The Influence of Preparation on the Priming of Response Rules.

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Abstract

Many areas of study within psychology have historically relied on a dissociation between consciously controlled, willfully driven behaviors and behaviors that are driven by unconsious, automatic mental processing systems. In many cases, it is further assumed that consciously controlled and automatic processes can both contribute to a single behavior, and that they are functionally independent and cannot directly influence one another. For example, driving a car relies on both consciously attending to staying within the speed limit and the automatic, trained associations between pressing the right footpedal and increasing speed and the left footpedal and decreasing speed. Although automatic and controlled processes generally appear to function independently from one another, there may be special exceptions to this rule. Exploration of these exceptions might allow for a better understanding of how these separate systems coordinate the performance of a single action.

In the current experiments, we demonstate a special circumstance under which conscious thought processes directly influence that automatic system and propose specific boundary conditions under which this may occur. Experiments 1 and 2 demonstrate that conscious preparation for an upcoming task suppresses the automatic influence of a prior task response when both of the following conditions are met: 1) preparation includes the selection of a response for an anticipated task, and 2) the previously performed task and the prepared task use conflicting response rules. Experiment 3 futher supports this hypothesis by showing that suppression of the prior response influence occurs when participants prepare a conflicting response rule but actually use the same response rules as the previous task. Subsequent experiments further investigate the time course of the suppression of prior response influences (Experiment 4) and the nature of the conflict between conscious and automatic influences (Experiment 5). The results of this series of experiments suggest that conscious and automatic processes do not always operate fully independently of one another, and that under specific circumstances conscious preparation for an upcoming task can modulate the influence of prior responses on subsequent task performance.

Acknowledgments

Thanks to all of the giants that let me stand on their shoulders for a while. Special thanks to Dan Willingham for putting back on those shoulders every time I started slipping off, and Denny Proffitt for teaching me that it’s giants all the way down. To the entire cognitive faculty at the University of Virginia, you complete me!

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Chapter 1

1. Introduction

1.1 Overview:

Many factors influence how well a person can perform a particular task. For example, an individual's intended goal or expertise in a specific field may alter his or her response to an object in the environment and how quickly these responses occur. Imagine you are driving a car while talking on a cell phone and taking sips of coffee. Although you may be adept at each of these specific actions, performing each of these simple tasks is more difficult when you must quickly alternate between them. Most researchers believe that this decrement in performance following a switch in tasks, or *switch cost,* originates in the conflict of response rules between two sequentially performed tasks. When performing a task, a mental representation is created that includes the rules for the appropriate action to a specific object in the environment. For example, if you are playing soccer, you activate the appropriate response rules, such as "To pass the ball, kick it with my foot" or "If the ball comes to me in the air, stop it with my chest." Switch costs occur because a previously used response rule influences subsequent behavior after the task has been performed. If you then change to a new task, such as playing basketball, a new set of response rules must be instantiated, such as "dribble the ball with my hand." Since the soccer task representation is still active, it interferes with the now appropriate basketball response rules and additional time is required to resolve this conflict.

Most day-to-day tasks are fairly complex, involving many different sets of rules for responding to objects or events in the environment that are sometimes under-defined. Once again considering a game of soccer, there are an indefinite number of responses that can be made to a soccer ball - pass left, pass right, dribble, kick, shoot, etc. In an experimental setting, it is possible to constrain the number of possible response rules for a task. In the case of a two-stimulus, two-choice spatial response task, the response rules are constrained to “response on the same side as (compatible to) the stimulus location” or “response on the opposite side as (incompatible to) the stimulus.” With this constraint it is possible to create distinct response rules for two different versions of the two-choice spatial response task that are both exclusive and exhaustive but remain analogous to real-life behavior.

In a series of experiments, we examine the relationship between the conflicting response rules during task performance and the role of task preparation. Specifically, we conjecture that under special types of advance task preparation, the influence of prior actions can be reduced or eliminated prior to the onset of a new task.

1.2 Automatic and Controlled Influences on Task performance

Nearly a century ago, Narcissus Ach (1910) proposed that performance on a sequence of tasks is driven by the dynamic combination of two factors: goal related cognitive processes and habitual response biases formed during previous experience.

Most recent models of task performance restate this dual process distinction as automatic and conscious influences on behavior:

1.2.1 Automatic Influences: Priming of Response Rules

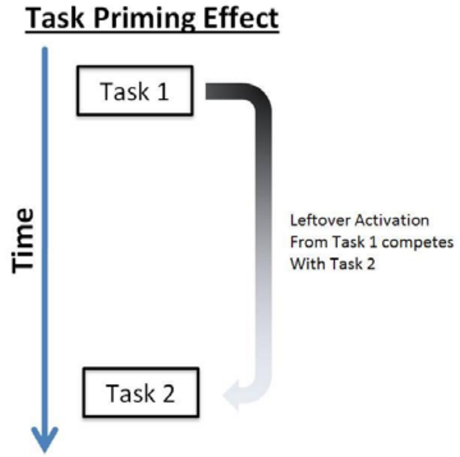

Figure 1. Influence of task priming from Task 1 on Task 2 responses

A significant portion of task switching costs represent low-level conflict between the newly activated processes that are appropriate for task performance and the still active biases created during performance of the previous and now irrelevant task (Altmann, 2002, 2003). For the sake of clarity, we broadly refer to left-over activation of previous task performance as *task priming effects*. Following completion of the task, these processes remain active, leaving behind an "echo" of this activation that can influence (Figure 1). There are two ways in which task competition then occurs: 1. Remaining activation from the previous task passively dissipates over time, acting as mental noise that interferes with any concurrent activities (Allport, Styles & Hsieh, 1994). 2. The previous task stimulus and response become associated with each other. If the same stimulus appears at a later time, the associated response once again becomes active (Allport & Wylie, 2000).

Task Set Inertia

One commonly described form of priming, *task set inertia*, assumes that activation that occurred during a previously performed task remains after the task is complete and dissipates over a short period of time (Allport, Styles & Hsieh, 1994; Allport & Wylie, 2000; Altmann, 2002; Meiran, Chorev, & Sapir, 2000; Sohn & Anderson, 2001). This leftover activation in task set inertia includes not only specific features of prior stimuli and responses, but also the rules governing the relationship between the sets of stimuli and responses. Bower (1996) suggests that task set inertia can be viewed as transient "readiness" to receive the same task features including the stimulus and response rule, and then respond in the same way as was done on the previously executed task.

Transient task priming, Allport, Styles & Hsieh (1994) argue, is a strong contributor to task switching performance costs. When the rule for responding changes, the remaining activation of the previously used rule competes with the currently appropriate response rule. Assuming that this activation is transient, interference from the earlier task should eventually completely diminish. According to Task Set Inertia, this diminution of activation is passive and takes place over a second or two.

Other research presents data contradictory to the Task Set Inertia account. For example, Rogers & Monsell (1995) presented a pair of characters – a letter and number – on a computer screen. Subjects either determined if the letter was a vowel or consonant or if the number was odd or even, based on the location of the character pair. The trial structure was such that subjects would receive a run of four trials of one task followed by four trials of the other task. According to Task Set Inertia hypothesis, when a task switch occurs, priming from the former task should interfere with the performance following a task switch for several subsequent trials. Their results showed a switch cost on only the first trial of the new task whereas the theory predicts that the switch costs should continue, but diminish with time. (It should be noted that using a similar procedure, Salthouse et. al. (1998), found switch costs through the second trial following a task switch for older adults). Another problematic finding for Task Set Inertia is that even at long durations between alternating trials (as long as 4 seconds, Sohn & Carlson, 2000), a residual task switching cost remains (Allport, Styles & Hsieh, 1994; Meiran, 1996; Rogers & Monsell, 1995). This enduring switch cost implies that either priming effects do not dissipate or that there are factors in addition to task inertia that are responsible for residual switch costs.

Stimulus-Based Priming

In a well known study of the influence of task switching on performance, Jersild (1927) further refined Ach's (1910) procedure for studying and provided a useful paradigm for examining such effects. A list of numbers was given to subjects. Some subjects were instructed to respond by subtracting 3 from each item whereas others alternated between subtracting 3 and adding 6 to each. As expected, performance was markedly better when a task was repeated than when tasks alternated. In another experiment, subjects alternated between subtracting 3 from presented numbers and naming the antonym to presented words. In this case, Jersild observed no alternation cost. Jersild therefore concluded that the performance costs associated with task switching are limited to cases in which all of the tasks use the same set of stimuli, and not just from task switching alone.

