of letters arranged vertically on a computer screen. Assuming individuals read from the top to the bottom of the screen, the top string of letters acted as the prime while the bottom string represented the probe. The experiment consisted of both word and non-word trials. During word trials, both strings of letters formed a word (BUTTER-NURSE). Alternatively, on non-word trials, the top string of letters formed a word and the second string formed a non-word (WINE-PLAME) or both were non-words (REAB-PLAME). Participants were instructed to press a key labeled "yes" if both items were words, and press a key labeled "no" if one or both of the items were non-words. Results indicated that responses to non-word trials were uninfluenced by a word or non-word prime. In contrast, on word trials, participants were faster to make a correct "yes" judgment if the words were semantically associated (BREAD presented with BUTTER) compared to when the words were unrelated (BREAD presented with NURSE). Hence, identifying "butter" as a word is much quicker to do if the lexical status of "bread" had been identified a moment earlier.

Following Meyer and Schvaneveldt's (1971) study, a host of single-word semantic priming experiments were conducted (e.g., Lupker, 1984; Seidenberg, Waters, Sanders, & Langer, 1984). During these single-word semantic priming studies, participants are given a word prime and presented with a related or unrelated probe word. Depending on the study, participants are either asked to name the target aloud (the naming task) or they may be asked to judge the target as a word or non-word (the lexical decision task). When the task is lexical decision, half of the probe items are words and the other half are non-words. Results of these studies indicate that, whether the probe task is naming or lexical decision, response times are speeded for word probes that follow an associated prime than for those that follow an unrelated prime word (see Neely, 1991, for a review).

Activation Accounts of Immediate Priming

An activation account of immediate priming is based on the idea that concepts are represented in memory as nodes in a lexical or semantic network. Processing an item will activate itself and other associated nodes. The rate of activation is thought to reflect the distance between nodes, with nodes most strongly associated to one another linked closer together in distance. The strength of association between concepts is determined by how often those concepts have been presented in relation to one another in one's past (Collins & Quillian, 1969; Collins & Loftus, 1975). For example, the concepts BALL and BAT are often encountered together, so there should be a closer link between these two concepts in semantic memory than between concepts that are rarely encountered together, such as BANANA and MUSKRAT.

Immediate priming is thought to arise from an activation process in which a change in activation of the prime stimulus influences the activation state of the node used to respond to the probe stimulus. Having processed a prime activates nodes in the network corresponding to the properties of that stimulus, such as its meaning and orthography. Furthermore, when these corresponding nodes are preactivated by the prime, less activation is required to access relevant information about that item in the future. Thus, an activation account of repetition priming suggests that probes require less activation for perception on repeated trials. In Posner and Snyder's (1975) study, even in the low validity condition, participants were faster at identifying two letters as the same when they were preceded by an identical prime than when the letters were preceded by either a different letter or a neutral fixation cross. From the activation perspective, processing of a prime letter, such as A, leaves the abstract representation corresponding to this stimulus preactivated in a lexical network. Hence, when presented with "AA" in a subsequent display, identification of these letters requires less activation, facilitating a judgment of sameness.

Likewise, associative priming can be explained through an activation approach. Activation of a node corresponding to the prime might spread to closely connected nodes in a semantic network. In turn, less activation would be needed to identify a related probe stimulus corresponding to these preactivated nodes. According to this approach, presenting the word BREAD activates the node for that concept and nodes for associated concepts, such as BUTTER or TOAST. If one of these related words later appears as the probe, identification of this item would require less activation, resulting in more efficient responding.

Alternatives to the Activation Approach

The Compound-Cue Account. Ratcliff and McKoon (1994) provide an explanation of how a retrieval process might account for immediate priming effects known as the compound-cue theory of priming. They propose that, because they are presented closely in time, both the prime and probe items form a compound cue in short-term memory when the probe stimulus appears. This compound cue then acts to cue information relevant to both stimuli stored in long-term memory. A greater degree of match between the compound cue and memory representations leads to more efficient access to information about the probe stimulus. In turn, information brought into short-term memory by the compound cue facilitates perception of the probe stimulus (Gillund & Shiffrin, 1984; Ratcliff & McKoon, 1988). To illustrate using the repetition priming study developed by Posner and Snyder (1975), presenting identical prime and probe items "A followed by AA" leads to a faster response time. Since both prime and probe make contact with the memory representations associated with "A" stored in memory, access to information about the identity of the probe letters will be enhanced leading to a facilitated sameness judgment. Similarly, since the prime and probe event are chosen to be related items in associative priming experiments, there is a pre-existing association between the items in memory because of multiple experiences encountering those concepts simultaneously. In conjunction, the prime and probe both support access to information in memory that aids perception of the probe stimulus. To illustrate, the prime word BREAD followed by the probe word BUTTER would both make contact with similar representations in memory. Thus, exposure to both concepts separated by only a brief delay might provide a useful cue for retrieving information about the identity of the probe, thereby resulting in a fast lexical decision response.

Although both activation accounts and compound-cue theory rely on learned semantic associations to explain priming effects, their ideas of how associations are conceptualized and the type of processes involved in immediate priming differ from one another. For instance, activation and retrieval views differ as to how priming occurs. An activation approach suggests immediate priming effects are mediated by the activation of abstract mental representations (or nodes) at the time of the prime event. Hence, it is activation brought about by the prime that influences the ease of probe identification. Additionally, an activation view proposes strongly associated concepts are linked closer together, while nodes that are less similar are linked further away. The amount of associative priming then depends on the number of links or the distance between links from the prime and probe item. With more links between the prime and probe concepts, a greater amount of time is needed for activation to reach the probe item. In contrast, compound-cue theory proposes that the strength of a compound cue is a reflection of the number of episodes found in memory. The more instances of an association between the prime and probe found in memory, the stronger they act as a compound cue.

The Episodic Retrieval Account. Another competitor to the activation approach to immediate priming involves the application of episodic memory principles to priming phenomena. Similar to compound-cue theories, an episodic retrieval approach claims priming is not mediated by abstract mental representations at the time of processing the prime. Instead, Hughes and Whittlesea (1990) propose the processes implemented during prior episodes are retrieved during similar events to help assist current performance.

Furthermore, greater similarity between the prior and current events leads to larger facilitation, thus explaining both repetition and associative priming.

This episodic retrieval approach applies the principle of Transfer-Appropriate Processing (TAP) to account for repetition and semantic priming effects (Whittlesea & Jacoby, 1990). Retrieval depends on the amount of overlapping information between the prime and probe episode. With large amounts of overlapping information, there is greater likelihood of retrieval (Tenpenny, 1995). According to TAP, having engaged in some cognitive process in the past will make it easier to engage in at some future occasion as long as the representation for that prior processing episode is made available by cues available in the current environment. Thus, performance is enhanced if the cognitive operations taken to process items are the same as or similar to, the cognitive operations implemented during an earlier encounter (Franks, Bilbrey, Lien, & McNamara, 2000). An overlap of details from a prior experience and the current situation would thus facilitate priming effects (Tenpenny, 1995). Consistent with this view, repetition priming studies have demonstrated that individuals are significantly faster at re-reading text when the text orientation matched that of an earlier encounter (Kolers & Ostry, 1974; Masson, 1984). For example, reading geometrically inverted text material (upside-down and backward) is faster after having read this same inverted material before.

Posner and Snyder's repetition priming demonstration using letters can be readily explained by a retrieval account. On valid trials, the prime and probe items are identical and so perception of those items requires identical processing. When the probe display cues retrieval of processes used to perceive the prime letter, those processes are made available to facilitate responding.

An episodic retrieval account of priming also states that strongly associated items are often represented together in episodic memories, since they have been frequently encountered together in one's prior experience (Tenpenny, 1995). Overlapping components between items as a result of their association formed in memory suggest that the processing resources required for the two related items are often similar. Thus, an episodic retrieval view explains associative priming effects as the result of processing resources made available by the prime event facilitating perception of the probe item. In this way, episodic retrieval can be used to explain semantic priming experiments. Responding to the probe word BUTTER is facilitated when it is preceded by an associated word such as BREAD. This might occur because related prime and probe items share an overlap of associated concepts stored in memory. In turn, this overlap of information will cause the processing required by these items to be similar. Hence, identifying the word BREAD and its related word BUTTER will require overlapping processes. As a result, retrieval of processes used to identify the word BREAD during the prime event could assist with completing a similar probe task involving the identification of the related word BUTTER.

Immediate Negative Priming Effects

As discussed in the above sections, presentation of a probe stimulus following a repeated or associated prime facilitates responding. However, a number of studies have also revealed that presentation of an identical or a related prime slows responses to a probe display (Neill, 1997). For example, studies have found impaired performance when a stimulus treated as irrelevant when presented in a prime display becomes relevant during the probe event (e.g., Tipper, 1985). A clear example of impaired performance due to recently treating a stimulus dimension as irrelevant has been observed using a modification of Stroop's (1935) colour-naming task. Using incongruent word and ink colour stimuli (e.g., RED printed in green ink), performance in naming the colour of words is usually impaired by the irrelevant dimension of word meaning. As an example, it appears failure to avoid reading the word RED interferes with the requirement to name the color green (see MacLeod, 1991, for a review). Subsequent Stroop colour-naming studies demonstrated that treating the meaning of a colour word as irrelevant while naming its colour impairs subsequent performance in identifying the corresponding colour when it appears in the subsequent display (Dalrymple-Alford & Budayr 1966; Neill, 1977; Lowe, 1979). For example, suppose a participant named the colour of the word GREEN printed in red ink. On the following trial, the participant would tend to be slower at identifying the colour of the probe word YELLOW presented in green ink. Thus, ignoring the word GREEN while responding to its ink colour impairs subsequent responding to the colour green when it appears in the probe display.

Similar demonstrations of this negative priming effect have been replicated with many different types of stimulus materials including pictures, words, and letters (see May, Kane, & Hasher 1995, for a review). For instance, in a series of trials, Tipper (1985) presented participants with line drawings of overlapping images. Participants were instructed to name aloud the images that appeared in red while ignoring images presented in green. For example, supposing a red line drawing of a table was presented with a green line drawing of a dog, the participants' task would be to respond, "TABLE." During the probe stage, the previous distractor (image of a dog) might appear in red, such that it became the attended image. To measure negative priming effects, the response times of those in a baseline condition in which participants were given a novel image to attend to and a novel distractor to ignore (e.g., the participant attended to the image of a TRUMPET while ignoring the image of a CAR) were subtracted from the response times of identifying previously ignored images. Results show a delay in identifying the target after it had been previously ignored compared to the time needed to identify a novel image.

Additionally, Tipper's (1985) study demonstrated associative negative priming effects through showcasing two different line drawings of figures that overlap one another. Similar to Tipper's negative repetition priming, participants were instructed to name aloud the red image and ignore the green image. For example, during the prime display an image of a chair might be displayed in red and superimposed on a trumpet displayed in green. Participants' task would be to respond "CHAIR", while ignoring the image of the trumpet. Tipper established that by ignoring the image of a trumpet during the prime event, the ability to name a semantically associated image, such as a guitar, was impaired in contrast to trials in which participants identified an unrelated image such as a drawing of a dog.

Inhibition Accounts of Negative Priming

Two contrasting accounts of negative priming explain how ignoring a stimulus could impair responding to that stimulus in a probe display. The activation account of negative priming suggests that underlying representations for a stimulus ignored during the prime event are suppressed to limit the amount of activation it receives. As a consequence of this inhibition, the probability of generating a response to the irrelevant stimulus will be low, helping to ensure that participants respond to the correct source of information. Despite this benefit for responding to the prime trial, however, prior inhibition of the mental representations used for perceiving a distracting stimulus makes it harder to identify that stimulus when it appears as the probe target. Thus, negative priming is believed to be the result of inhibition of irrelevant information during the prime episode resulting in suppressed activation of its representational node (or logogen) upon onset of the probe display (Neill, 1977; Tipper, 1985).

Similar to the activation view of immediate repetition and associative priming effects, the distractor inhibition account suggests negative priming effects are mediated by abstract mental representations at the time of processing the prime. A slowed probe response is due to inhibition of the irrelevant stimulus during the prime task, resulting in below baseline activation of its representational node when the probe display appears (Neill, 1977; Tipper, 1985). To illustrate, suppression of processing the image of a dog may reduce activation of the mental representation for that concept (Tipper, 1985; May, Kane & Hasher, 1995). This reduction of activation would then impair participants in reaching the threshold level of activation necessary to name that image at the time of the probe display. In other words, if the irrelevant stimulus becomes relevant during a later task, a response requires additional amounts of activation to overcome prior inhibition. The time it takes for this additional activation slows responses to the probe target, revealing a negative priming effect. Thus, from the inhibition perspective, negative repetition priming, such as that observed in Tipper's (1985) study, is explained as the result of previous inhibition of distracting information.

An inhibition process can also explain Tipper's (1985) observation of associative negative priming. Suppose a prime display consisted of a red line drawing of a chair and a green line drawing of a trumpet. The participants' task would be to respond to the red chair and ignore the green trumpet. According to the inhibition view, identifying the line drawing of a chair requires inhibiting attention to the distracting image of a trumpet. This inhibition would lower activation of the mental representation for trumpet below its usual baseline level, and this inhibition would spread to related concepts, such as guitar. If the image of a guitar then became the probe target, this inhibition would need to be overcome before one could identify that stimulus. In this case as well, it is the time it takes to overcome inhibition that occurred during the prime event that is thought to be responsible for negative semantic priming.