Wylie & Allport (2000) came to a similar conclusion about the nature of automatic influences on performance. In particular, they found that performance on a previous task trial influences subsequent behavior, and this is especially strong when the same stimulus reoccurs. Furthermore, as participants perform a given task multiple times with the same stimulus, a reoccurrence of that stimulus has an even strong influence on subsequent task performance. Wylie and Allport interpreted this as evidence for the creation of a specific stimulus-response association during task performance that is enduring. When the same stimulus is subsequently presented, the associated task from past performance is automatically retrieved and activated. Furthermore, the strength of this readiness can be increased with repeated exposure to the same response rule or reduced over time when the relationship between a stimulus and response changes. In some situations, this form of priming can also have long term-influences on task behavior. For example, Allport, Styles, & Hsieh (1994) showed that a previously used response rule can interfere with using a new a new response rule at a much later time – even after as many as 100 intervening task trials.

In both the stimulus-based priming and the task inertia accounts of response rule priming effects, the competition between two concurrently active response rules is similar to a balance scale – whichever response rule has the most activation drives behavior. As such, task conflict can be resolved in two ways. First, additional weights can be added to one side of the balance, tipping it in favor of one of the responses. In other words, activation associated with the to-be-performed response rule can be increased so that it overwhelms the activation of irrelevant response rule and leads to the correct behavior. Alternatively, weights can be removed from the side of the irrelevant response rule, once again tipping the balance in favor of the proper, or relevant, task. In this scenario, irrelevant response rule activation is suppressed or inhibited. When examining the resolution between two response rule alternatives, it is difficult to discriminate whether the resolution results from increased activation of the relevant rule, suppression of activation for the alternative rule, or a combination of both since the common measure of response conflict (compatible versus incompatible trial RTs) confounds both of these possibilities.

1.2.2 Conscious Influences: Preparation and Task Performance

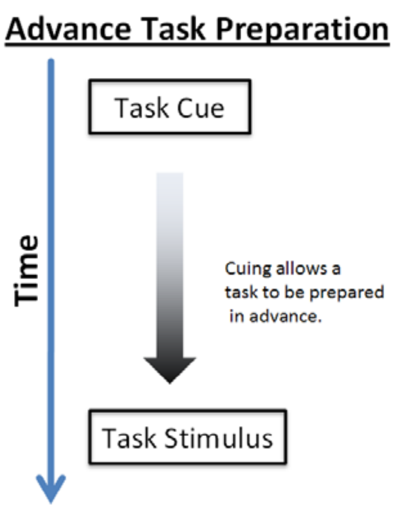

Figure 2. Increasing the predictability of an upcoming task improves performance.

Cognitive control of task switching involves two separate factors

To successfully perform any new task, it is necessary to establish the new task goal, choose the appropriate rule for responding to a stimulus based on this goal, and then select the appropriate response based on this rule (Rogers & Monsell, 1995). Each of these components contributes to the amount of time and effort required to accurately execute an appropriate response. If given advance information about an upcoming task, it is possible to do some of this reconfiguration prior to the task onset (Biederman,1973; LaBerge, Petersen & Norden, 1977; Meiran, 1996; Sudevan & Taylor, 1987). For example, individuals are faster and more accurate at performing an arithmetic task such as adding or subtracting if they know what type of operation they will perform ahead of time, even if they don't know the specific numerals used in the ensuing math problem (Biederman, 1973). The beneficial effect of advance knowledge on subsequent task performance suggests that it is possible to prepare the cognitive system for an upcoming task endogenously, or without the need of any external stimuli. As the time allowed for preparation increases, so does its benefit to subsequent performance (Figure 2.).

Although providing foreknowledge of an upcoming task leads to an overall improvement in performance, the influence of advance preparation on the size of task switching costs is not fully understood. Although some researchers contend that advance preparation cannot fully ameliorate the costs associated with switching tasks (Allport, Styles & Hsieh, 1994; Altmann, 2004; Sohn & Carlson, 2000; Ward, 1982), many studies show that preparation at least partially reduces switch costs (Lien et al, 2005; Meiran, 1996; Rogers & Monsell, 1995). Additionally, increasing the amount of preparation time may benefit overall performance, but even extended durations of advance preparation do not fully eliminate switching costs. It might appear, therefore, that task reconfiguration (which presumably occurs during the time between the cue and the stimulus) plays a minor role in task switching costs. That is not necessarily the case, however. Rather, ***it is likely that not all of the reconfiguration process takes place during advance preparation***. Rogers & Monsell (1995) and others (Logan & Gordon, 2001; Meiran, 1996, 2000) suggest that some additional task reconfiguration must take place only after the imperative task stimulus appears.

Perhaps the most contentious debate in task switching research is the source of the remaining switch costs that cannot be eliminated by advance preparation, referred to as *residual switching costs* (Rogers & Monsell, 1995). There are many accounts of residual switching costs, but usually they are attributed to either the inability to fully configure cognitive processes for an upcoming task prior to the onset of the task stimulus (first promoted by Rogers & Monsell, 1995) or to remaining activation of the processes associated with the previous and now irrelevant task (Allport, Styles, & Hsieh, 1994; Waszak, Hommel, & Allport, 2003). A critical test for any of these theories is to predict the specific circumstances under which residual switch costs will and will not occur.

1.2.3 The Interaction of Conscious and Automatic Processes

When provided with foreknowledge of an upcoming task, it is possible to prepare a task in advance and activate the new response rule(s) before a task begins. Still, this preparation does not eliminate the effect of the lingering representation of the just-completed task. Prior research consistently finds that although preparation improves overall performance, it has no effect on the costs associated with switching tasks (Sohn & Carlson, 2000). However, there may be certain types of preparation that can indeed reduce switch costs and further improve performance. That is the subject of the proposed research.

Performance following a task switch improves both when more preparation time is provided for reconfiguration to the new task and when the duration between task trials increases, thereby possibly reducing the conflict between tasks (Altmann, 2004). In earlier task switching research, it was difficult to separate the respective influences of preparation and priming on switch costs, since foreknowledge of an upcoming task was provided by some feature of the previous task stimulus and therefore the duration of preparation and priming prior to a task switch were perfectly correlated. However, more recent studies utilize the explicit cuing paradigm, which separates the previous task trial from the instructional cue for the subsequent task, thereby allowing the duration of both to be independently varied (Altmann, 2004; Logan & Bundesen, 2003; Meiran, 1996).

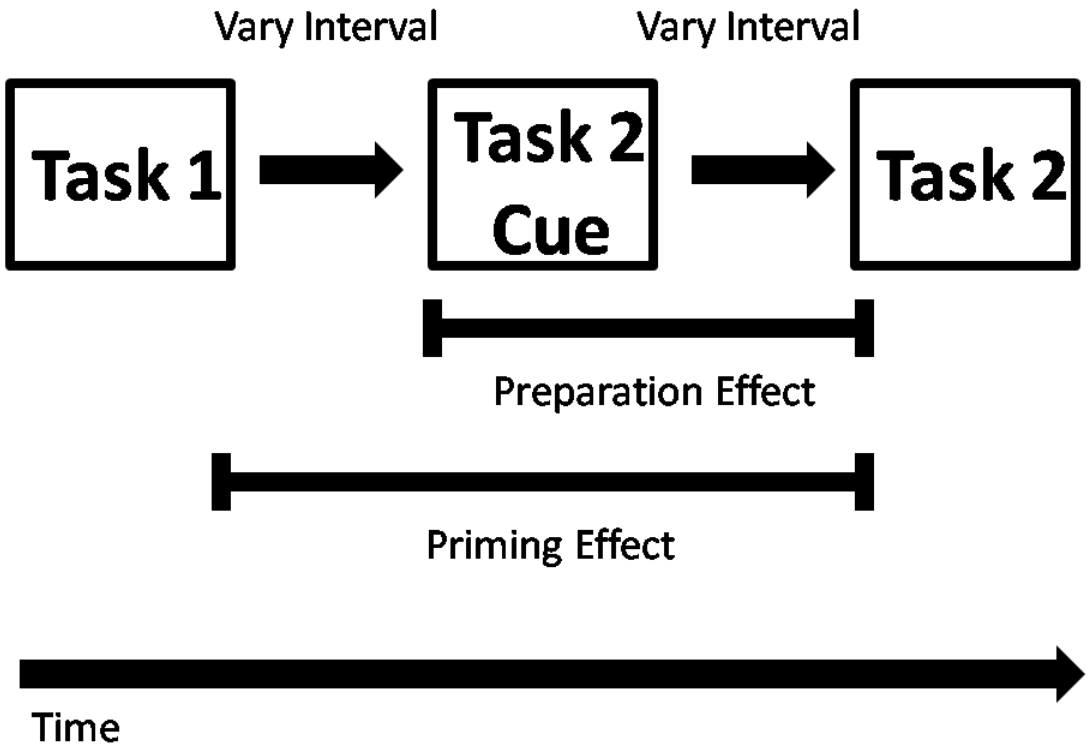

Figure 3. The basic Explicit Cuing Paradigm procedure. The interval between the first task response and the second task cue and the interval between the second task cue and second task are varied independently. This in turn allows the influence of the priming effect (First task's influence on the second task) and the preparation effect (conscious cue-based preparation for the second task) to also be varied separately.

The basic design of the explicit cuing paradigm is first to present a task trial, followed at a later time by a cue stimulus that provides foreknowledge of the task in the subsequent trial, and then the next trial stimulus appears (Figure 3). Thus, both the interval between trials and the duration between the cue and subsequent trial can be manipulated: the inter-trial interval determines the influence of the priming effect and the interval between the onset of the cue and the subsequent task stimulus determines the amount of advance preparation that takes place. Using this design, it was found that the influences of preparation and priming do not interact – increasing the amount of time allocated to preparation does not change the influence of the priming effect on switch costs (Altmann, 2004; Koch, 2001; Schuch & Koch, 2003;).

Another, arguably more radical way to investigate the interaction between preparation and priming effects is to vary their existence prior to a switch in task. Sohn and Carlson (2000) used a simple factorial design in which a task trial was or was not preceded by another trial and foreknowledge of the task was or was not provided. Their results corresponded with those in the explicit cuing paradigm: both preparation and priming from a previous trial influenced subsequent performance, and their influences were fully additive and thus independent from one another. .***Although preparation did not interact with priming in the aforementioned studies, it cannot not be concluded that advance preparation NEVER affects priming effects.*** As with most previous task switching studies, the foreknowledge provided for the upcoming task informed subjects about the task that would be used, but not the specific stimulus nor response that would be selected and therefore these components of task reconfiguration did not occur until the onset of the task stimulus.

Inhibition reduces response conflict, but only during response selection

Mayr & Keele (2000) provided compelling evidence that in order to respond following a switch in tasks, the activation associated with the previous task is suppressed in order to reduce its competition with the relevant to-be-performed task. Once again using the scale balance metaphor, this suppression is the removal of weight from the side of the scale representing the previous task, which tips the scale in the direction of the now relevant one. In Mayr & Keele‘s experimental paradigm, participants sequentially performed one of three tasks (Task 1, 2, or 3) that could change on a trial-by-trial basis. The crucial data are the performance on the last task in a sequence of trials (task 1, in the example below), given different sequences of tasks in the previous trials. Results showed that participants exhibit greater performance costs when returning to a recently abandoned task (Task 1 – Task 2 – Task 1) than when the task was not recently switched from (Task 3 – Task 2 – Task 1). Mayr & Keele argued that in order to resolve any task conflict following a switch, the previous task must be inhibited, and this *backwards inhibition* remains upon a return to the abandoned task and impairs performance.

Subsequently, it was determined that inhibition of the switched-from task only occurs when a response is prepared in the switched-to task (Figure 3.). Using Mayr & Keele‘s paradigm, Schuch & Koch (2003) included Go/No-Go trials in which an additional signal appeared on the screen when the task stimulus appeared that instructed subjects to either make or withhold a response to the task. Therefore, in No-Go (withhold response) trials, subjects saw the task stimulus and prepared for the task, but did not select a response. Unlike Mayr and Keele‘s (2000) result that responses were slower following a return to a recently switched-from task (Task 1 - Task 2 - Task 1) because of backwards inhibition, this was not the case when a response was not selected in the intermediary task (Go Task 1 – No-Go Task 2 – Go Task 1). In an additional experiment, they also showed that no backwards inhibition takes place when a non-directional response (a response unrelated to the task) is made. Schuch and Koch concluded that suppression of a previous task only occurs when subsequent task-related response selection takes place.

If preparation for a task and actual task performance share many of the same mental processes, then why does task performance resolve competition from previously performed tasks and preparation does not? Clearly the answer lies in the differences between task preparation and performance rather than in their similarities. In nearly all modern task switching paradigms, foreknowledge of upcoming tasks only partially predicts the subsequent trials, usually by providing advance knowledge of the specific set of response rules that will be used but not information about the specific task stimulus.

For most task switching research, the comparison of interest is between performance following a task switch and following a task repetition. Therefore, the fact that preparation is incomplete is of little interest since this partial preparation is the same in both of these trial types. This prevents the active selection of the correct response from occurring until this stimulus appears. As demonstrated by the backward inhibition studies of Mayr & Keele (2000) and Schuch and Koch (2003), response selection is a necessary condition for the suppression of previous task activation. Therefore, we contend that there is nothing special about the mental processes that occur during advance preparation that absolutely prevent it from suppressing prior task activation; the independence of conscious processes (task preparation) and unconscious processes (backward inhibitory priming processes) observed by previous researchers (Altmann, 2004; Koch, 2001; Schuch & Koch, 2003) were an artifact of the tasks that they used. As with actual overt task performance, if preparation includes response selection, it should also directly lead to the suppression of irrelevant task activation, thereby eliminating competition between tasks and eliminating or at least severely reducing, task switching costs (Figure 4.).

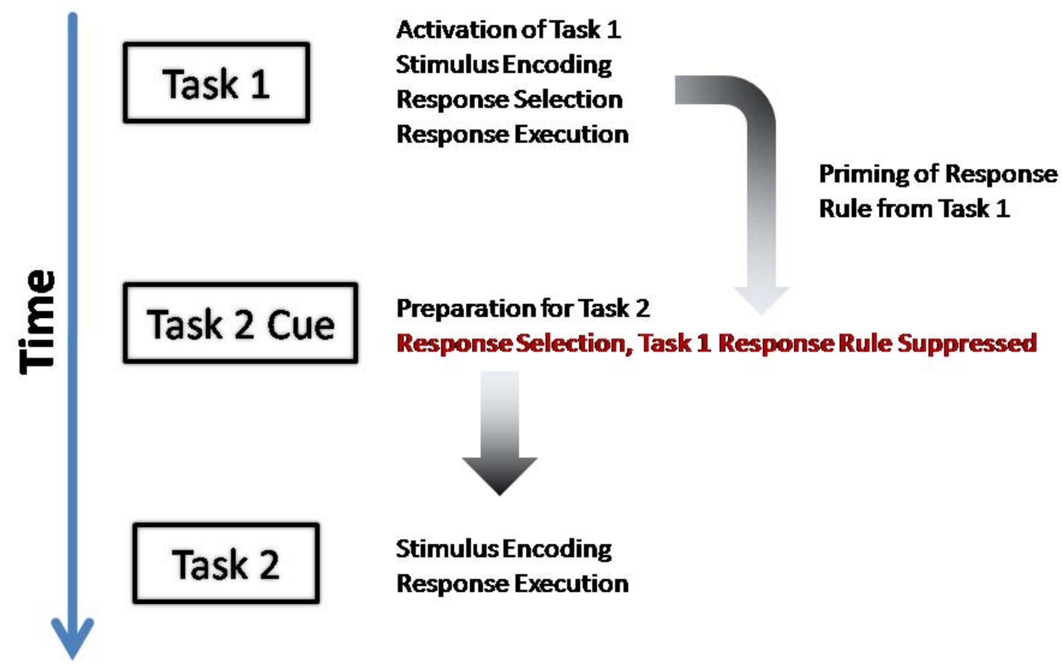

Figure 4. A combination of priming and preparation. When preparation for an upcoming task includes advance response selection, then priming may be suppressed during this stage

1.3 Experiment 1: Trial predictability and Rule Switches

To summarize, current task switching literature has generally shown that advance preparation for an upcoming task does not interact with the influence of the task rule that was used on the previous trial. In task switches, preparation for the new task improves response times and the prior response rule interferes with, and thus slows down response times on the subsequent trial. Experiment 1 investigates the possibility that this lack of an interaction occurs because partial predictability of an upcoming task trial is simply not sufficient to suppress the priming of the response rule from the previous trial. Therefore, trial predictability is manipulated so that participants either can only predict the response rule of an upcoming task trial (similar to most previous research), or can predict both the response rule and the specific stimulus that will appear. In the latter case, a response may be selected during the advance preparatory period, leading to the suppression of the priming effect from the previously used response rule.

Method

Participants

Participants were 31 undergraduate students (10 male, 21 female) at the University of Virginia ranging in age from 18 to 22. They participated in exchange for class credit.

Tasks

Variants of a standard spatial two choice RT task were used, in which participants were sequentially presented a pair of stimuli, S1 and S2. The nature of the S1 stimulus was varied in two ways. First, participants either simply watched the S1 stimulus or responded to S1 (No Prime and Prime trial types). Second, the level at which the S1 stimulus predicted S2 was also manipulated (Full Trial Predictability and Partial Trial Predictability).

In the *No Prime* trial type, a white cross (S1) appeared for 500ms in one of the boxes. The offset of S1 was immediately followed by a randomly determined 500ms, 750ms, 1000ms, 1500ms, or 2000ms interval with blank boxes only. The interval was varied to prevent participants from predicting the onset of S2. A white “X” (S2) then appeared and remained in one of the boxes until a spatially compatible response was made (R2).