Retrieval Accounts of Negative Priming

The retrieval approach to negative priming is based on Logan's (1988) view of automatization that completion of a task occurs either through effortful algorithmic processing or the retrieval of a prior memory episode with similar stimuli (Neill, 1997). Algorithmic processing involves rule-based strategies used to solve a task. For instance, solving a mathematical problem (e.g., 2X4) can be solved using a mathematical formula involving addition operations (e.g., 2+2+2+2=8). However, if an individual has often encountered the mathematical equation, 2X4=8, they may be capable of retrieving the answer from memory without having to perform the mathematical operations. Neill (1997) mentions that whether one implements algorithmic processing or episodic retrieval in completing a task depends on which of these two processes leads to the fastest response. If a current task requires similar processing used in the past, then algorithmic processing may be bypassed through the fast retrieval of a prior instance.

The probability that retrieval of a prior episode will occur sooner than a response derived from algorithmic processing depends primarily on whether a relevant prior episode can be retrieved quickly. Several factors determine speed of memory retrieval. For example, an important factor in Logan's (1988) model is how often similar episodes have been encountered in one's past. The more episodes available for generating a response, the greater the likelihood that one will be retrieved before completion of the task with the use of an algorithm. On the other hand, if there are only a few similar events in memory, a task may be completed sooner using more effortful algorithmic processing.

Obviously, other factors influence speed of retrieving a memory episode. The two factors that apply most directly to priming are recency and encoding specificity. In general, more recent episodes will be retrieved more quickly than episodes that occurred in the more distant past (Roediger & Crowder, 1976). It appears that the primary reason for this influence of recency is that events that occur in the delay between some prior experience and the present interfere with the retrieval of that episode (McGeoch, 1932). Retrieval of a prior episode will also occur to the extent that features of that episode overlap with aspects of the current situation (Tulving & Osler, 1968; Tulving & Thompson, 1973; Eysenck, 1978; Tenpenny, 1995). The implication is that the probe display will be an especially effective cue for retrieving the prime episode when the same stimulus appeared in both displays. In addition, it is highly likely that the prime episode will be retrieved when that event occurred only a moment before the appearance of the probe display.

Neill (1997) has applied his episodic retrieval approach to explain the results of Tipper's (1985) experiment and other negative priming effects. He assumes that treating the prime stimulus as a distractor may form part of a memory representation for that event. Retrieval of the prime event when responding to the probe display may then interfere with performance when the prime distractor becomes the probe target. Accessing an experience of having ignored the prime distractor conflicts with the subsequent requirement to treat that stimulus as the probe target. Thus, negative priming reflects slowed responding because of the need to overcome the conflicting influence of the prime episode.

To illustrate, suppose participants ignored the image of a dog during the prime event and later were required to identify that image during the probe task. Negative priming might occur because processes engaged in during the prime event directly oppose the need to respond to the image of a dog in the next display. That is, the processes used to ignore the image of a dog are inappropriate for the later task of attending to it. Similarly, retrieval of an episode of having ignored a prime stimulus that is related to the probe target could explain associative negative priming effects. When the probe display appears, an experience of withholding a response to the picture of a dog might generalize to stimuli with a strong prior association to that concept. In turn, this prior episode when an image of a dog was ignored could be a source of conflict when later responding to the picture of a related object, such as a cat.

Transfer-Inappropriate Processing. More recently, Transfer-Inappropriate Processing (TIP) theories of episodic-retrieval have been applied to account for negative priming effects that do not necessarily involve ignoring a prime distractor. TIP suggests that negative priming can occur whenever people retrieve processes associated with a prior experience that are inappropriate for performing the current task (Leboe, Whittlesea, & Milliken, 2005; Neill & Mathis, 1998; Wood & Milliken, 1998). This approach provides for a more general basis of explaining negative priming effects, whereas an activation/inhibition view of priming is designed to account for negative priming effects that involve ignoring a prime stimulus. For example, the inhibition account of negative priming suggests that ignoring irrelevant information, such as the image of a dog, involves restricting the amount of representation this image receives. Less activation makes this image less accessible for identification which proves helpful during a task that does not require attending to the image. However, if a later task requires this image to be identified, additional activation will be needed, resulting in slowed responding.

Unlike the inhibition account, one of the first episodic retrieval interpretations of negative priming suggests that it is the retrieval of an experience of having ignored the probe target that causes negative priming. This account is equally limited, however, in that it cannot explain examples of negative repetition priming for a stimulus that was not ignored during the prime event. A study by MacDonald and Joordens (2000) provides an example of this type of result. In their study, participants were presented with two animal words during the prime event. One of these words was printed in red ink to signify having to name the smaller of the two animals. For example, presented with the words TURTLE and CAMEL, the participants' task might be to respond, "TURTLE". Note that to perform this task participants were required to identify and attend to both prime words. During the probe event, participants were presented with two animal words printed in white ink, signaling the need to name the larger of the two animals. They found when the smaller animal in the prime display became the larger of the two during the probe task (TURTLE presented with FLEA), response times were much slower than when the probe target was unrelated to the item named during the prime display.

This result suggests that the appearance of a previously ignored stimulus as the probe target is not essential for negative priming to occur, limiting the breadth of applicability of both the inhibition and the early episodic retrieval approaches to explaining that effect. Instead, this finding supports a more general TIP approach. The negative priming observed by MacDonald and Joordens (2000) provides an example of how the type of processing engaged in during the prime task can interfere with processing required by the probe task (Neill & Mathis, 1998; Wood & Milliken, 1998). The earlier task of treating TURTLE as the smaller of two animals requires processes that differ from carrying out the task of treating TURTLE as the larger of two animals. Since the first and second task share overlapping information (the word TURTLE) the probe task cues the retrieval of the prime episode and the cognitive resources used to identify TURTLE as the smaller animal is retrieved. However, because these processes are inappropriate for the current task, their retrieval leads to slowed responding.

Task-Switching

To this point, the discussion has focused mainly on how responses to a probe stimulus can be facilitated or impaired by presentation of the same or a related stimulus in a preceding display. In general, investigations of these repetition and associative priming effects either require participants to perform the same task in response to both the prime and probe displays or there is no requirement to generate a response to the prime prior to responding to the probe. In contrast, the proposed study is primarily interested in the consequence of requiring participants to perform different tasks when responding to prime and probe stimuli. This “task-switching” methodology might initially seem quite different from other studies of repetition and associative priming. Nevertheless, there are some compelling reasons to consider the cognitive processes underlying these different forms of immediate priming as fundamentally similar. In general, people perform a task more slowly following the completion of some other task than after performing the same task (Monsell, Yeung & Azuma, 2000; Monsell, 2003; Allport, Styles & Hsieh, 1994). As a result, this phenomenon is analogous to positive immediate priming effects, only the basis of facilitation is at the level of task repetition rather than stimulus repetition. Moreover, the activation/inhibition and retrieval approaches to immediate priming also provide two of the most dominant theoretical approaches to task-switching.

To illustrate how a task-switching cost might be observed in everyday life, consider the following example. Motivated by an effort to be more friendly to the earth’s environment, a recycling bin is added to a workplace lunch room. A problem arises, however, if the workers have always thrown their recyclables in the trash bin. In consequence, it may be difficult to cause them to acquire the habit of using the recycling bin. The previous experience of tossing recyclables in the trash bin may obstruct an effort to encourage workers to make use of the recycling bin. In essence, this scenario illustrates a task-switch cost. The goal is to cause workers to switch from treating objects that they have traditionally thought of as garbage to treating those items as recyclable. Both the activation/inhibition (A/I) and episodic retrieval accounts of priming offer adequate explanations for this type of task-switching cost. According to an activation/inhibition view, the previous task of discarding the recyclables in the trash bin might require inhibiting oneself from placing those items in any other place. Thus, a later task requiring a response that involves discarding recyclables in a place other than the trash bin will require overcoming prior inhibition of such a response. To overcome inhibition, additional activation is needed, resulting in more errors or slower response times. Alternatively, according to a retrieval view there might be impairment in performing the second task because the retrieved processes used to place recyclables in the trash bin are inappropriate for the current task of placing those items in the recycle bin. Retrieval of these inappropriate processes causes interference with engaging the appropriate cognitive operations; thus, performance of the second task is impaired.

In the laboratory, a common method for investigating the effect of task switching relies on responses to Stroop (1935) colour-word stimuli. As described above, these stimuli consist of colour words presented in a font colour that either matches or mismatches the meaning of the word. For example, the word YELLOW printed in blue font would be referred to as an "incongruent" Stroop stimulus, while the word BLUE printed in blue font would be referred to as a "congruent" Stroop stimulus. Using these stimuli to study task-switching typically involves presentation of incongruent Stroop stimuli on a sequence of trials. On each trial, the participants' task is to either read the word or to identify the font colour as quickly and accurately as possible. In general, these studies demonstrate that, relative to when participants perform the same task on successive trials, responses are slower for both colour-naming and word-reading when the previous trial required performance of the alternative task.

A study by Allport et al. (1994) provides an example of this type of result. In their study, participants were presented with several lists of incongruent Stroop stimuli (consisting of the words red, green, blue, yellow, or brown printed in a mismatching colour). On "repeat" trials, for all items within a list, participants were instructed to either read the sequence of words aloud or to name the font colour of the words. On "alternate" trials, participants were requested to switch between the word-reading and colour-naming task. Participants were told before an alternate list was given, which task to perform first. Their results indicated that response times on alternate trials were significantly slower than response times on repeat trials. This demonstrates that performance of a task suffers after having performed some different task a moment before.

Similar results were observed by Spector and Biederman (1976) using a procedure that did not involve responses to Stroop stimuli. In their experiment, participants were given a total of three lists of arithmetic problems and instructed to complete each list, one at a time. One list was a pure list requiring participants to add 3 to a set of two-digit numbers, another list was also a pure list, except that participants were to subtract 3 from a set of two-digit numbers, and the final list type was a mixed list requiring participants to alternate between adding 3 and subtracting 3 for a sequence of two-digit numbers. Thus, given the numbers 47, 23, 56, and 18 on a pure list with instructions to add 3 to each, the corresponding responses would be 50, 26, 59, and 21. Alternatively, participants given a mixed list were required to switch from adding 3 to subtracting 3 such that responses given to the list of numbers 47, 23, 56, and 18 would be

50, 20, 59, and 15. Results showed that participants exhibited slower performance when they alternated between the two arithmetic tasks compared to those in a baseline condition in which participants performed one mathematical operation throughout the experiment. As suggested above, similar to studies that demonstrate repetition and associative priming effects, this type of task-switching cost can be readily explained by either an A/I approach to priming or by an account that emphasizes the role of episodic retrieval and involves application of the principle of Transfer-Appropriate Processing (TAP).

Activation/Inhibition versus Episodic Retrieval Approaches to Task-Switch Costs

A possible explanation for why task-switch costs occur is that performing one task might sometimes require active avoidance of processing required by some competing task. Thus, a task that is currently irrelevant might be inhibited, leading to impaired performance of that task on the next trial. Hence, in Allport et al.'s (1994) study, performing the task of colour identification might require suppressing the task of word-reading. Thus, if the next trial requires a word-reading response, additional activation is required to perform that task. The extra time it takes to overcome the inhibition of the word-reading task leads to a task-switch cost.

In contrast to the A/I view, a retrieval approach applies episodic memory principles, such as TAP, to explain impaired performance caused by task-switching. Different processing skills are engaged in when analyzing different features of a stimulus. As a result, when the prime and probe tasks are very different in the processes they require, retrieval of processes that occurred during the prime episode will contribute a source of interference to performance of the probe task. From this perspective, the task-switch costs observed by Allport et al. (1994) could be interpreted as an outcome of the probe task cueing the retrieval of inappropriate processes on alternate trials. When word-reading is the task on the current trial, retrieval of processes involved in naming the colour of the preceding item may conflict with generating a correct response. The participant may find it difficult to avoid processing the irrelevant dimension of colour when they should be responding to word identity.

Once again, both the activation/inhibition approach and the episodic retrieval approach are capable of accounting for an effect of immediate priming. The only difference is that, in this case, the critical dimension is task repetition versus alternation, rather than similarity between prime and probe stimuli. The purpose of this study is to determine which of these two approaches are best able to explain task-switching costs. As discussed above, this goal is challenging because both approaches often make similar predictions as to the consequence of immediate priming. One phenomenon commonly observed with investigations of task-switching, however, provides an opportunity to distinguish between the A/I and episodic retrieval accounts. Specifically, participants often experience a greater cost when switching from a difficult task to one that is relatively easy than when the reverse switch is required. In the next section, I provide a more detailed description of this phenomenon and its significance for the two theoretical approaches to task-switching costs described above.

Switch Cost Asymmetries

Since results from studies using incongruent Stroop stimuli suggest there is a greater tendency to name words than to name the colour of words (see MacLeod, 1991), it would seem logical that a switch from colour-naming to a word-naming task would result in less switching costs (Yeung & Monsell, 2003). If the probe task is relatively easy, one might assume performance of this task should be quick, regardless of the task performed in response to the prime display. Yet, studies involving presentation of incongruent Stroop items reveal that switching to the more familiar word-naming task after completing the relatively more difficult colour-naming task leads to much higher switch costs than switching from the word-reading to the colour-identification task (see Yeung & Monsell, 2003, for a review). These asymmetric switch costs could be easily explained by an A/I or an episodic retrieval account. According to an A/I account, participants might have difficulty suppressing the more familiar task of word-reading during the prime event. As a result, considerable inhibition of that task might be necessary to allow people to respond on the basis of colour. In contrast, processing of colour is a less dominant task and interferes less with performing the task of word-reading. Consequently, reading a word in the prime display might involve less inhibition of the alternative task of colour-naming. Greater costs of switching to word-reading than colour-naming would then simply reflect differences in the amount of task inhibition that occurred when responding to the prime display.