In the *Prime* trial type, a white cross (S1) appeared in one of the boxes. Unlike the No Prime trials, participants also made a spatially *incompatible* response (R1) to S1. Although a response was made to the S1, the stimulus remained on the screen for 500ms so that the timing between the onset of first and second stimulus remained equivalent between Priming trial types. A white “X” (S2) then appeared in one of the boxes and participants responded a second time with a spatially *compatible* response (R2).

The key conceptual distinction between No Prime and Prime trials is that although both provide equivalent levels of S2 trial predictability, prime trials also include the aforementioned response rule priming effect. In addition to the manipulation of response versus no response during S1, the S2 trial predictability provided by S1 was also varied. Throughout the entire experiment, participants were always aware of the response rule that was to be used following the presentation of the S2 stimulus – specifically, participants were instructed that they should always respond on the same side as (compatible) the location of the stimulus. However, in half the trial blocks of both No Prime and Prime, S1 also perfectly predicted that the stimulus location of S2 would be on the same side as the S1. Since the response rule of S2 was always known, participants could select the correct response prior to the onset of the S2 (Full Trial Predictability). On the other half of the blocks, participants were informed that S1 was not informative of the location of S2 (Partial Trial Predictability). In this case, the S2 location varied independently of the S1 location, with half the trials on the same side as the S1 and half on the opposite side; therefore, participants could only predict the response rule that would be used with S2.

Procedure

Participants were told to rest their left and right index fingers on the "Z" (left) and "M" (right) buttons on a computer keyboard. The viewing distance from the screen was approximately 60cm. Prior to each trial, the words "Prepare for Next Trial" were presented in the center of the computer screen for 2000ms, followed by a black screen for 250ms. Two horizontally aligned empty boxes (each 2.5 cm square) then appeared. The centers of the boxes were separated by a 5.0° viewing angle and were centered vertically. The boxes remained blank for 250ms, followed by the cue, which varied by trial type.

Trials were blocked such that each block consisted of 40 trials of either the Prime or No Prime trial type. Each participant performed two blocks of No Prime and of Prime at both levels of S2 Predictability (Full versus Partial Predictability) for a total of 8 trial blocks. Block order was counterbalanced across participants (ABBACDDC). Prior to the first block of each Priming Type and S2 Predictability condition, participants received extensive instructions on how to perform the task followed by 10 practice trials. Participants were always instructed to prepare for the S2 trial as much as possible. Anticipations, which included any response following the offset of the S1 stimulus until the onset of S2, were discouraged by the visual message "You responded too early" and such trials were not further analyzed. Errors were signaled by the message "Incorrect Response."

Due to the nature of the experimental design, all of the trials in the Full Preparation condition involved a repetition of the stimulus location between cue and target but this was only true for half the trials in the Partial Preparation condition. Therefore, only the trials in which the stimulus location repeated in the Partial Preparation trials were used in the final data analysis across conditions in order to make the data comparable across the preparation conditions.

Results

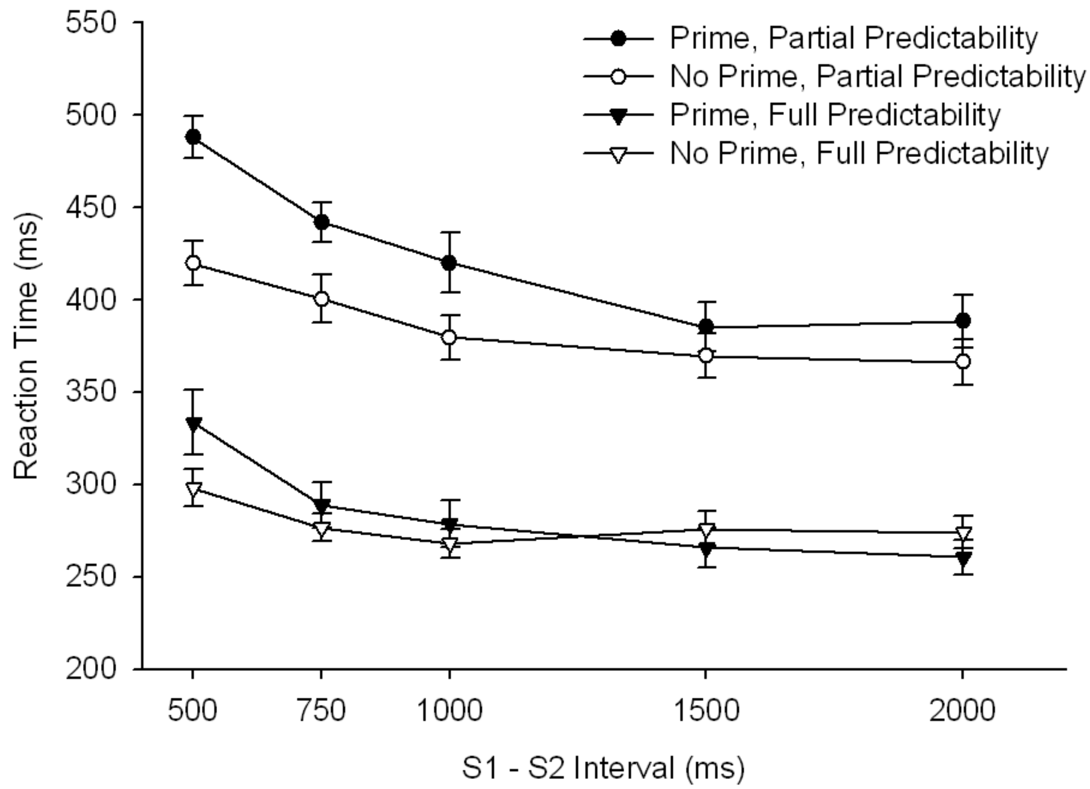

Figure 5. Response Times to S2 in response rule switch trials. The cost of priming is quickly reduced when full predictability is available.

A key distinction between full and partial trial preparation in the current experimental paradigm is that participants can include response selection during preparation in the former but not the latter condition. If preparation that includes response selection leads to the suppression of priming effects, then an interaction between the factors of Priming and Predictability should be found such that full trial predictability leads to a decrease in the priming effect (No Prime minus Prime trials) when compared to the priming effect under partial predictability.

Four participants were removed from the analysis because of computer crashes. Response times to S2 are shown in Figure 5. Of particular interest in the current experiment, there was a significant interaction between Priming and Predictability conditions, $F(1, 26) = 11.26$, $p < .01$, $MSE = 31{,}763$, such that the influence of priming had a greater detrimental effect on S2 performance when the S2 trial could only be partially predicted in advance. The main effect of Priming Type was reliable, $F(1, 26) = 6.64$, $p < .05$, $MSE = 66{,}500$, showing slower overall S2 response times in the Prime trials. As expected, there was also a main effect of Predictability, with full predictability leading to faster S2 responses than partial predictability, $F(1, 26) = 246.29$, $p < .01$, $MSE = 2{,}071{,}608$. There was also an effect of S1-S2 interval, indicating that response times were significantly reduced with longer intervals between the S1 and S2, $F(4, 104) = 53.08$, $p < .01$, $MSE = 71{,}382$. As the duration between S1 and S2 increased, the detrimental influence of the priming effect also decreased (Priming x S1-S2 interval), $F(4, 104) = 10.26$, $p < .01$, $MSE = 10{,}843$. Additionally, an interaction was found between trial predictability and S1-S2 interval, $F(4, 104) = 4.59$, $p < .01$, $MSE = 6{,}141$. No interaction was found between Priming, Predictability and S1-S2 interval, $F(4, 104) = .08$, $p > .05$, $MSE = 104$.

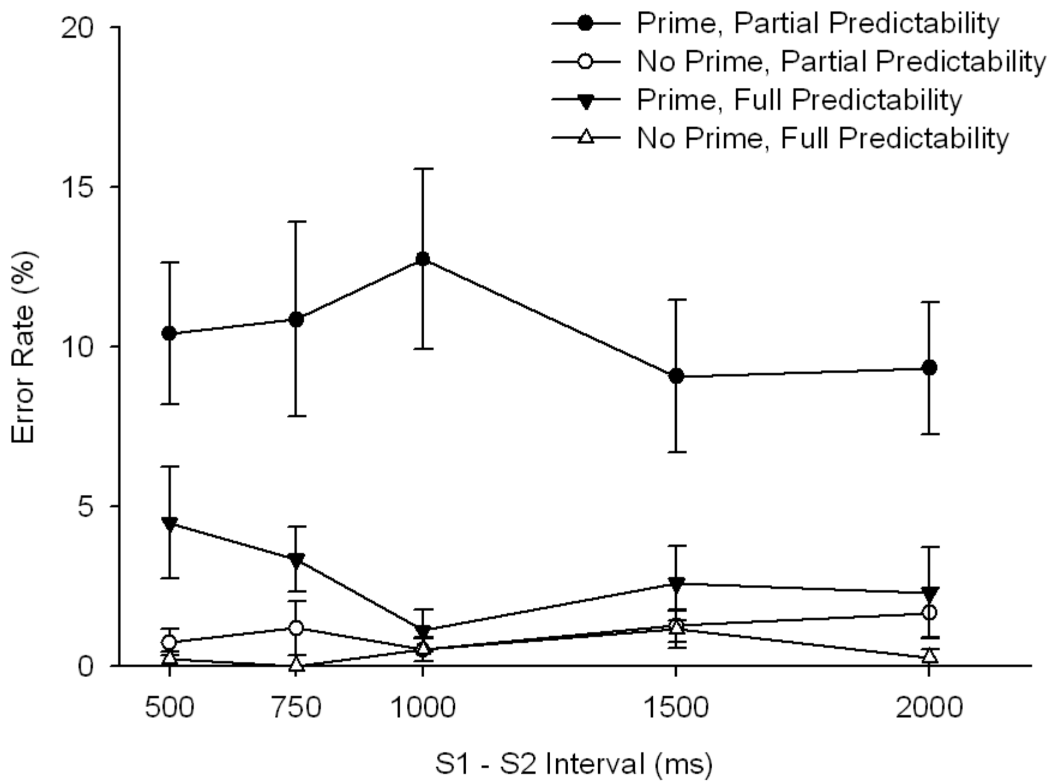

Figure 6. Error rates for S2 in response rule switch trials.

Error rates show a similar pattern (Figure 6). Participants made more errors to S2 in the Prime trials than in No Prime, $F(1, 26) = 31.19$, $p < .01$, $MSE = 3{,}275$, and made fewer errors when Predictability was full than when it was only partial, $F(1, 26) = 16.45$, $p < .01$, $MSE = 1{,}874$. There was no main effect for S1-S2 interval on error rates, $F(4, 104) = .637$, $p = .637$, MSE.= 36. An interaction was found for Priming and Predictability, $F(1, 26) = 9.79$, $p < .01$, $MSE = 907$, such that S2 errors were greater with partial predictability than full predictability.

Discussion

The results of experiment 1 can be summarized simply: 1) A previous trial response (R1) leads to both slower R2 response times and higher R2 error rates than when no previous response was made 2) The influence R1 on R2 decreases over time 3) Full trial predictability leads to better R2 performance than partial trial predictability, and 4) Full trial predictability of S2 significantly reduces the effect of R1 on task switching performance when compared to partial S2 predictability (Priming Type x Preparation Type interaction). Even at the shortest S1-S2 interval, the detrimental effect of R1 was greatly reduced when participants knew both the task and identity of S2 and could ostensibly fully select a response for the S2 trial, thus confirming the proposal that when a task switch occurs, full, but not partial trial predictability greatly reduces the influence of priming effects on task performance. The implications of this finding are further described in the general discussion.

1.4 Experiment 2: Trial Predictability and Rule Repetitions

The results from Experiment 1 show that the response rule priming effect is suppressed in switch trials when full trial predictability is available prior to the S2 stimulus. Experiment 2 investigates whether this suppression also occurs in trial repetitions. In this case, the priming effect benefits performance since the same response rule is used during both S1 and S2. Based on the hypothesis that suppression of the priming effect only occurs when full trial predictability is available *and* a conflict exists between the primed response rule and the prepared task rule, it is predicted that the beneficial effect of the prime will not be influenced by the level of predictability of the upcoming trial.

Participants

Participants were 30 undergraduate students (9 male, 21 female) at the University of Virginia ranging in age from 18 to 22. They participated in exchange for class credit.

Tasks and Procedure

The tasks and procedure were identical to Experiment 1 with the following exception: the stimulus-response relationship was always spatially compatible for both S1 and S2 in the Prime trial type, leading to a response rule repetition.

Results

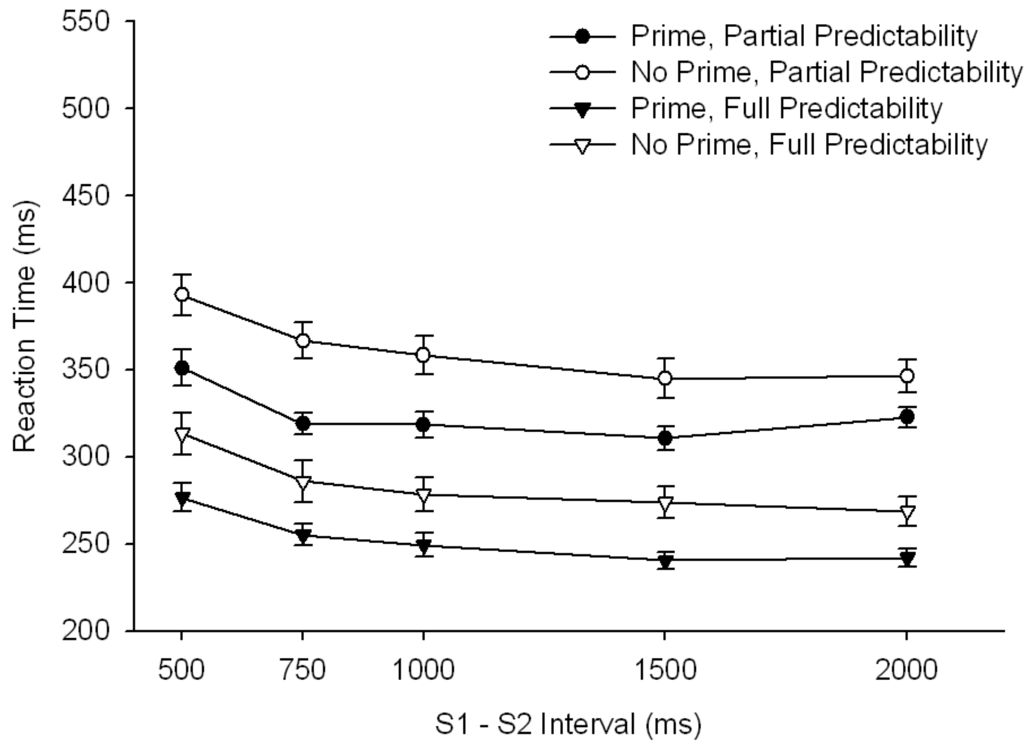

Figure 7. Response times for S2 on response rule repetition trials. There is an overall performance benefit to the priming effect that is not influenced by the amount of predictability.

The data analysis procedure was identical to that of Experiment 1. RTs for Priming Type and Predictability Type are summarized in Figure 7. In contrast to Experiment 1, the type of predictability (full versus partial) had no effect on the contribution of repetition priming to task performance (Predictability x Prime), $F(1, 29) = 1.7$, $p = .20$, $MSE = 1446.15$. The main effect of Priming Type was significant; Prime trials in Experiment 2 provided a numerically small but statistically reliable decrease response times to S2 when compared to No Prime trials $F(1, 29) = 36.51$, $p < .01$, $MSE = 177{,}314$. There was also an effect of S1-S2 interval, indicating that response times were significantly reduced for trials with longer intervals between the first and second stimulus, $F(4, 104) = 54.39$, $p < .01$, $MSE = 32{,}450$. Although full predictability once again led to lower S2 response times, $F(1, 29) = 171.26$, $p < .01$, $MSE = 837{,}798$, there were no other significant main effects or interactions (all *F*'s < 1.8, all *p*'s > .20)

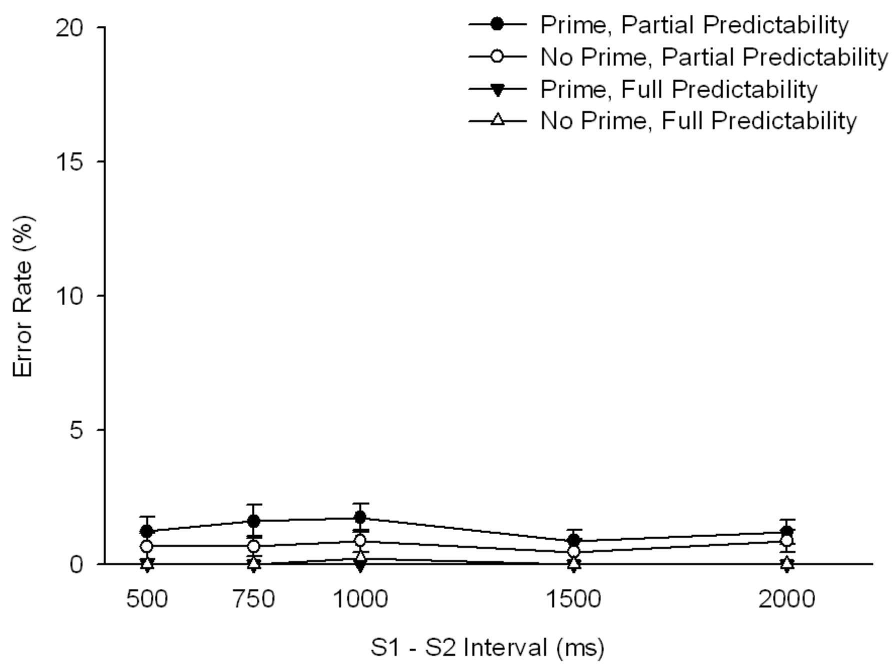

Figure 8. Error rates for S2 in response rule repetition trials.