The episodic retrieval approach would explain this switch cost asymmetry in a different way. One factor known to increase the probability of retrieving an event from memory is the distinctiveness or elaborateness of that prior experience (Eysenck, 1978;

Craik & Lockhart, 1972). Whether the probe task is colour-naming or word-reading, having performed a different task in response to the prime display provides an opportunity for retrieval of inappropriate processes that could provide a source of interference. Still, the amount of actual interference observed depends on whether those inappropriate processes are made available through the retrieval of the prime episode. If the prime task requires a colour-naming response, the relative difficulty of that task will generate a more elaborate representation for that event in memory. If so, at the time of the probe display there would be a greater likelihood of retrieving the prime episode if the prime task was colour-naming than if it required a word-reading response.

As a consequence, on switch trials, inappropriate processes engaged during the prime event would be more readily accessed to interfere with word-reading than when the probe task is colour-naming.

More recently, Leboe et al. (2005) provided some evidence favouring this episodic retrieval interpretation of greater difficulty participants exhibit when switching to the easier task. For Stroop demonstrations of task-switching, proponents of the A/I account assumed that, since word-reading is the dominant response, that task would be deeply inhibited during efforts to generate a colour-naming response. Less inhibition would occur for the less-dominant task of colour-naming when the prime task is word-reading, resulting in less of a cost of switching to colour-naming in response to the probe display (Allport, et al., 1994). Leboe et al. demonstrated that observation of this type of asymmetric switch costs does not depend on participants' bias to respond to one stimulus dimension over another. Instead, similar asymmetrical switch costs can be observed between two tasks that differ only in difficulty. Specifically, they required participants to either name the colour of words and nonwords (the "easy" task) or to judge their lexical status (the "hard" task). Relative to when both prime and probe displays required performance of the same task, participants were generally slower when the probe task differed from the prime task. More importantly for current purposes, switch costs were much higher when the probe task was colour identification than when it was lexical decision.

These results could not be explained by the need to inhibit the dominant response during the prime event. There is no reason to suppose that the stimuli in that study compelled participants to identify colour, especially since this was precisely the dimension that was presumed to undergo less inhibition in Stroop versions of the task-switching procedure. Also, participants had no motive to orient preferentially to either colour or lexical status in their study because participants were required to perform both tasks equally often across the experimental session. Instead, the authors interpreted this result in terms of the relative elaborateness of colour-naming versus lexical decisions. They proposed that the more elaborate experience of making a lexical decision response creates a richer memory representation. In turn, that memory representation is more retrievable upon onset of the probe display, contributing a more potent source of interference when a switch to colour identification was required.

CHAPTER 2

THE PRESENT STUDY

Leboe et al.'s (2005) study ruled out differences in task dominance as critical for observing switch cost asymmetries, establishing that differences in task difficulty is the critical factor. Nevertheless, contrary to the episodic retrieval explanation they propose, it is possible to interpret their results with reference to the A/I approach to task-switching. Specifically, when performing a prime task, participants might tend to inhibit an alternative task to the extent that it is easy. In Leboe et al.'s study, although colour identification might not have been the dominant response, it's possible that colour identification was so easy that participants engaged in processing colour identity even when a lexical decision was required. Since engaging in colour processing might interfere with the current task of judging lexical status, it might be necessary for participants to inhibit the different task of colour identification. The same amount of inhibition would not occur when the current task is colour identification because of the greater difficulty of accessing stimulus lexicality. One purpose of the current study is to test whether this A/I account provides an adequate explanation for the switch cost asymmetry observed by Leboe et al. or whether this effect can be better explained by an episodic retrieval approach.

The purpose of Experiment 1 was to replicate the switch cost asymmetry observed by Leboe et al. (2005) using different combinations of tasks than were used in that study. Replication of this result with a slightly new procedure provided the basis for identifying the source of this effect in Experiment 2. Specifically, the goal of this experiment was to determine whether greater difficulty switching to an easier task occurs because:

1. Easier tasks are more deeply inhibited when responding to a more difficult prime task.
2. More difficult prime tasks are more retrievable, thereby providing a more potent source of inappropriate transfer.

Experiment 1

In Experiment 1, participants performed either an easy or a difficult task in response to both prime and probe words. All words presented in the study referred to animals. For separate groups of participants, the easy task entailed judging the font colour or the font size of these words. For half of the participants within each of these two groups, the difficult task involved categorizing the animals according to their habitat or their size. Since prior research has suggested perceptual (sensory) information tends to undergo less cognitive processing (Craik & Lockhart, 1972), identifying colour and size of font should constitute relatively easier tasks compared to categorizing animals according to habitat or size. Since participants only performed one easy and one difficult task within an experimental session, the combination of both easy and difficult tasks generated four conditions (Font Size vs. Font Colour X Animal Habitat vs. Animal Size). Within each of these conditions, on half of the trials participants performed an easy, perceptual task in response to the probe display, while on the other half of trials the probe task required a more difficult, meaning-based judgment. For both easy and difficult probe trials, participants performed the same task in response to the prime display and the alternative task on the remaining trials. For example, for those selected to perform the font colour and animal habitat tasks, on same-task trials people might have been presented with the prime word CAMEL followed by the probe word SHARK. Presentation of both of these words was accompanied by either the question, "Red or Green Word?" or "Land or Sea Animal?". On different-task trials, one of these questions appeared during presentation of the prime word, with the alternative question appearing upon onset of the probe word.

Participants

A total of 57 participants (15 – Font Colour vs. Animal Habitat, 16 – Font Colour vs. Animal Size, 13 – Font Size vs. Animal Habitat, 13 – Font Size vs. Animal Size) composed of both male and female undergraduate psychology students attending the University of Manitoba under the age of 30 were recruited for participation. Additionally, it was required that participants' native language was English. In exchange for their participation, they were given credit in their Introduction to Psychology course.

Apparatus and Stimuli

Participants were seated in front of a 15-inch colour monitor connected to an IBM-compatible 486 Microcomputer. MEL-2 (Micro-Experimental Laboratory 2) software was used to present stimuli and record participant responses. The stimuli consisted of 16 well-known animal names, chosen such that an equal number of words corresponded to both categories of animal habitat (Land vs. Sea) and animal size (Big vs. Small). Specifically, four names represented small sea animals (TROUT, SHRIMP, GUPPY, LOBSTER), four represented large sea animals (SHARK, DOLPHIN, OCTOPUS, WHALE), four represented small land animals (MOUSE, GOPHER, RACOON, RABBIT), and the remaining four represented big land animals (CAMEL, GIRAFFE, COUGAR, GORILLA). On each trial, words appeared in either red or green font. Additionally, words appeared in one of two sizes. Using font options provided by MEL2, System 56 font was used for the smaller font size, while System 96 font was used for the larger font size. Letters presented in small font size subtended 1.0 degree of visual angle vertically and 0.6 of a degree horizontally, while the letters presented in large font size subtended 2.0 degrees of visual angle vertically and 1.0 degree horizontally.

Procedure

Participants were randomly assigned to one of four conditions, depending on the combination of easy and difficult tasks they were required to perform (Font Size/Animal Size, Font Colour/Animal Size, Font Colour/Animal Habitat, Font Size/Animal Habitat). For each condition, there were 2 practice blocks and 10 test blocks, each composed of 32 trials. Participants were provided with instructions pertaining to their condition at the start of the experiment. Furthermore, they were given the opportunity to take breaks after every block. Participants were instructed to sit within a comfortable reading distance away from the computer screen. They were asked to respond as quickly and accurately as they could, by pressing buttons on the keyboard, corresponding to the keys ‘v’, ‘b’, ‘n’, and ‘m’. In the order of ‘v’, ‘b’, ‘n’, and ‘m’ the response mappings were: 1) big letters/big animal/small animal/small letters (for the Font Size/Animal Size condition), 2) big animal/red/green/small animal (for the Font Colour/Animal Size condition), 3) land animal/red/green/sea animal (for the Font Colour/Animal Habitat condition), 4) big letters/land animal/sea animal/small letters (for the Font Size/Animal Habitat Condition). To assist participants with the learning of the mapping of keys with designated responses, the keys ‘v’, ‘b’, ‘n’, and ‘m’ were labeled according to the task condition. Thus, key ‘v’ was either labeled as Bl (big letters), Ba (big animal) or L (land animal). Key ‘b’ had been labeled as Ba (big animal), R (red font) or L (land animal). The ‘n’ key was labeled as Sa (small animal), G (green font) or S (sea animal). Lastly, key ‘m’ was labeled Sl (small letters), Sa (small animal), or S (sea animal).

Prior to each trial, both prime and probe words were drawn randomly from the set of 16 animal names with the constraint that the two words were never identical. Within each block, and therefore across the experimental session as a whole, the probe task required an easy perceptual judgment or a more difficult meaning-based judgment on one half of trials. Specifically, the probe task was easy on 16 trials and difficult on the remaining 16 trials within each block. Within each of these sets of trials, the probe task matched the prime task on 8 trials, while the prime and probe task differed on the remaining 8 trials. Within each of these combinations of Probe Task (Easy vs. Hard) X Prime Task (Same vs. Different) conditions, match/mismatch in the font size and font colour of prime and probe were counterbalanced independently of the relationship between the prime and probe tasks. The manipulation of these two factors generated prime font size (Same vs. Different) X prime font colour (Same vs. Different) trials. Before each trial, the font size and colour of the prime were determined at random without replacement to ensure that both font sizes and colours were presented equally across the experimental session. The font size and colour of the probe depended on which of the four Prime Font Size/Prime Font Colour conditions corresponded to the current trial. Trial types determining the prime and probe tasks and the perceptual relationship between prime and probe words were selected at random within each block.

Each block began with the request “Press b to Begin” displayed in the middle of the screen. Pressing the ‘b’ key started the block of trials. A fixation cross (‘+’) was displayed on the left side of the screen for 500 milliseconds (ms) followed by onset of the prime word at the former location of the fixation cross. Simultaneously, a question corresponding to the prime task (e.g., “RED or GREEN letters?”) appeared directly above the prime word. The prime word and question remained on the screen until the participant responded by making a key press. Once a response was made, the animal word was masked by a row of ampersands (&&&&&&&) for 100 ms. The screen then cleared for a duration of 500 ms. If a correct response was made, a fixation cross appeared on the right side of the screen for 500 ms. This cross was then replaced by the probe word and the presentation of the question corresponding to the probe task (e.g., “LAND or SEA animal?”) directly above.

If the response to the prime was incorrect, feedback was provided prior to the appearance of the fixation cross signaling presentation of the probe word. Error feedback consisted of the presentation of the word, “WRONG!”, for 500 ms below the prior location of the prime question. The same error feedback followed incorrect responses to the probe display. Otherwise, response to the probe initiated the disappearance of the probe word and question followed by a two second delay prior to the beginning of the next trial.

Results and Discussion

For both of the experiments described here, both prime and probe response times (RTs) were automatically excluded from further analysis if they were greater than 3 seconds and less than 200 ms. Overall, exclusion of RTs on this basis resulted in the elimination of about 4% of observations.

Prime Responses

The first goal in analyzing responses to prime stimuli was to compare performance on the two tasks we classified as “easy” and the two tasks we classified as “difficult”. The expectation was that speed in making the font size and font colour judgments would not differ, and that there would not be a difference in participants’ speed in judging animal habitat versus animal size. To test these predictions, mean correct RTs for each participant and for each combination of easy and difficult tasks were first submitted to two separate 2 X 2 between-participant Analyses of Variance (ANOVAs). The mean RTs and proportion of incorrect responses for both the easy and hard prime tasks can be seen in Table 1.

Table 1

Mean response times (RT) in milliseconds and proportion of errors (ERR) when responding to prime words in Experiment 1 as a function of task pairing (font size/animal habitat vs. font size/animal size vs. font colour/animal habitat vs. font colour/animal size) and prime task (font size vs. font colour vs. animal habitat vs. animal size).

Font Size/Animal Habitat

Prime Task	Font Size		Animal Habitat	
	RT	ERR	RT	ERR
Mean	1397	.024	1455	.030
SE	67.9	.005	65.3	.007

Font Size/Animal Size

Prime Task	Font Size		Animal Size	
	RT	ERR	RT	ERR
Mean	1427	.038	1487	.042
SE	40.0	.007	45.4	.011

Font Colour/Animal Habitat

Prime Task	Font Colour		Animal Habitat	
	RT	ERR	RT	ERR
Mean	1273	.045	1366	.045
SE	61.6	.005	61.1	.009

Font Colour/Animal Size

Prime Task	Font Colour		Animal Size	
	RT	ERR	RT	ERR
Mean	1188	.040	1308	.037
SE	52.5	.007	39.5	.006

SE = Between-participant standard error of the mean RTs and proportion of errors.