Overall, error rates were very low in Experiment 2 (Figure 8). The only significant difference was an increase in S2 errors when participants could only partially predict the S2 task compared to when they could fully predict S2, $F(1, 28) = 13.73.$, $p <.01$, $MSE = 117.64$. No other significant effects were found for errors (all *F*'s < 2.4, all *p*'s > .13).

Discussion

Three results from the first two experiments are important. First, full predictability of an upcoming trial greatly reduces the influence of priming effects following a task switch

(Experiment 1). Second, priming effects during task switches are reduced as the interval between task trials (S1 – S2 interval) increases and when full predictability occurs, but there is no interaction between predictability level and trial interval. Third, task repetitions lead to a small but consistent priming benefit that is unaffected by the amount of predictability of the upcoming task.

If backward inhibition occurs during response selection in a subsequent trial, can backward inhibition also take place during advance preparation when it includes response selection? In most task switching paradigms response selection cannot occur until the imperative task stimulus appears because advance preparation instructions include only the upcoming task goal and rules for responding to a set of stimuli (for examples, Altmann, 2004; De Jong 2000; Hübner et al., 2003; Koch, 2001; Meiran, 1996, 2000; Sohn & Carlson, 2000). However, in the current experiment, it was possible to prepare for response selection prior to the onset of the upcoming task stimulus. This allowed for inhibition of the previously performed task to take place during preparation, thereby eliminating any switching costs associated with response rule conflict that occurred when the new task stimulus appeared.

Additionally, the reduction of the priming effect that is due to full predictability is already apparent at the shortest trial interval (500ms). In Mayr & Keele's (2000) study of backward inhibition, they consider the possibility that inhibition of a disengaged task may begin as soon as the ensuing task is fully known. According to our current results, it is more accurate to assert that inhibition begins when a response can be selected for the upcoming task, even when this occurs prior to the appearance of the task stimulus. This position is complimentary to recent suggestions of Schuch and Koch (2003), who contend that response selection is necessary for inhibition of the previous task to take place. The encoding of a new task stimulus and/or a non-task related response are not sufficient to suppress prior task activation. Here I have shown that response selection alone may be sufficient for inhibition to occur, even without the presence of either a new task stimulus or any type of overt response execution.

Of particular note, full trial predictability greatly reduced the priming effect in switch trials, but the time course of the dissipation of prior task activation remained the same between the full and partial trial predictability conditions, as evidenced by the lack of a Priming x Predictability x S1-S2 interaction in Experiment 1. This result is compatible with the proposal of Koch and Allport (2006) that the priming effect consists of two components – task activation that automatically decays over time and stimulus-specific priming that can be eliminated by increasing cue-based preparation.

Last, in accordance with the findings of Altmann (2005), in Experiment 2 we found that the performance benefit of priming effects was not affected by the duration of time between trials. Furthermore, the level of trial predictability also had no influence on repetition priming. This result, along with that of Experiment 1 provides a hint as to the source of switch costs. With some exceptions (Koch & Philipp, 2005; Schuch & Koch, 2001), most researchers use the difference between task alternations and repetitions as a measure of task switching costs (Goschke, 2000; Mayr & Kliegl, 2000; Meiran, 1996). As mentioned in the introduction, this methodology makes it difficult to discern whether this switch cost is based in the decrements in performance following a task switch or benefits in task repetitions. Experiment 1 shows a short-lived priming cost to performance following a task switch that is partially mediated by the amount of preparation available. On the other hand, Experiment 2 shows a small but consistent and long lived (at least 2000ms) repetition benefit that is not influenced by level of preparation. Based on this pattern of results, I suggest that the source of switch costs greatly varies depending on the paradigm used to study them. Experiments 1 and 2 indicate that, at greater levels of task predictability and longer intervals between task trials, the performance difference between task repetitions and switches is largely driven by a repetition benefit. Alternatively, at lower levels of predictability and shorter trial intervals, the difference between task repetitions and task switches is more driven by the costs associated with a task switch.

In summary, the results of Experiments 1 and 2 demonstrate that full advance trial predictability reduces the influence of response rule priming during a response rule switch but not during a response rule repetition. This finding is at odds with the notion that priming effects from a previous trial cannot be resolved until the presentation of the subsequent task stimulus (Allport, Styles, & Hsieh, 1994; Waszak, Hommel, & Allport, 2005). However, it does not necessarily conflict with current accounts of backward inhibition, which suggest that suppression of previous task activation is not driven by the presentation of a new task stimulus, but rather by the processes of response selection that are afforded by that stimulus. Furthermore, this result supports the proposal that the source of residual switching costs found in many other task switching paradigms are due to interference from a previously used response rule that cannot be suppressed until response selection can take place for the subsequent task.

Chapter 2

2.1 Experiment 3: Inaccurate Trial Predictability

Experiment 1 showed that full knowledge of an upcoming switch in response rule allows for the suppression of the conflicting priming effect of the previously used rule. If the suppression of response rule priming during preparation requires both the ability to select a specific response during advance preparation and a conflict between the anticipated response rule and the response rule that was previously used, then two specific predictions can be made:

1) The benefit of an actual response rule repetition between S1 and S2 will be suppressed when preparation is for a switch in response rule and trial predictability is full
2) The cost of an actual response rule switch between S1 and S2 will be not be suppressed when preparation is for a repetition in response rule and trial predictability is full

In other words, full trial predictability of S2 suppresses the priming effect from Task 1, but the predictability need not convey accurate information about Task 2. In Experiment 3, the advance information about the response rule was occasionally inaccurate and lead to preparation for the incorrect S2 response rule. For example, in the Prime trial type, participants made a compatible response to S1 and then prepared for the alternative incompatible response rule during S2 (left stimulus-right response, right stimulus-left response) response. However, when S2 appeared, they were instructed to respond using the compatible response rule. To summarize, Experiment 3 included false preparation trials in which the type of preparation (repetition or switch) is occasionally inaccurate and leads to preparation for the incorrect target task.

Method

Participants

Participants were 68 undergraduate students (18 male, 50 female) at the University of Virginia ranging in age from 17 to 20. They participated in exchange for class credit.

Tasks

The task design was similar to Experiments 1 and 2 with the following exceptions: 1) An additional cue (the word “SAME” or “OPPOSITE”) was centrally presented above the two stimulus boxes at the same time as the S2 stimulus. This cue was used by participants to determine which rule to use in order to respond to the S2 stimulus – respond on the opposite side to the S2 stimulus if the word “OPPOSITE” appears and respond on the same side as the S2 stimulus if the word “SAME” appears, 2) In the current experiment, half of the participants (switch preparation group) received trial blocks that were 80% switch trials and 20% repetition trials and the other half received blocks that were 80% repetitions trials and 20% switch trials (repetition preparation group), 3) The number of inter-stimulus intervals between S1 and S2 was reduced to two – 500ms and 1500ms. The use of two intervals rather than the five used in Experiments 1 and 2 allows for data from more trials to be collected at each interval while retaining the uncertainty of the time between S1 and S2 on a given trial.

Once again, the level of Trial Predictability (Full or Partial) and Priming Type (No Prime and Prime) were varied between blocks.

Procedure

The procedure was similar to both Experiments 1 and 2. Prior to each trial, the words "Prepare for Next Trial" were presented in the center of the computer screen for 2000ms, followed by a black screen for 250ms. Two horizontally aligned empty boxes (each 2.5 cm square) then appeared. The boxes remained blank for 250ms, followed by the S1 stimulus, which varied by trial type. Participants did not make a response to S1 on the No Prime trials and responded on the same side as S1 (compatibly) in the Prime trials. In either case, S1 remained on the screen for 500ms. The boxes on the screen then remained blank for an interval of either 500ms or 1500ms. The S2 stimulus then appeared in one of the two boxes along with either the word "SAME" or "OPPOSITE" presented centrally above the boxes. This word was a cue for participants to either respond on the same side as the S2 stimulus (compatible response rule) or the opposite side as the stimulus (incompatible response rule). Once again, in the Full Trial Predictability condition, the S1 perfectly predicted the location of the S2 and in the Partial Predictability condition, S1 offered no predictability of the S2 location.

Trial types were blocked such that each block consisted of 40 trials of one type. Each participant performed two blocks of No Prime and of Prime at both levels of S2 predictability (Full versus Partial Predictability) for a total of 8 trial blocks. Block order was counterbalanced across participants (ABBACDDC). Prior to the first block of each Priming Type and Predictability Type condition, participants received extensive instructions on how to perform the task followed by 10 practice trials. Participants were always instructed to prepare for the S2 task as much as possible.

Participants were placed in one of two conditions, the Repetition Group or the Switch Group, which varied whether a repetition or switch in response rule was anticipated between S1 and S2, respectively. In the Repetition Group, participants were instructed to always prepare for a repetition of the same response rule from S1 to S2, even though only 80% of the trials actually used the same response rule and 20% of the trials switched the response rule. Thus, at both levels of predictability (full and partial) and both levels of priming (No Prime and Prime), 80% of the trials were true repetition trials (Prepared for a repetition, received an actual repetition) and 20% of the trials were false repetition trials (Prepared for a repetition, received an actual switch). In the Switch Group, the probabilities were reversed such that 80% of the trials involved a switch in the response rule between S1 and S2 and 20% of the trials were repetitions. In this case, participants were instructed to always prepare for a switch in the response rule. Thus, 80% of the trials were true switch trials (Prepared for a switch, received an actual switch) and 20% of the trials were false switch trials (Prepared for a switch, received an actual repetition).

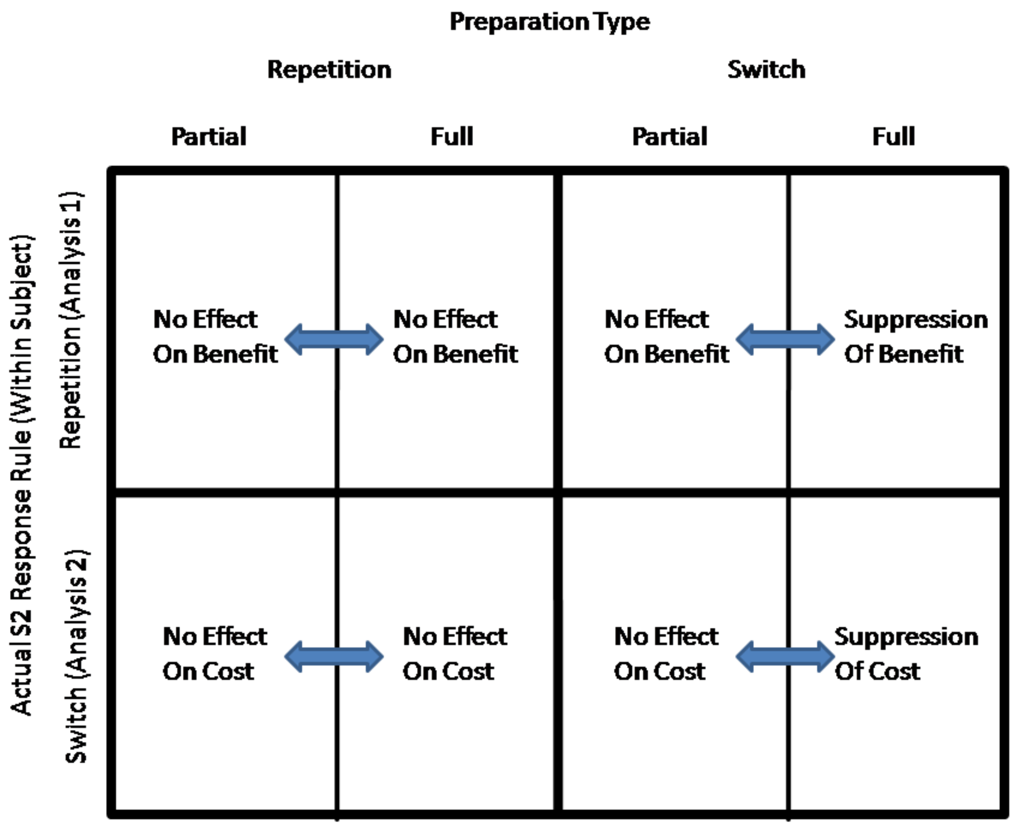

Figure 9. The predicted outcomes and important comparisons for each combination of preparation type, actual trial type, and level of predictability for S2 response times in Experiment 3.

Figure 9 shows the between and within subject factors created by varying the predicted and actual response rules between S1 and S2. The arrows represent the important comparisons for the current hypothesis.

Data Analysis

The comparisons of interest were the size of the priming effect under partial and full trial predictability. As in Experiments 1 and 2, it was predicted that the priming effect would be suppressed when full trial predictability occurred and a response rule conflict exists between the previously performed task and preparation for the upcoming task (i.e., an anticipated task switch). The validity of the task preparation should be irrelevant. Therefore, the priming effect was first calculated by finding the difference in S2 response times between No Prime and Prime Trials (No Prime – Prime). This difference represented the unique influence of a S1 response on subsequent S2 performance. Therefore, the dependent variable is no longer mean response times as in Experiments 1 and 2, but rather the priming effect. Priming effect was used as the dependant variable rather than response times because of the complexity of the design. If response times were used, the comparison of interest would be a three-way interaction (Preparation x Predictability x Prime) and therefore increasingly difficult to interpret. In the current analysis, the comparison of importance is instead the interaction between Preparation Type (Repetition versus Switch) and Predictability Type (Partial versus Full), with the prediction that the priming effect will be greatly reduced when participants prepare for a response rule switch and can fully predict the location S2 in advance.

Two separate ANOVAs were performed on the priming effect scores for the factors of Predictability (Partial versus Full), Preparation Type (Repetition versus Switch), and S1-S2 interval (500ms versus 1500ms) for trials were actually a response rule repetition between S1 and S2 and trials which were actually a response rule switch between S1 and S2.

Results

Table 1

S2 response times and error rates for predictability type and priming type for actual repetition and switch trials when participants either prepared for a response rule repetition or a switch.

	S1 - S2 Interval							
	500ms				1500s			
	No Prime		Prime		No Prime		Prime	
Predictability	RT	% Error	RT	% Error	RT	% Error	RT	% Error
	Prepared Repetition: Actual Repetition							
Partial	472	1.16	408	1.41	469	0.75	396	1.53
Full	428	1.53	381	0.91	418	0.28	359	0.81
	Prepared Switch: Actual Repetition							
Partial	633	18.09	585	21.91	614	15.03	534	23.19
Full	586	16.00	583	21.84	549	11.59	526	23.97
	Prepared Repetition: Actual Switch							
Partial	591	18.09	547	21.91	585	15.03	529	23.19
Full	538	16.00	487	21.84	529	11.59	483	23.97
	Prepared Switch: Actual Switch							
Partial	547	2.27	534	4.84	525	2.05	503	6.65
Full	498	2.22	511	3.68	473	3.27	456	5.78

The important comparison in each analysis was the interaction between Predictability and Preparation type, with the prediction that the priming effect (No Prime – Prime trials) will be reduced when full predictability of the upcoming task trial is provided and participants prepare for a switch in response rules. Furthermore, this would be the case regardless of whether an actual response rule switch or repetition took place. Table 1 provides mean response times and error rates to the S2 stimulus in each trial type.

Actual Repetition Trials

According to the hypothesis that priming effects are suppressed during preparation when trial predictability is full and a change in response rule is anticipated, the priming benefit in response rule repetition trials should only be observed when both these conditions occur at the same time (Predictability x Preparation interaction).