In the first analysis, the between-participant factors were easy task (Font Size vs. Font Colour) and alternate task (Animal Habitat vs. Animal Size). Unexpectedly, the outcome revealed that participants were 182 ms faster at identifying font colour than font size (1231 ms vs. 1413 ms), *F*(1, 56) = 11.89, *MSe* = 45,812, $p < .001$. This result suggests that the font size task was more difficult than the font colour task. Slower RTs for judging the font size of prime words might have been due to the fact that font size judgments are based on relative differences whereas, font colour judgments are not. For instance, to respond to the size of letters one must compare it with memory representations of items presented previously. Therefore, judging font to be of smaller size can only be made after comparing it against items in memory that were of bigger font size. Likewise, judging font to be of bigger size, involves a comparison against items in memory that are of smaller font size. In contrast, identifying words as red or green does not require any comparison against some relative standard. Thus, the font size task requires processing that the font colour task does not. The between-participant factors were difficult task (Animal Habitat vs. Animal Size) and alternate task (Font Size vs. Font Colour). Participants were about 13 ms faster at categorizing animals according to their size than according to their habitat (1398 ms vs. 1411 ms), but this difference was not statistically significant, $F < 1$. Thus, the animal habitat and animal size tasks seemed to be of equal difficulty. A main effect of alternate task was also found, in that responses to the two difficult tasks were about 134 ms slower when the alternate task was font size than when it was font colour (1337 ms vs. 1471 ms), *F*(1, 56) = 7.29, *MSe* = 40,508, $p < .01$.

For current purposes, the central concern was to validate the classification of the font colour and font size tasks as “easy” relative to the animal size and animal habitat tasks. Since responses to font size were slower, on average, than responses to font colour, performance on each of these tasks was separately compared against performance on the two difficult tasks combined. Specifically, mean correct RTs obtained from each participant were submitted to two separate 2 X 2 mixed-design ANOVAs. In both analyses, the within-participant factor was task (Font Size vs. Difficult Tasks in one analysis; Font Colour vs. Difficult Tasks in another) and the between-participant factor was difficult task (Animal Habitat vs. Animal Size). The first of these analyses revealed that participants were about 58 ms faster at identifying the size of font than at performing the two difficult tasks (1413 ms vs. 1471 ms), $F(1,25) = 7.76$, $MSe = 44{,}606$, $p < .01$. The second analysis confirmed that participants were significantly faster at judging the colour of font than at completing the more difficult conceptual tasks. Specifically, RTs were about 111 ms faster, on average, when the prime task was font colour than when it required a judgment of either animal size or habitat (1215 ms vs. 1326 ms), $F(1, 30) = 17.35$, $MSe = 10{,}991$, $p < .001$.

The same analyses described above were also performed on the proportion of incorrect responses to the prime display computed for each participant. None of these analyses yielded any significant differences between conditions.

Probe Response Times

Mean probe response times observed in Experiment 1 are displayed in Tables 2 and 3.

Table 2

Mean response times in milliseconds to probe words in Experiment 1 when the easy task required font size judgments as a function of task pairing (font size/animal habitat vs. font size/animal size), probe task (font size vs. animal habitat vs. animal size), prime font colour (same vs. different), prime font size (same vs. different), and prime task (same vs. different).

Task Pairing	Font Size/Animal Habitat							
Probe Task	Font Size				Animal Habitat			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	1159	1125	1164	1128	1181	1174	1269	1256
Different	1360	1395	1349	1343	1420	1398	1401	1408
SC	-201	-270	-185	-215	-239	-224	-132	-152
Corrected SC	-.161	-.215	-.148	-.171	-.182	-.171	-.100	-.116
SE	.050	.043	.030	.037	.036	.034	.026	.015

Task Pairing	Font Size/Animal Size							
Probe Task	Font Size				Animal Size			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	1145	1238	1159	1280	1239	1248	1335	1342
Different	1368	1437	1320	1302	1427	1366	1435	1423
SC	-223	-199	-161	-22	-188	-118	-100	-81
Corrected SC	-.174	-.156	-.125	-.017	-.139	-.087	-.074	-.060
SE	.050	.047	.030	.022	.021	.022	.030	.017

SS = Same Size; SC = Same Colour; DS = Different Size; DC = Different Colour
SC = Switch costs were derived by calculating the difference in mean response times for the same prime task vs. the different prime task conditions, with negative values representing slower responding on task-switching trials and positive values representing speeded responding on task-switching trials.
SE = Between-participant standard error of the corrected switch costs.

Table 3

Mean response times in milliseconds to probe words in Experiment 1 when the easy task required font colour judgments as a function of task pairing (font colour/animal habitat vs. font colour/animal size), probe task (font colour vs. animal habitat vs. animal size), prime font colour (same vs. different), prime font size (same vs. different), and prime task (same vs. different).

Task Pairing	Font Colour/Animal Habitat							
Probe Task	Font Colour				Animal Habitat			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	975	1011	1003	1073	1097	1192	1123	1221
Different	1254	1244	1257	1255	1304	1349	1284	1291
SC	-279	-233	-254	-182	-207	-157	-161	-70
Corrected SC	-.246	-.206	-.224	-.161	-.168	-.127	-.131	-.057
SE	.054	.035	.028	.048	.025	.039	.028	.033

Task Pairing	Font Colour/Animal Size							
Probe Task	Font Colour				Animal Size			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	912	977	948	1020	1161	1192	1160	1207
Different	1214	1180	1218	1221	1261	1292	1246	1302
SC	-302	-203	-270	-201	-100	-100	-86	-95
Corrected SC	-.278	-.187	-.249	-.185	-.081	-.082	-.070	-.077
SE	.048	.028	.039	.041	.022	.028	.026	.037

SS = Same Size; SC = Same Colour; DS = Different Size; DC = Different Colour
SC = Switch costs were derived by calculating the difference in mean response times for the same prime task vs. the different prime task conditions, with negative values representing slower responding on task-switching trials and positive values representing speeded responding on task-switching trials.
SE = Between-participant standard error of the corrected switch costs.

Trials in which a prime error occurred were excluded from further analysis. The primary focus was on the cost of performing a probe task different from the prime task, depending on the difficulty of the prime. The prediction was that switching from a hard conceptual task would lead to significantly higher switch costs than a switch from an easy perceptual task. Since the prime RTs when responding to the easier perceptual tasks were faster than those observed when participants performed the more difficult conceptual tasks, it was necessary to correct switching costs for these differences in task duration. To calculate corrected switch costs for each condition, and for each participant, the mean RTs on task-switch trials were first subtracted from mean RTs on task-repeated trials. These raw switch costs were then divided by the grand mean of the probe RTs for each of the four probe tasks. For each trial type, this procedure allowed for computation of the cost of switching to each task that was proportional to the typical speed of performing that task.

Corrected Switch Costs. In analyzing the RT data, the first objective was to confirm the presence of switching costs for both the easy and hard probe task conditions. After deriving corrected switch costs from the mean RTs observed for each participant, these data for the easy and difficult probe task conditions were submitted to separate 1-way repeated-measures ANOVAs, collapsing across prime font colour (Same vs. Different), prime font size (Same vs. Different), and treating prime task (Same vs. Different) as a within-participant factor. This analysis revealed that mean RTs were significantly higher on task-switch trials than on task-repeated trials whether the probe task was easy, $F(1,56) = 149.17$, $MSe = 35355.78$, $p < .001$, or difficult, $F(1,56) =$

113.96, *MSe* = 18551.27, $p < .001$. No other main effects or interactions were statistically significant.

The mean corrected switch costs were then submitted to a 2 X (2 X 2 X 2) mixed-design ANOVA, treating probe task (Easy vs. Hard), probe font size (Same vs. Different) and probe font colour (Same vs. Different) as within-participant factors and treating easy task (Font Size vs. Font Colour) as a between-participants factor. Whereas corrected switch costs for the two hard probe tasks were combined in this analysis, the cost of switching to the font colour and font size tasks were analyzed separately. This is because in the analysis of prime RTs, there was no difference in the amount of time it took to identify the habitat of an animal than it did to identify the size of animals. This suggests that animal habitat and animal size are of equal task difficulty. However, font size judgments were somewhat slower than font colour judgments. As mentioned in the analysis of prime RTs, I expected that this difference occurred because font size judgments are based on relative differences, whereas font colour judgments are not. This analysis revealed a main effect of probe task, $F(1,55) = 32.53$, *MSe* = .018, $p < .001$, that interacted with easy task, $F(1,55) = 12.36$, *MSe* = .018, $p < .001$. The source of this interaction was that the difference in the cost of switching to an easy versus difficult probe task was greatest when the easy task required colour identification than when it required a judgment of font size. Based on switch costs computed to be proportional to the grand mean of response times for each probe task, the cost of switching to the colour task was about 11.9% greater than the average cost of switching to the two difficult tasks (.217 vs. .098), $F(1,30) = 37.10$, *MSe* = .024, $p < .001$. In contrast, the cost of switching to the font size task was only about 3% greater than the average cost of switching to the two tasks (.146 vs. .116), $F(1,30) = 4.02$, $MSe = .012$, $p < .06$. Consequently, switch costs were higher when the probe task required a colour judgment than when it required a font size judgment, $F(1,30) = 5.72$, $MSe = .050$, $p < .05$. The average cost of switching to the colour task was about 7.1% greater than the cost of switching to the font size task (.217 vs. .146).

Nevertheless, similar to earlier research findings, this experiment revealed a switch cost asymmetry. Switching from one of the difficult tasks (Animal Habitat and Animal Size) to one that was relatively easier (Font Size and Font Colour) led to higher switching costs than the reverse. Since switching to an easier task leads to higher switch costs than switching to a harder task, the general rule might be that the easier the probe task, the greater the switch costs. As mentioned earlier, the font colour task is considerably easier than the font size task. That could be the reason why there were higher switch costs when switching to the font colour task than when switching to the font size task. Alternatively, it could be the difficulty of the prime task that controls the magnitude of switch costs. These two possibilities lie at the center of whether an inhibition process or a retrieval process provides the best account of task-switching costs.

According to the inhibition view, engaging in processing of the alternative task might interfere with responding to the current task. To prevent responding inappropriately, participants might find that it is necessary to inhibit this irrelevant task. Inhibition of an irrelevant task, however, makes it difficult to respond to immediately afterwards. Thus, task-switch costs are thought to reflect impaired responding towards a previously inhibited task. Switch cost asymmetries result from greater amounts of inhibition needed to prevent responding to an easy irrelevant task compared to a difficult irrelevant task. It is thought that participants are more likely to engage in processing of easy tasks even when it is inappropriate then they are to engage in processing of difficult tasks. This is because the processes associated with responding to easy tasks are easily accessible from memory compared to the processes of difficult tasks. Since a response towards an easy irrelevant task is more likely to occur, easy tasks act as a greater source of interference compared to difficult tasks. To prevent responding to the easy irrelevant task, it might be more necessary to inhibit an irrelevant easy task than one that is more difficult. This deep inhibition of the easy task during the prime event should impair performance when it becomes the probe task. Thus, switch costs are expected to be highest when switching to the easiest task and lowest when switching to the hardest task.

Another possible explanation of task-switching costs is that of an episodic retrieval approach. According to the episodic retrieval approach to task switching, an overlap of information between the prime and probe on font colour or font size would be expected to cue the retrieval of processes engaged in during the prime event. During task-repetition trials, the probe task requires similar processes as those employed to complete the prime task. Cued retrieval of processes engaged during the prime event due to an overlap of information between the prime and probe stimuli would be expected to speed probe responding. This is because retrieval of processes engaged during the time of the prime event shortens the amount of time that would be needed to engage in these same processes during the probe event. As a result, probe RTs are facilitated. In contrast, during task-switching trials responding to the probe task requires processes that are different from the prime task. Retrieval of processes engaged at the time of the prime event would not be helpful in accessing processes necessary for responding to the probe word. Switching from a hard task to an easier task might lead to higher switch costs because hard tasks create memory representations that are more retrievable. If switch costs depends on the retrievability of inappropriate processes then increasing the amount of overlapping featural information between the prime and probe episode should increase switching costs. Alternatively, the elaborative processing that is associated with performance of a hard task might be the primary source of interference when switching to some alternative task. It could be that hard tasks involve more elaborative cognitive operations compared to easier tasks making these events more distinctive in memory. The more distinctive the events in memory the more they act as a source of interference when retrieved at the time of the probe task. Thus, switch costs are highest when switching from a difficult task to one that is relatively easier because the elaborative processes of a difficult prime task are retrieved at the time of the probe event and interfere with correct responding.

The analysis also revealed main effects of both prime font colour, $F(1,55) = 19.58$, $MSe = .011$, $p < .001$, and prime font size, $F(1,55) = 8.58$, $MSe = .011$, $p < .005$, that did not interact with any of the other factors. Switch costs were 3.7% greater when the prime and probe words were the same colour than when they were a different colour (.159 vs. .122). Likewise, switch costs were 3.9% greater when the prime and probe words were the same size than when they were a different size (.160 vs. .121). No other main effects or interactions were statistically significant.

Featural Match Effects on Mean Probe RTs. I investigated this contribution of overlap in the perceptual features of prime and probe words to task switch costs by submitting mean probe RTs on task-repeated and task-switch trials to separate 2 X (2 X 2

X 2) mixed-design ANOVAs, treating probe task (Easy vs. Hard), probe font size (Same vs. Different), and probe font colour (Same vs. Different) as within-participant factors and treating easy task (Font Size vs. Font Colour) as a between-participants factor.

On task repetition trials, there was a main effect of prime font colour, $F(1,55) = 19.11$, $MSe = 9816.23$, $p < .001$, that interacted with easy task, $F(1,55) = 6.30$, $MSe = 9816.23$, $p < .05$. When one of the two tasks participants performed in a session required identification of font colour, responses were 64 ms faster when the colour of the prime and probe words was the same than when they differed in colour (1047 ms vs. 1111 ms), $F(1,30) = 34.78$, $MSe = 7321.48$, $p < .001$. This effect did not depend on whether the probe task of that session was easy or difficult, $F < 1$. In contrast, when the easy task required participants to make font size judgments, participants were only 17 ms faster when the prime and probe words matched in colour than when they differed in colour (1207 ms vs. 1224 ms), $F(1,25) = 1.22$, $MSe = 12809.92$, $p > .05$, and this difference was not significant.

There was also a main effect of prime font size on task-repetition trials, $F(1,55) = 37.28$, $MSe = 5171.90$, $p < .001$ that was modulated by a 3-way interaction between prime font size, easy task, and probe task, $F(1,55) = 6.50$, $MSe = 10552.86$, $p < .05$. When the easy task was colour identification, responses were about 30 ms faster when the prime and probe words matched in font size than when they differed in font size (1064 ms vs. 1094 ms), $F(1,30) = 9.84$, $MSe = 5516.51$, $p < .005$. This effect did not depend on whether the probe task was easy or difficult, $F = 1.04$. When the easy task required a font size judgment, the effect of a match in font size depended on the probe task (Prime Font Size X Probe Task interaction), $F(1,25) = 5.83$, $MSe = 12079.34$, $p <$

.05). On trials that required participants to perform the same difficult task in response to both the prime and probe words (either requiring a judgment of animal size or habitat), responses were about 90 ms faster when the prime and probe words also matched in size than when they differed in size (1211 ms vs. 1301 ms), $F(1,25) = 37.44$, $MSe = 5596.49$, $p < .001$. However, on trials that required participants to make a font size judgment to both the prime and probe words, responses were only about 16 ms faster when the prime and probe words were the same size than when they were different in size (1167 ms vs. 1183 ms), and this difference was not statistically significant, $F < 1$.

According to the episodic retrieval approach to task switching costs, an overlap of information between the prime and probe items ought to facilitate retrieval of processes engaged during the prime task. Thus, a match between prime and probe on font colour or font size would be expected to cue the retrieval of processes engaged in during the prime event. During task-repetition trials, the probe task requires processes similar to those employed to complete the prime task. Cued retrieval of processes engaged during the prime event due to an overlap of information between the prime and probe stimuli would be expected to speed probe responding. This is because retrieval of processes engaged during the time of the prime event shortens the amount of time that would be needed to engage in these same processes during the probe event.

With respect to the effects of colour match, the results of Experiment 1 generally confirm these expectations to the extent that the colour of words was task-relevant during the experimental session. When participants responded to colour on 50% of prime and probe displays, a match in the colour of prime and probe words speeded probe RTs on task-repetition trials whether the task was colour identification or required a judgment of either animal size or animal habitat. This effect of colour match, however, was not present when participants never performed colour identification judgments throughout the experimental session. When the easy task was font size, presenting prime and probe words in the same colour did not significantly influence probe RTs on task-repetition trials whether the probe task required a font size judgment or a judgment of either animal size or habitat. Processing of word colour during the prime event should only occur if colour is often a relevant dimension for generating responses. From an episodic retrieval approach, then, colour match should only facilitate performance on task-repetition trials if it is task-relevant within the experimental context. If it is not, the colour of words will not form an important aspect of the memory representation for the prime event and will not serve as an effective cue for retrieval of the prime episode at the time of the probe display (Leboe, et al., 2005).

Accounting for the effects of a match in font size is not as straightforward. When font size was task-relevant, a match on that dimension facilitated probe RTs on task-repetition trials only when the probe task required judgments of either animal size or animal habitat. There was no statistical evidence that a match in font size speeded judgments of font size on task-repetition trials. This result is surprising, given that one might expect judging the font size of a prime word to be most appropriate for judging the font size of a probe word that is identical in size. Even so, the results of Experiment 2 demonstrate that a match in font size can significantly speed probe RTs when both the prime and probe tasks require a judgment of font size. Also puzzling was the observation that a match in the font size of prime and probe words speeded probe RTs on task-repetition trials even when participants were never required to make font size judgments (i.e., when the easy task was colour identification). It is unclear why information about font size is processed and available for contributing to priming effects when it is not directly task relevant, but information about font colour is not. One possibility is that processing of stimulus size occurs whenever some participants are required to orient to some other perceptual dimension of a stimulus, such as colour. Based on the results of Experiment 2 described below, this dimension does not seem to be processed merely as a consequence of performing the conceptual judgments of animal habitat and animal size. When participants only made animal habitat and animal size judgments throughout the experimental session, matches in the font size of prime and probe words did not contribute to priming effects. Thus, in Experiment 1, the font size of both prime and probe words might have been processed incidentally as a consequence of participants' attending to the dimension colour. In consequence, that dimension was available to provide a source of positive priming on task-repetition trials, even when the easy task required judgments of font colour.

On task-switch trials, the analysis revealed a 4-way interaction between easy task, probe task, prime font colour, and prime font size. To determine the source of this interaction effect, the data for the two easy probe task conditions (Font Colour and Font Size) were submitted to separate 2 X 2 X 2 repeated-measures ANOVAs, treating probe task (Easy vs. Hard), prime font size (Same vs. Different), and prime font colour (Same vs. Different) as within-participant factors.

When the easy task was font colour, a match in the font size of the prime and probe words had no significant effect on response times. However, the analysis did yield a significant interaction between prime font colour and probe task, *F*(1,30) = 4.81, *MSe* =

6715.88, $p < .05$. When the probe task required a colour identification response, a match in the colour of the prime and probe words did not significantly contribute to response times, $F < 1$. When the probe task required a judgment of either animal habitat or animal size, participants were about 35 ms faster when the prime and probe words matched in colour than when they differed in colour (1273 ms vs. 1308 ms), $F(1,30) = 6.95$, $MSe =$ 5482.30, $p < .05$.

When the easy task was font size, the analysis yielded a 3-way interaction between prime font colour, prime font size, and probe task, $F(1,25) = 5.10$, $MSe =$ 6770.98, $p < .05$. When the probe task required either a judgment of animal habitat or animal size, there was no effect of a match in either the font colour or font size of the prime and probe words and these two features did not interact to influence performance. When the probe task required a judgment of font size, however, the interaction between prime font colour and prime font size approached significance, $F(1,25) = 3.97$, $MSe =$ 6626.98, $p < .06$. The source of this interaction was that switching from a hard task to the font size task was particularly slow when the prime and probe words differed in colour, but matched in font size. When there was a match in colour between the prime and probe words, there was no significant difference in the speed of font size judgments depending on whether the prime and probe words matched or mismatched in font size, $F(1,25) =$ 1.91, $MSe = 6082.24$, $p > .05$. In contrast, when the prime and probe words differed in colour, participants were about 93 ms slower to make font size judgments when the prime and probe words were the same size than when they differed in size (1416 ms vs. 1323 ms), $F(1,25) = 8.69$, $MSe = 13093.45$, $p < .01$. Other than its role in modulating this effect of a match in font size, prime font colour did not significantly contribute to the speed of font size judgments on task-switch trials. None of the other main effects or interactions was statistically significant.

Consequently, the effect of featural overlap between prime and probe stimuli was responsible for a somewhat complex pattern of results on task-switch trials. On those trials, from an episodic retrieval perspective, factors that enhance retrieval of the prime episode upon onset of the probe display should impair performance. Enhancing retrieval of the prime episode through presentation of a probe word that matches the prime in either its colour or font size, would engage processes inappropriate for performing the current task. Interference from these inappropriate processes should, in turn, produce slowed responses to the probe word.

There was no evidence that featural overlap between prime and probe words, impaired responses on task-switch trials. This outcome contrasts with the results of Leboe et al.'s (2005) study, which revealed that a match in the perceptual features of prime and probe stimuli can impair responding on task-switch trials. Thus, it appears that the effect of featural overlap between prime and probe stimuli is most robust at enhancing the accessibility of appropriate processes on task-repetition trials. Perceptual overlap does not seem to be quite as effective at making available inappropriate processes to cause interference on task-switch trials.

Even so, unlike the pattern of results on task-repetition trials, a match in font size did not facilitate probe RTs for any of the four tasks. Similarly, whereas a match in colour facilitated probe RTs when colour was a task-relevant dimension on task-repetition trials, there was no evidence that colour match enhanced colour identification performance on task-switch trials. Nevertheless, a match in colour did provide a benefit to performance on task-switch trials when the prime task required a colour identification response and the probe task required a judgment of either animal habitat or animal size. The observation of a benefit of colour repetition when switching from colour identification to a more difficult conceptual task has also been observed in a study by Leboe et al., 2005. The authors of that study speculated that identifying colour in response to the prime represents a weak source of interference for performing a task-switch. The outcome is that probe responses are speeded by a perceptual benefit arising from encountering a probe stimulus presented in the same colour as the prime.

Probe Error Rates

The mean proportion of errors in response to probe words observed in Experiment 1 are displayed in Tables 4 and 5.

Table 4

Mean proportion of errors in response to probe words in Experiment 1 when the easy task required font size judgments as a function of task pairing (font size/animal habitat vs. font size/animal size), probe task (font size vs. animal habitat vs. animal size), prime font colour (same vs. different), prime font size (same vs. different), and prime task (same vs. different).

Task Pairing	Font Size/Animal Habitat							
Probe Task	Font Size				Animal Habitat			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	.004	.016	.008	.028	.021	.016	.033	.024
Different	.066	.039	.023	.027	.047	.031	.023	.051
SC	-.062	-.023	-.015	+.001	-.026	-.015	-.010	-.027
SE	.021	.018	.012	.013	.018	.018	.013	.017

Task Pairing	Font Size/Animal Size							
Probe Task	Font Size				Animal Size			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	.020	.020	.004	.012	.062	.020	.036	.008
Different	.044	.048	.060	.051	.053	.027	.056	.037
SC	-.022	-.028	-.056	-.039	+.009	-.007	-.020	-.029
SE	.012	.016	.020	.017	.029	.018	.019	.013

SS = Same Size; SC = Same Colour; DS = Different Size; DC = Different Colour
SC = Switch costs were derived by calculating the difference in the mean proportion of errors for the same prime task vs. the different prime task conditions, with negative values representing more errors on task-switching trials and positive values representing fewer errors on task-switching trials.
SE = Between-participant standard error of the mean difference in the proportion of errors between same task and different task trials.

Table 5

Mean proportion of errors in response to probe words in Experiment 1 when the easy task required font colour judgments as a function of task pairing (font colour/animal habitat vs. font colour/animal size), probe task (font colour vs. animal habitat vs. animal size), prime font colour (same vs. different), prime font size (same vs. different), and prime task (same vs. different).

Task Pairing	Font Colour/Animal Habitat							
Probe Task	Font Colour				Animal Habitat			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	.007	.000	.017	.011	.052	.036	.039	.055
Different	.058	.042	.038	.042	.044	.080	.042	.060
SC	-.051	-.042	-.021	-.031	+.008	-.044	-.003	-.005
SE	.012	.014	.014	.014	.018	.019	.012	.025

Task Pairing	Font Colour/Animal Size							
Probe Task	Font Colour				Animal Size			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	.003	.021	.003	.003	.000	.043	.019	.033
Different	.048	.048	.039	.026	.047	.067	.036	.049
SC	-.045	-.027	-.036	-.023	-.047	-.024	-.017	-.016
SE	.015	.014	.018	.012	.011	.016	.014	.017

SS = Same Size; SC = Same Colour; DS = Different Size; DC = Different Colour
SC = Switch costs were derived by calculating the difference in the mean proportion of errors for the same prime task vs. the different prime task conditions, with negative values representing more errors on task-switching trials and positive values representing fewer errors on task-switching trials.
SE = Between-participant standard error of the mean difference in the proportion of errors between same task and different task trials.

In order to confirm the presence of switching costs on error rates, the proportion of errors in responding to probe words for both the easy and hard probe tasks were submitted to separate 1-way repeated-measures ANOVAs, collapsing across prime font colour (Same vs. Different), prime font size (Same vs. Different), and treating prime task (Same vs. Different) as a within-participant factor. This analysis revealed that error rates were significantly higher on task-switch trials than on task-repeated trials whether the probe task was easy, $F(1,56) = 51.83$, $MSe = .002$, $p < .001$, or difficult, $F(1,56) = 20.13$, $MSe = .002$, $p < .001$. Within each condition and for each participant, the cost of task-switching on probe error rates was then calculated by subtracting the proportion of incorrect responses on task-switch trials from the mean proportion of incorrect responses on task-repeated trials. Similar to the analysis of RT switch costs, the cost of task-switching on error rates were then submitted to a mixed-design ANOVA, treating probe task (Easy vs. Hard), probe font size (Same vs. Different) and probe font colour (Same vs. Different) as within-participant factors and treating easy task (Font Size vs. Font Colour) as a between-participants factor. The only significant effect generated by this analysis was a main effect of probe task, $F(1,55) = 5.21$, $MSe = .003$, $p < .05$. The cost of switching on error rates was about 1.5% higher when the probe task was easy than when it was hard (-.035 vs. -.020). The greater error rates associated with switching to an easier probe task from a difficult prime task suggests that it is more difficult to switch from a difficult to an easy task than it is to switch from an easy task to a relatively harder task.

In summary, the analysis of prime RTs observed in Experiment 1 revealed that participants were faster at responding to the two tasks that were defined as easy (Font Colour and Font Size) than they were at responding to the two tasks that were defined as difficult (Animal Habitat and Animal Size). Therefore, I obtained validation for categorizing the font size and font colour tasks as relatively easy and the animal habitat and animal size tasks as relatively hard. Confirmation the that two perceptual tasks were relatively easier than the two conceptual tasks provided the basis for a replication of previous research that observed costs when switching from a difficult to an easy task than when the reverse switch was required. In the current experiment, the need to switch to the easier font size and font colour tasks led to significantly higher costs than the need to switch from one of those tasks to the harder animal habitat and animal size tasks. This switch-cost asymmetry can be explained by both an inhibition and episodic view. It could be that during the prime event the irrelevant tasks that are easy require greater amounts of inhibition than irrelevant tasks that are difficult. One might expect greater inhibition of an easy task-set to be necessary because a response associated with performing an easy task would be more accessible than a response associated with performing a more difficult task. Greater switch costs associated with switching to an easy task compared to a harder task might then result because of greater amounts of inhibition that must subsequently be overcome when performing that task in response to the probe display. Alternatively, greater costs when switching to an easy task occur because the elaborative cognitive operations associated with a difficult prime task are retrieved at the time of the probe event and interferes with correct responding.

Experiment 2

The purpose of Experiment 2 was to determine whether higher switch costs when switching to an easier task occurs because of deeper inhibition of easy tasks during the prime event, or because the more elaborative processing that occurs when performing a difficult prime task makes the prime event more retrievable. By the episodic retrieval view, greater availability of processes involved in responding to the difficult task will provide a larger source of interference when performing the probe task.

In Experiment 2, participants were placed in one of two conditions. In the first condition, each display required performance of one of the easy perceptual tasks of font size or font colour that was used during Experiment 1 (Easy Tasks condition). In the second condition, each display required performance of one of the more difficult meaning-based tasks of animal size or animal habitat that participants performed during Experiment 1 (Hard Tasks condition). For example, for those selected to perform easy tasks, on same task trials participants might be presented with the prime word CAMEL followed by the probe word SHARK. Presentation of both of these words could be accompanied by either the question, “Big or Small letters?” or “Red or Green letters?”. On different task trials, one of these questions appeared during presentation of the prime word, with the alternative question appearing upon onset of the probe word. In both conditions, one half of trials required performance of the same task in response to both prime and probe displays, while the other half required switching from one prime task to a different probe task.

From an inhibition account of switch cost asymmetries, higher switch costs should be observed in the Easy Tasks than in the Hard Tasks condition. Since processing either font size or font colour occurs relatively quickly, participants might engage in processing those stimulus dimensions even when they are not required by the current task. If so, it might be more necessary to inhibit an irrelevant easy task than one that is more difficult. This deep inhibition of the easy task during the prime event should impair performance when it becomes the probe task.

In contrast, a retrieval view would propose that switch costs depend on the retrieval of inappropriate processes. Conceptual tasks require more elaborative processing that creates a more distinctive, retrievable representation in memory (Craik & Lockhart, 1972). Because these processes are more retrievable, they provide a greater source of interference if they are inappropriate for the current task. If switch cost asymmetries occur because of a retrieval process, the cost of switching should be greatest in the Hard Tasks condition than in the Easy Tasks condition.

Participants

A total of 67 participants (35 for the Easy Tasks condition, and 32 for the Hard Tasks condition) composed of both male and female undergraduate psychology students attending the University of Manitoba under the age of 30 were recruited for participation. Additionally, it was required that participants' first language is English. In exchange for their participation, participants were given credit in their Introduction to Psychology course.

Apparatus and Stimuli

The apparatus and stimuli of Experiment 2 were identical to that of Experiment 1.

Procedure

The procedure was identical to that of Experiment 1 except that participants were placed in either the Easy Tasks condition in which they judged font colour or font size in response to every display or the Hard Tasks condition in which they responded to words by either judging animal habitat or animal size. Similar to Experiment 1 the participants responded by pressing one of the buttons, 'v', 'b', 'n', and 'm', on the keyboard. In the order of 'v', 'b', 'n', and 'm' the response mappings were: 1). big letters/ red/green/small letters (for the Easy Tasks condition) and 2). big animal/land animal/sea animal/small animal (for the Hard Tasks condition).

Results and Discussion

Prime Responses

The mean RTs and proportion of incorrect responses for both the easy and hard prime tasks of Experiment 2 can be seen in Table 6.

Table 6

Mean response times (in milliseconds) and proportion of errors when responding to prime words in Experiment 2 as a function of task condition (easy vs. hard) and prime task (font size vs. font colour vs. habitat vs. animal size).

	Task Condition			
	Easy Tasks		Hard Tasks	
	Font Size	Font Colour	Animal Habitat	Animal Size
Response times	1314	1366	1567	1514
SE	44.7	40.9	52.4	55.1
Prop. of error	.035	.020	.044	.020
SE	.013	.003	.007	.004

SE = between-participant standard error; Prop. = proportion.

As in the analysis of prime responses for Experiment 1, the current analysis began with separate comparisons of the two easy tasks and the two difficult tasks. Mean correct prime RTs and error rates for each participant were submitted to two separate 1–way ANOVAs, treating prime task (Font Colour vs. Font Size; Animal Size vs. Animal Habitat) as the within-participant factor. In the analysis of prime RTs, participants made font size judgments about 52 ms faster than font colour judgments (1314 ms vs. 1366 ms), $F(1,34) = 9.29$, $MSe = 4973.36$, $p < .001$. Although participants were about 1.5% more likely to make incorrect responses for the font size task than the font colour task, this difference was not significant, $F(1,34) = 1.31$, $MSe = .003$, $p < .05$. The advantage in RT observed for the font size task is surprising since participants were faster at making font colour than font size judgments in Experiment 1. It could be that the prime RTs of font size task were faster than the prime RTs of font colour because 50% of the prime responses were made after completing a different probe task. As has been discussed at length in this paper, task-switching studies reveal a switch cost asymmetry in that switching from a colour task to one that is harder leads to smaller switching costs than the reverse. Thus, slower responses to the prime word could reflect the high cost of switching from the more difficult font size task, rather than revealing the colour task as more difficult. Consistent with this interpretation, mean probe RTs were about 73 ms slower on task-switch trials for the font colour task than for the font size task (1353 ms vs. 1280 ms), $F(1,34) = 12.12$, $MSe = 31218.99$, $p < .001$. In contrast, participants were about 34 ms faster at performing font colour judgments than font size judgments on task-repetition trials, a difference that approached statistical significance (1131 ms vs. 1165 ms), $F(1,34) = 3.73$, $MSe = 31218.99$, $p < .07$. Thus, the weight of evidence suggests that colour identification judgments are more easily performed unless they are impaired by interference from having to switch from having just performed a font size judgment.

Participants were also about 53 ms faster at responding to the animal size task than the animal habitat task (1514 ms vs. 1567 ms), $F(1,31) = 11.82$, $MSe = 3922.51$, $p < .001$, and they made 2.4% fewer errors when making animal size judgment than when making animal habitat judgments, $F(1,31) = 30.05$, $MSe = .0003$, $p < .001$.

The next set of analyses involved paired between-groups ANOVAs, comparing participants' performance in responding to each easy task to their performance in responding to each hard task. With respect to RTs, performance on the font size task was about 253 ms faster than the animal habitat task, $F(1,66) = 13.66$, $MSe = 78418.89$, $p < .001$ (1314 ms vs. 1567 ms), and about 200 ms faster than the animal size task (1314 ms vs. 1514 ms), $F(1,66) = 7.97$, $MSe = 83325.62$, $p < .01$. Responses to the font colour task were made about 201 ms faster than responses to the animal habitat task (1366 ms vs.

1567 ms), *F*(1,66) = 9.40, *MSe* = 72411.66, $p < .005$, and about 148 ms faster than responses to the animal size task (1366 ms vs. 1514 ms), *F*(1,66) = 4.73, *MSe* = 77318.39, $p < .05$. Faster RTs observed for the easy font size and font colour tasks compared to the harder animal habitat and animal size tasks confirm that the easy tasks were easier than the hard tasks. In the error data, the only significant difference was that participants were about 2.4% more likely to make an error on the animal habitat task than on the font colour task (2.0% vs. 4.4%), *F*(1,66) = 10.15, *MSe* = .001, $p < .005$. Insignificant differences in error rates were obtained between judgments of animal habitat and font size, animal size and font colour, and animal size and font size.

Probe Responses

With respect to probe RTs and error rates, trials in which a prime error occurred were excluded from further analysis. Based on the remaining trials, mean probe RTs for both the easy and hard task conditions are displayed in Table 7.

Table 7

Mean response times (in milliseconds) to probe words in Experiment 2 as a function of probe task (hard tasks - animal size vs. animal habitat vs. easy tasks - font colour vs. font size), prime font colour (same vs. different), prime font size (same vs. different), and prime task (same vs. different).

	Hard Probe Tasks							
	Animal Size				Animal Habitat			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	1333	1327	1338	1328	1301	1324	1292	1335
Different	1496	1492	1506	1532	1589	1602	1605	1583
SC	-163	-165	-168	-204	-288	-278	-313	-248
Corrected SC	-.115	-.116	-.118	-.144	-.198	-.191	-.216	-.171
SE	.017	.020	.019	.018	.021	.020	.017	.021

	Easy Probe Tasks							
	Font Size				Font Colour			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime task								
Same	1072	1189	1137	1262	1044	1152	1140	1188
Different	1283	1328	1233	1275	1346	1343	1364	1361
SC	-211	-139	-095	-013	-301	-191	-224	-172
Corrected SC	-.172	-.114	-.078	-.010	-.243	-.154	-.180	-.139
SE	.019	.027	.016	.018	.021	.021	.019	.022

SS = Same Size; SC = Same Colour; DS = Different Size; DC = Different Colour
SC = Switch costs were derived by calculating the difference in the mean proportion of errors for the same prime task vs. the different prime task conditions, with negative values representing more errors on task-switching trials and positive values representing fewer errors on task-switching trials.
SE = Between-participant standard error of the mean corrected switch costs.

In an initial analysis, the purpose was to confirm the presence of RT switching costs for both the easy and hard probe task conditions. After deriving switch costs from the mean RTs observed for each participant, these data for the easy and difficult probe task conditions were submitted to separate 1-way repeated-measures ANOVAs, collapsing across prime font colour (Same vs. Different), prime font size (Same vs. Different), and treating prime task (Same vs. Different) as a within-participant factor. This analysis revealed that mean RTs were significantly higher on task-switch trials than on task-repeated trials whether the probe task was easy, $F(1,34) = 124.90$, $MSe = 31766.02$, $p < .001$, or difficult, $F(1,31) = 230.59$, $MSe = 28954.57$, $p < .001$. Similar to the findings of Experiment 1, switching between tasks is more difficult than repeating a task. No other main effects or interactions were statistically significant.

Corrected Switch Costs. In the comparison of switch costs for each probe task in Experiment 2, the difference in mean RT on task-repeated and task-switch trials was calculated for each participant as proportional to the overall mean RT for the relevant probe task. These corrected switch costs were then submitted to a 2 X (2 X 2) mixed-design ANOVA, treating prime font colour (Same vs. Different) and prime font size (Same vs. Different) as within-participant factors, and task condition (Easy vs. Hard) as a between-participant factor. This analysis revealed interactions between both task condition and prime colour, $F(1,65) = 13.81$, $MSe = .008$, $p < .001$, and task condition and prime size, $F(1,65) = 21.92$, $MSe = .009$, $p < .001$. The source of this interaction was that the difference in switch costs between the hard tasks and easy tasks conditions depended on the match in the features of the prime and probe words. When the prime and probe words matched in colour, there was no difference in switching costs between the easy and hard tasks conditions, $F < 1$. When the prime and probe words differed in colour, however, corrected switching costs were about 5.2% higher in the hard tasks condition than in the easy tasks condition (.156 vs. .104), $F(1,65) = 7.75$, $MSe = .023$, $p < .01$. Similarly, there was no difference in switching costs between the two task conditions when the prime and probe words were the same size, $F < 1$, but switching costs were about 6.1% higher in the hard tasks condition than in the easy tasks condition when the prime and probe words differed in size (.163 vs. .102), $F(1,65) = 11.85$, $MSe = .021$, $p < .001$. No other main effects or interactions were statistically significant.

Within the easy and hard tasks conditions, there were also differences in the costs of switching, depending on the nature of the probe task. In the Hard Tasks condition, the cost of switching was about 7.0% higher when the probe task required a judgment of animal habitat than when the probe task required a judgment of animal size (.194 vs. .124), $F(1,31) = 28.18$, $MSe = .011$, $p < .001$. In the Easy Tasks condition, the cost of switching was about 8.5% higher when the probe task required a judgment of font colour than when the probe task required a judgment of font size (.179 vs. .094), $F(1,34) = 29.37$, $MSe = .017$, $p < .001$.

Featural Match Effects on Mean Probe RTs. The contribution of featural matches between prime and probe words on the effect of pairing easy vs. hard tasks on switching costs arose primarily from the easy tasks condition. Switch costs were not influenced by the relationship between prime and probe words on the dimensions of either colour or size in the hard tasks condition ($F < 1$ in both cases). When the task involves an animal habitat or animal size judgment, participants are required to process conceptual information, not perceptual information. Perhaps featural matches between the prime and probe words did not act as effective cues for retrieving the prime episode because these stimulus attributes were not strongly processed by participants in the Hard Tasks condition. However, when the two easy tasks of font colour and font size were paired within the same experimental session, there were significant main effects of both prime colour, $F(1,34) = 33.13$, $MSe = .009$, $p < .001$, and prime font size, $F(1,34) = 42.65$, $MSe = .008$, $p < .001$, on corrected switch costs. In the easy tasks condition, switch costs were 6.5% higher when the colour of the prime matched the colour of the probe than when the prime and probe were a different colour (.169 vs. .104). In that same condition, switch costs were 6.9% higher when the size of the prime matched the size of the probe than when the prime and probe differed in size (.171 vs. .102). This suggests that when the tasks require processing of more primitive stimulus attributes, featural matches between the prime and probe words serve as a basis for enhanced retrieval processes that occurred during the prime event. This contribution of the relationship between the prime and probe on the dimension of size to switch costs depended on the nature of the probe task, $F(1,34) = 5.58$, $MSe = .011$, $p < .05$. When the probe task required a colour judgment, the cost of switching from the font size task was 4.0% greater when the size of the prime and probe were the same than when they were different (.199 vs. .159), $F(1,34) = 6.77$, $MSe = .008$, $p < .05$. When the probe task required a font size judgment, the cost of switching from the font colour task was 9.8% greater when the size of the prime and probe were the same than when they were different (.143 vs. .045), $F(1,34) = 32.07$, $MSe = .011$, $p < .001$. Enhanced retrieval of the prime event through either a match in colour or font size would tend to inflate switching costs. Enhanced retrieval of the prime event could either contribute a source of facilitation on task-repetition trials, when processes engaged during the prime episode would be appropriate for responding to the probe task. Conversely, promotion of retrieval of the prime episode through a featural match between the prime and probe words could impair performance on task-switch trials, given that processes completed during the prime event would be inappropriate for completing the probe task.

In order to better understand the effect of a match in prime and probe features on switching costs for the Easy Tasks condition, mean probe RTs for that condition were submitted to a 2 X 2 X 2 X 2 repeated-measures ANOVA, treating probe task (Font Colour vs. Font Size), prime task (Same vs. Different), prime font colour (Same vs. Different), and prime font size (Same vs. Different) as within-participant factors. This analysis yielded significant prime task X prime font colour, $F(1,34) = 33.12$, $MSe = 6595.83$, $p < .001$, and prime task X prime font size interactions, $F(1,34) = 42.79$, $MSe = 5872.16$, $p < .001$. A match between the prime and probe either on the dimensions of colour or size significantly influenced probe RTs on task-repetition trials. When participants repeated the same task in response to both prime and probe, responses to the probe were about 100 ms faster when there was a match in the colour of the prime and probe than when there was a mismatch (1098 ms vs. 1198 ms), $F(1,34) = 110.08$, $MSe = 6291.76$, $p < .001$. Similarly, participants were about 68 ms faster in responding to probes on task-repetition trials when the prime and probe were the same size than when they differed in size (1114 ms vs. 1182 ms), $F(1,34) = 32.33$, $MSe = 9860.38$, $p < .001$. Probe RTs were facilitated during task-repetition trials when the prime and probe words matched on font size or font colour. This suggests that when the probe shares overlapping information with the prime item, the prime event becomes more retrievable. On task-repetition trials the retrieval of processes lessens the amount of time needed to access these same processes during the probe task. Since the probe task is identical to the prime task on task-repeated trials, retrieval of processes engaged during the prime episode facilitates responding.

A match in the size of prime and probe words did not have a significant main effect on probe RTs on task-switch trials, $F(1,34) = 1.85$, $MSe = 11255.72$, $p > .05$. However, there was a probe task X prime size interaction, $F(1,34) = 12.05$, $MSe = 6993.73$, $p < .001$. When participants were required to switch from the font size task to the font colour task, there was no effect of prime font size, $F(1,34) = 1.35$, $MSe = 7892.08$, $p > .05$. In contrast, when participants switched from the font colour task to the font size task, response times were about 52 ms *slower* when the prime and probe matched in size than when they differed in size (1306 ms vs. 1254 ms), $F(1,34) = 9.12$, $MSe = 10357.36$, $p < .005$. The effect of colour match on task-switch trials approached significance, $F(1,34) = 3.59$, $MSe = 8165.12$, $p < .07$, owing to the observation that participants were about 44 ms faster on colour match than on colour mismatch trials when they were required to switch from judging the font colour of the prime to judging the font size of the probe (1258 ms vs. 1302 ms), $F(1,34) = 6.84$, $MSe = 9734.76$, $p < .05$. There was no significant difference in response times between colour match and colour mismatch trials when participants switched from the font size task to the font colour task, $F < 1$. Thus, as in Experiment 1, it appears that featural overlap between prime and probe words affected switching costs mainly through facilitating RTs on task-repetition trials. Once again, it appears that the presence of a colour or font size match between the prime and probe stimuli is most effective at promoting retrieval of prime episodes in which the same task was performed. Moreover, the lack of a contribution of a match on those two dimensions to performance in the Hard Tasks condition suggests that perceptual attributes of prime and probe stimuli must be task-relevant during the experimental session in order to have an influence on priming effects. No other main effects or interactions were statistically significant.

Probe Error Rates

Mean proportions of incorrect responses to probe words are displayed in Table 8.

Table 8

Proportion of errors when responding to probe words in Experiment 2 as a function of probe task (hard tasks - animal size vs. animal habitat vs. easy tasks- font colour vs. font size), prime font colour (same vs. different), prime font size (same vs. different), and prime task (same vs. different).

	Hard Probe Tasks							
	Animal Size				Animal Habitat			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	.017	.007	.017	.019	.029	.025	.005	.009
Different	.039	.035	.040	.048	.051	.066	.056	.066
SC	-.022	-.027	-.023	-.029	-.022	-.041	-.041	-.057
SE	.012	.009	.008	.013	.010	.015	.013	.022

	Easy Probe Tasks							
	Font Size				Font Colour			
	SS,SC	SS,DC	DS,SC	DS,DC	SS,SC	SS,DC	DS,SC	DS,DC
Prime Task								
Same	.039	.049	.026	.029	.016	.012	.015	.015
Different	.063	.045	.068	.052	.038	.041	.026	.029
SC	-.024	-.004	-.042	-.023	-.022	-.029	-.011	-.014
SE	.012	.008	.015	.012	.009	.009	.006	.009

SS = Same Size; SC = Same Colour; DS = Different Size; DC = Different Colour
SC = Switch costs were derived by calculating the difference in the mean proportion of errors for the same prime task vs. the different prime task conditions, with negative values representing more errors on task-switching trials and positive values representing fewer errors on task-switching trials.
SE = Between-participant standard error of the mean difference in the proportion of errors between same task and different task trials.

Collapsing across the two difficult (Animal Size and Animal Habitat) and two easy probe tasks (Font Size and Font Colour), the error rate data were submitted to a 2 X (2 X 2 X 2) repeated-measures ANOVA, treating prime task (Same vs. Different), prime font colour (Same vs. Different), and prime font size (Same vs. Different) as within-participant factors and task condition (Easy vs. Hard) as a between-participants factor. This analysis revealed an overall main effect of prime task, $F(1,65) = 45.43$, $MSe = .004$, $p < .001$. Participants made about 2.7% fewer errors on same task trials than on task switch trials (.021 vs. .048). Although, due to a restriction in the range of values, statistically significant effects are more difficult to observe in error rates than in RTs, the predicted interaction between prime task and prime condition approached statistical significance, $F(1,65) = 3.09$, $MSe = .004$, $p < .09$. That is, the cost of switching on accuracy in responding to probe words was generally greater in the hard tasks condition than in the easy tasks condition. In the hard tasks condition, participants made about 3.4% fewer errors on task-repetition than on task-switch trials (.016 vs. .050), $F(1,31) = 24.88$, $MSe = .003$, $p < .001$. Whereas, in the easy tasks condition, participants made only about 2.0% fewer errors on task-repetition than on task-switch trials (.025 vs. .045), $F(1,34) = 20.04$, $MSe = .001$, $p < .001$. The difference in error rates between task-repeated and task-switch trials indicates, once again, that completing a task-switch trial is more difficult than repeating the same task whether the two tasks are relatively easy or difficult. No other main effects or interactions were statistically significant.

The purpose of Experiment 2 was to determine whether the magnitude of switch costs depends more on the likelihood of retrieving the prime episode than on the need to inhibit an alternative task. A retrieval view suggests that responding to a difficult prime task involves more elaborate processing, thereby creating a more distinctive memory representation. More distinctive prime events are more accessible upon presentation of a probe display, making it a stronger source of interference during subsequent performance of an alternative task. From this perspective, switching between two hard tasks should result in higher switch costs than switching between two easy tasks; an expectation that was generally confirmed by the results of Experiment 2. When featural matches between prime and probe words were not present to facilitate responding on task-repetition trials in the easy tasks condition, switch costs were significantly higher in the hard tasks condition than in the easy tasks condition.

This support for an episodic retrieval account of task switching costs directly contradicts the predictions that would be made from a task-set inhibition perspective. According to that view, switch costs result from inhibition of the alternative task during the prime event. Because easier tasks illicit a faster response than difficult tasks, it is possible that performing some different task might require more inhibition when the alternative task is easy than when it is difficult. This inhibition might then carry over to the probe event, making it particularly difficult to perform an easy than a difficult probe task on task-switch trials. If this approach to task-switching is correct, switching from any task to an easy task should lead to higher switching costs than when one is required to switch to a difficult task. Contrary to this prediction, the results of Experiment 2 show that higher switch costs can occur when the probe task is relatively difficult, as long as the requirement to perform a difficult probe task follows performance of some other difficult prime task.

CHAPTER 3

GENERAL DISCUSSION

Often, both an A/I approach and an episodic retrieval approach are capable of accounting for priming effects. From an A/I perspective, priming effects are mediated by processes occurring during the prime event. Upon the onset of the prime, relevant dimensions of that stimulus are put in a state of heightened activation, thereby preactivating corresponding abstract nodes that provide access to semantic, phonological, and orthographic features of that stimulus (Collins & Quillian, 1969; Collins & Loftus, 1975). When abstract representations are preactivated, accessing a response for an identical or semantically-related probe item requires less activation; thus, there is usually facilitated responding to that stimulus. On the other hand, irrelevant dimensions of a stimulus are thought to be inhibited in order to prevent incorrect responding. By inhibiting irrelevant features, the activation state of these features is lowered making them less accessible. If these items are then treated as relevant during the probe event, generating a response will require overcoming prior inhibition through additional activation, which slows responding (Neill, 1977; Tipper, 1985).

In contrast, the episodic retrieval view applies a TAP/TIP framework of priming. Unlike an A/I approach, an episodic retrieval view proposes that priming is also importantly controlled by processes occurring at the time of the probe event. Assuming there is an overlap of contextual information between the prime and probe episodes, the probe will cue retrieval of the prior experience (Tulving & Osler, 1968; Tulving & Thompson, 1973; Eysenck, 1978; Tenpenny, 1995). Furthermore, the extent of how much is retrieved depends on the degree of overlapping information. With greater overlap, more of the prime event is retrieved. In addition, the probability of retrieving processes engaged at the time of the prime event might depend on recency of the episode being retrieved as well (Roediger & Crowder). When processes used during the prime episode are similar to the processes needed for an identical or related item, retrieval of prior processes will assist responding, illustrating positive priming. However, if the processes used during the prime event are inappropriate for the current task, these retrieved processes become a source of interference during the probe episode and performance is impaired (Leboe, Whittlesea, & Milliken, 2005; Neill & Mathis, 1998; Wood & Milliken, 1998).

The purpose of my study was to distinguish which of the two competing theories best explains switching costs using a priming methodology. Instead of performing the same task throughout the experimental session as in conventional studies of priming, individuals had to perform one of two tasks in response to each stimulus display, either requiring them to repeat the same task or switch tasks in response to the prime and probe stimuli. Similar to the phenomenon of repetition priming, repeating a task often improves performance (e.g., practicing how to play piano you become a better pianist), whereas the need to switch tasks can impair performance (e.g., having treated recyclables as garbage makes it difficult to acquire the habit of tossing them into a recycling bin). Initial impaired performance after a switch in task is known as a task-switching cost (Monsell, Yeung & Azuma, 2000; Monsell, 2003; Allport, Styles, & Hseih, 1994). Similar to priming effects, task-switching costs can be explained by both an inhibition view and an episodic retrieval approach. An inhibition view declares that engaging in processing of the alternative task interferes with performance of the current task. To prevent the alternative task from interfering with correct responding, engaging in processing of this irrelevant task is actively avoided. Inhibition of a task makes it difficult to respond to this same task immediately afterwards (Tipper, 1985; May, Kane, & Hasher, 1995). Thus, switch costs reflect impaired responding to a previously inhibited task. Alternatively, task-switching costs might reflect impaired responding due to the retrieval of inappropriate processing at the time of the probe episode (Leboe, Whittlesea, & Milliken, 2005). It could be that when two tasks occur close in time and/or share an overlap of featural information, the processes engaged at the time of the prime event will be cued for retrieval to assist with the probe task (Roediger & Crowder, 1976; Tulving & Osler, 1968; Tulving & Thompson, 1973; Eysenck, 1978; Tenpenny, 1995). During a task-switch, however, the retrieved prime episode interferes with engaging in processing of an alternative probe task. That is, switching costs might reflect impaired performance of a task due to the interference caused by the retrieval of inappropriate processes.

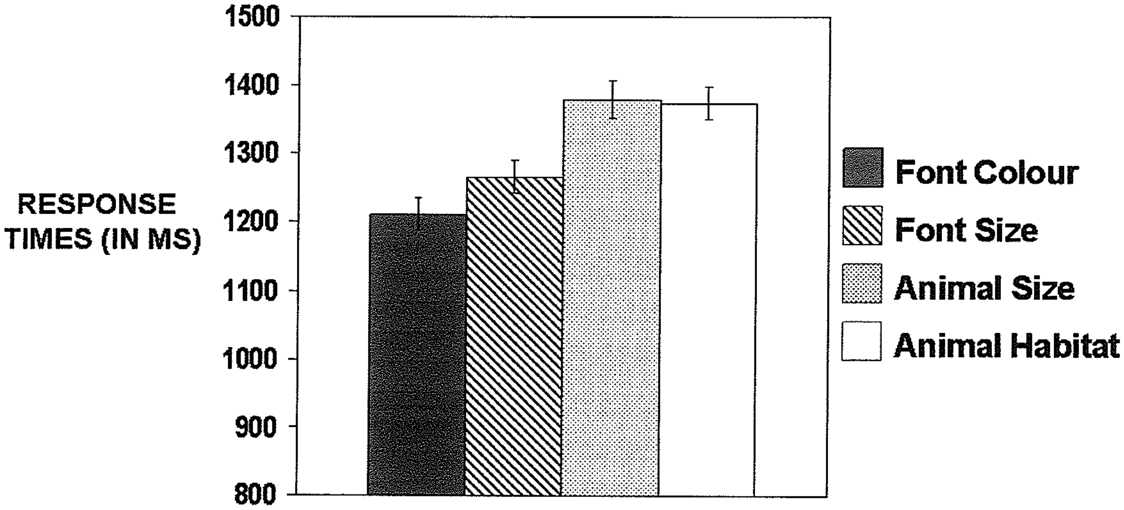
Interestingly, task-switching costs are influenced by the level of task difficulty. Research has frequently shown a switch cost asymmetry in that switching from a difficult task to an easy task results in higher switching costs than the reverse (Allport & Wylie, 2000). This switch cost asymmetry was replicated in Experiment 1. A switch from one of the difficult conceptual tasks (Animal Habitat or Animal Size) to an easier perceptual task (Font Size or Font Colour) led to higher switch costs than a switch from one of the easy tasks to one of the more difficult tasks. One explanation for this asymmetric switch cost is based on the inhibition view. Participants are more likely to inappropriately respond to the alternative task when that task is easy compared to when it is difficult. This is because the responses associated with easy tasks are more accessible from memory than responses associated with difficult tasks. As a result, it ought to be necessary to apply more inhibition to an irrelevant easy task than one that is more difficult. Thus, higher costs of switching to an easy task might reflect greater impairment due to deeper inhibition of that task-set during the prime episode.

Another possible explanation of asymmetric switch costs is based on an episodic retrieval approach. Higher switch costs associated with switching from a hard task to an easy task might occur because difficult tasks require elaborative processing that generates a distinctive representation in memory. In turn, these more distinctive memory representations will be more accessible for retrieval during the probe event. When the probe event requires performance of a different task than the prime event, enhanced retrieval of the prime episode through distinctiveness will contribute an especially potent source of inappropriate processing. Thus, switch cost asymmetries are also predictable based on the episodic memory principle that elaboratively encoded events are more likely to be retrieved from memory (Eysenck, 1978; Craik & Lockhart, 1972).

The purpose of Experiment 2 was to distinguish whether an inhibition approach or an episodic retrieval approach best explains switch costs using an immediate priming methodology that required participants to either repeat or switch between two easy tasks or two harder tasks. Based on an inhibition account of task-switching, it was expected that inhibition of an alternative task at the time of the prime event impairs responding for this same task at a later time. The processes needed to respond to a difficult task are less accessible from memory than the processes needed to respond to an easy task, thus less inhibition is required to suppress a response when a difficult task is currently irrelevant, whereas more inhibition would be necessary to suppress performance of an easy task that is currently irrelevant. More inhibition applied to easy tasks compared to harder tasks should make switching from any prime task to an easy probe task more difficult (Allport, et al., 1994). If this "task-set inhibition" account of task-switching costs is correct there ought to have been higher switching costs in the Easy Tasks condition compared to the Hard Tasks condition in Experiment 2. However, the results revealed higher costs of switching in the Hard Tasks condition after removing the effect of perceptual overlap on switching costs in the Easy Tasks condition. Moreover, if it is more necessary to inhibit an irrelevant task to the extent that it is easy making it difficult to respond to when it becomes the probe task, then switch costs should increase as the difficulty level of the probe task decreases. To determine if the prediction made by an inhibition view is correct, I computed the mean probe RTs across Experiments 1 and 2 for each of the four tasks. Since, featural matches between the prime and probe on probe RTs made their own contribution to task-switching costs separate from the effects of probe task difficulty, only probe RTs for trials in which the prime and probe words differed in both font size and font colour were examined. Figure 1 displays the mean probe RTs across both experiments for each of the four tasks when the prime and probe words differed in both font colour and font size. This pattern of results establishes the font colour task as the easiest of all four tasks. The font size task was intermediate in difficulty, and the meaning-based animal size and animal habitat tasks generally took the longest amount of time for participants to perform.

Figure 1

Mean probe RTs obtained in Experiments 1 and 2 for each of the four tasks (font size, font colour, animal habitat, animal size) for trials in which the prime and probe words differed in both font colour and font size.

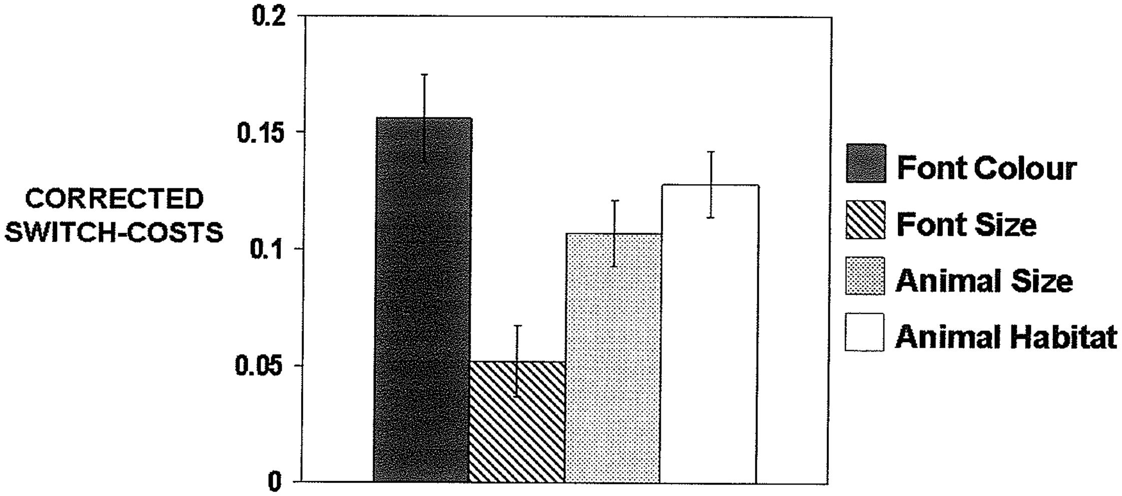


Note: Error bars represent the between-participant standard error of probe RTs.

Based on this pattern of probe RTs, an inhibition view would predict the highest costs would occur when the probe task was font colour, an intermediate level of switching costs when the probe task was font size, and the lowest magnitude of switching costs when the probe task required either a judgment of animal size or animal habitat. Figure 2 displays the mean corrected costs of switching to each of the four possible probe tasks averaged across both Experiments 1 and 2. In this case as well, the switch costs are restricted to trials in which the prime and probe words differed in both font colour and font size.

Figure 2

Mean corrected switch costs obtained in Experiments 1 and 2 when switching to each of the four tasks (font size, font colour, animal habitat, animal size) for trials in which the prime and probe words differed in both font colour and font size.



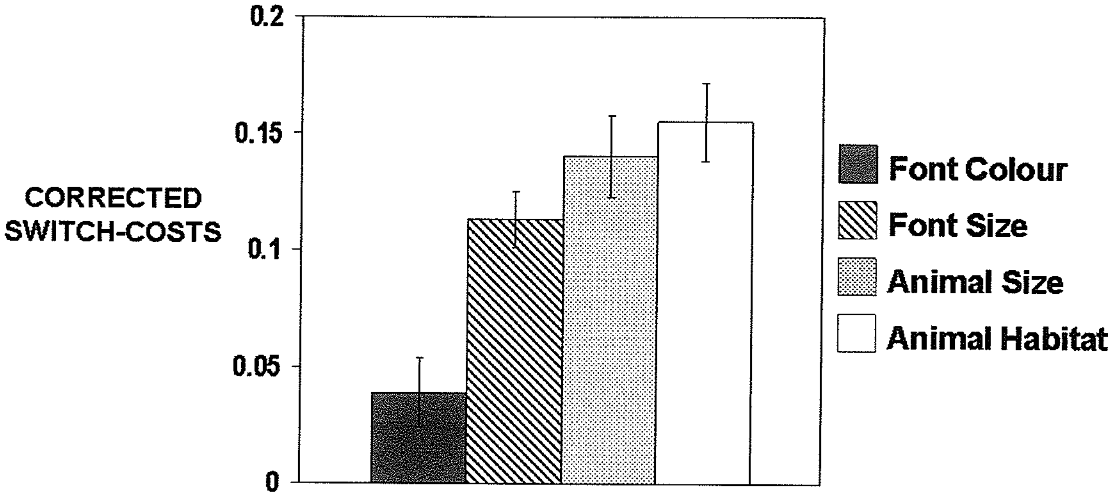
Note: Error bars represent the between-participant standard error of corrected switch costs.

The results obtained from Experiments 1 and 2 do not conform to the predictions that would be made from the task-set inhibition perspective on switching costs. Switching costs did not consistently increase depending on the relative ease of the probe task. The easiest probe task of colour identification did produce the highest switch costs. However, the font size task was intermediate in difficulty, yet produced the lowest switch costs. Thus, the magnitude of switch costs might not result from the need to more deeply inhibit easy tasks at the time of the prime event. Instead, it might be more appropriate to explain task-switching costs in terms of episodic retrieval. Unlike the inhibition view of task-switching costs, the episodic retrieval view suggests that switch costs reflect impaired responding due to the interference caused by the retrieval of inappropriate processes at the time of the probe episode. The extent of these costs should be modulated by the difficulty of the prime task. A difficult prime task involves elaborative processing that creates a distinctive representation in memory (Craik & Lockhart, 1972). The more difficult the prime task, the more this event will be made available to interfere with responding to some different probe task. Thus, in Experiment 2, switch costs should be highest in the Hard Tasks condition, when the prime task was always relatively difficult, than in the Easy Tasks condition, when the prime task was always relatively easy. After eliminating the confounding effects of perceptual overlap between the prime and probe words on the dimensions of font colour and font size, the results of Experiment 2 confirmed this prediction.

In contrast with the inhibition approach to switching costs, support for a retrieval view would be obtained if switch costs increased systematically as a function of prime task difficulty. Figure 3 displays the mean corrected switch costs obtained when participants switched from each of the four possible prime tasks, averaging across Experiments 1 and 2. In this case as well, I included only trials in which the prime and probe words differed in both font colour and font size.

Figure 3

Mean corrected switch costs obtained in Experiments 1 and 2 when switching from each of the four tasks (font size, font colour, animal habitat, animal size) for trials in which the prime and probe words differed in both font colour and font size.



Note: Error bars represent the between-participant standard error of corrected switch costs.

Consistent with an episodic retrieval account, corrected switching costs increased systematically as the difficulty of the prime task increased. These results support the idea that elaborative processing associated with performance of a hard task represents the primary source of interference when switching to some alternative probe task. That is, responding to the probe task is most impaired by interference due to the enhanced likelihood of retrieving of a more distinctive prime episode.

The present study used a novel approach to distinguish which of two competing views best captures task-switching costs. Since switching between two difficult tasks resulted in higher switch costs in Experiment 2, the current study supports an episodic retrieval account of switch cost asymmetries and task-switching costs in general. Since results of prior priming studies can be accounted for by both an A/I and episodic retrieval view, results of this particular study that favour an episodic retrieval approach indicates there are some circumstances that are not well accounted for by the A/I framework. Thus, it is possible that that other priming phenomena accounted for by an A/I view might be inaccurately conceptualized as resulting from activation or inhibition of abstract mental representations. Instead, upon the suggestion made by an episodic retrieval view, performance in immediate priming experiments might depend on the likelihood of accessing the processes associated with the prime event from memory. The factors that determine whether retrieval of a prime episode will occur include the closeness of the two events in time, the similarity between aspects of the prime event and those associated with the probe display, and the distinctiveness of the prime episode. Moreover, whether retrieval of the prime episode impairs or facilitates responding to a probe display will depend on the appropriateness of processes engaged in during the prime event for performing the probe task. If processes that occurred during the prime event are appropriate, positive priming effects can be expected to occur, resulting in both stimulus repetition and task repetition benefits. However, if processes occurring during the prime event are inappropriate, negative priming effects can be expected to occur, giving rise to both stimulus repetition and task-switch costs.

Everyday we change from one task to the next. The relevance of studying task-switching costs is important for tasks in which fast responding and minimal errors are important. For instance, surgeons might be required to switch from performing a routine operation on one patient to a more complex operation on another patient. Any impairment in their ability to switch from one task to another will be detrimental to their patient's life. With a better understanding of the causes and influences of task-switching costs a method of controlling the extent of impaired performance due to a change in task can be developed. For instance, this study found that the lowest costs occur when switching from an easy task. Thus, the costs associated with a change in task can be reduced if the easier of the two tasks is performed first.

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