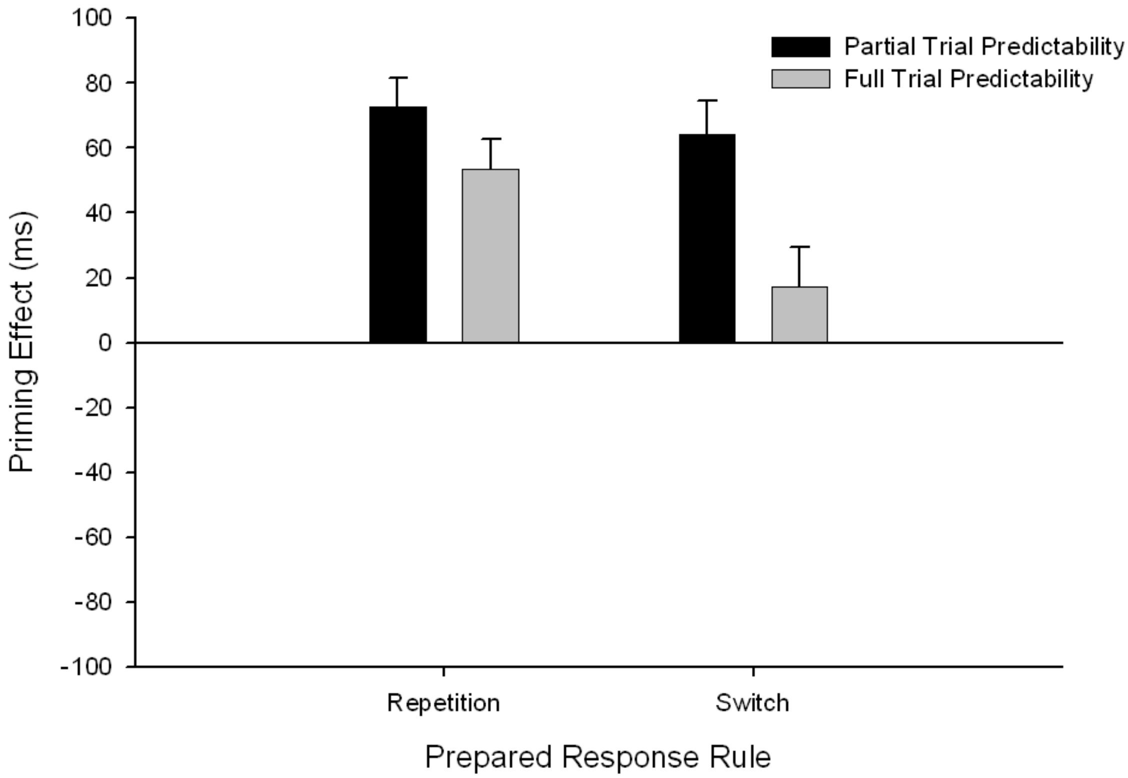

Figure 10. The effect of priming on S2 response times for response rule repetition trials when participants prepare for a repetition or a switch with perceived partial and full S2 predictability. Positive values represent a priming benefit and negative values are a priming cost.

As predicted, for S2 response times on trials that involved a actual trial repetition between S1 and S2, an interaction was found between Predictability and Preparation, $F(1, 65) = 4.03$, $p < .05$, $MSE = 21{,}976$, such that the beneficial effect of repeating the same response rule was suppressed when participants falsely prepared for a switch in response rule and had full trial predictability (Figure 10).

Additionally, full trial predictability lead to overall faster S2 response times, $F(1, 65) = 13.50$, $P < .05$, $MSE = 73{,}700$. S2 response times when preparation was for a repetition was lower than preparation for a switch, $F(1, 65) = 4.71$, $p < .05$, $MSE = 26{,}592$. This is attributable to the fact that preparation for a switch lead subjects to incorrectly prepare for S2. There was also a significant main effect for S1-S2 Interval, such that the the influence of the priming effect on S2 decreased as the time between S1 and S2 increased $F = 6.\ 70$, $p < .05$, $MSE = 26{,}592$. No other interactions were found in the analysis (All F's < 1.6, all p's > .2).

As shown in Table 1, changes in error rates were low when participants prepared for a response rule repetition and actually received a repetition, and error rates were higher when participants falsely prepared for a switch and actually received a repetition. As with response times, there was significant interaction between Predictability and Preparation for a response rule switch greatly reduced the beneficial effect of the priming effect on S2 when participants had full predictability of the S2 trial $F(1, 67) = 6.86$, $p < .05$, $MSE = 1{,}924$. Error rates due to the priming effect also significantly increased when participants prepared (incorrectly) for a response rule switch, $F(1, 67) = 9.8$, $p < .05$, $MSE = 3{,}129$, under full predictability, $F(1, 67) = 5.48$, *MSE* = 1,537, and at the short versus long S1-S2 interval, $F(1, 67) = 4.48$, $p < .05$, *MSE* = 1,009. Interactions were also found for S1-S2 Interval and Preparation Type, $F(1, 67) = 6.67$, $p < .05$, *MSE* = 1,502, S1-S2 Interval and Trial Predictability, $F(1, 67) = 6.02$, $p < .05$, *MSE* = 1,410, and S1-S2 Interval, Preparation Type, and Trial Predictability, $F(1, 67) = 6.90$, $p < .05$, *MSE* = 1,611. These interaction can be attributed to a greater progression of preparation with increased preparation time. In particular, when preparation was for a response rule switch and trial predictability was full, increased preparation time lead to a greater decrease in the priming effect.

Actual Switch Trials

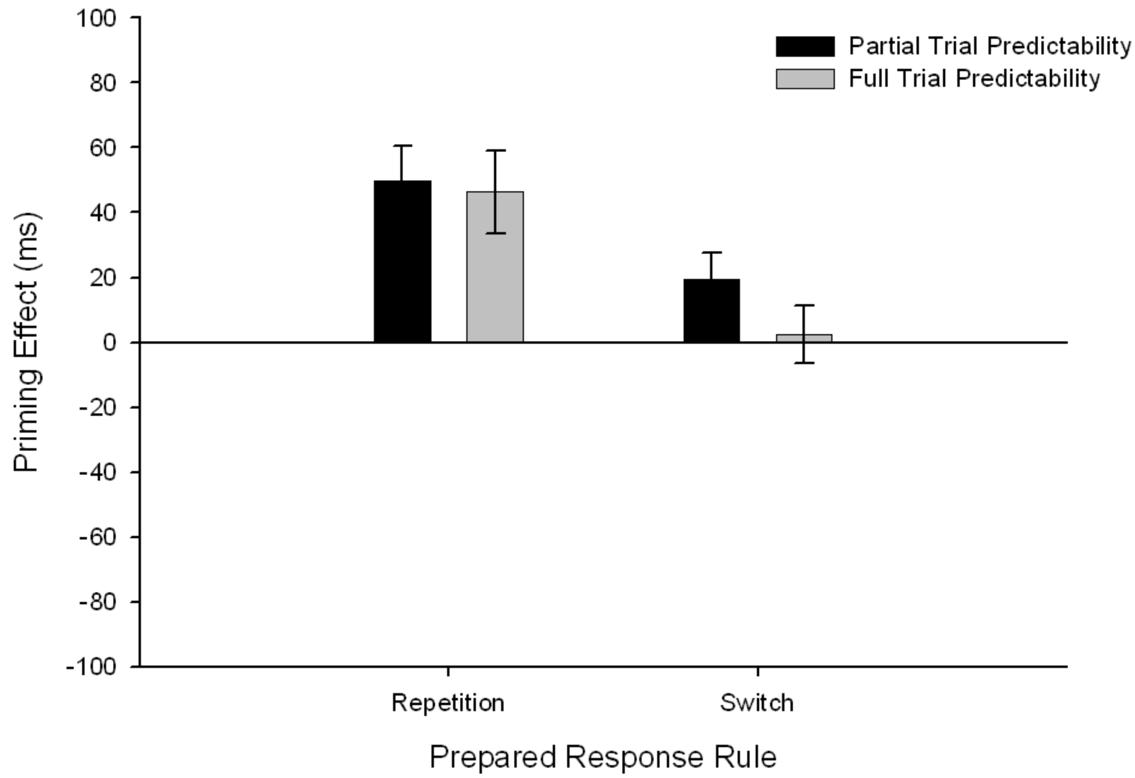

Figure 11. The effect of priming on S2 response times for response rule switch trials when participants prepare for a repetition or a switch with perceived partial and full S2 predictability. Positive values represent a priming benefit and negative values are a priming cost.

As with actual repetition trials, the cost of the priming effect in response rule switches should also only be reduced when both full trial predictability and switch preparation occurred together (Predictability x Preparation interaction). However, no interaction of the priming effect on response times was found between Predictability and Preparation for trials which involved an actual response rule switch between S1 and S2, $F(1, 67) = .37$, $p < .05$, $MSE = 1{,}878$. Quite unexpectedly, as shown in Figure 11, the priming effect leads to a performance benefit rather than a cost when participants prepared for a response rule repetition. The possible reasons for this unusual result are addressed in the interim discussion for Experiments 3 and 4. Increases in the S1-S2 interval also lead to an overall slight decline in the beneficial priming effect, but this was non-significant, $F(1, 67) = 3.18$, $p > .05$, *MSE* = 7,392. Furthermore, the only significant effect was for the Preparation Type: Preparation for a response rule switch reduced the beneficial influence of this priming effect, $F(1, 67) = 15.19$, $p < .05$, *MSE* = 85,130. No other significant effects were found for the priming effect on S2 response times (all F's < 2.5, all p's > .10).

The only factor that influenced the priming effect on error rates was the S1-S2 interval. Errors due to the priming effect were higher at the short interval (500ms) compared to the longer S1-S2 interval, $F(1, 67) = 5.56$, $p < .05$, *MSE* = 836. All other factors did not influence errors due to the priming effect (all F's < 2.20, all p's > .15).

Discussion

Two specific predictions were made for the outcome of Experiment 3:

The priming effect benefit of an actual response rule repetition between S1 and S2 will be suppressed when preparation is for a switch in response rule and trial predictability is full.

The results of the analysis of actual repetition trials support this prediction. When participants received an actual response rule repetition, there was always a sizeable response rule priming benefit (approximately 60ms) except when preparation was for a response rule switch and full trial predictability was provided. In this latter case, the priming benefit was reduced to 0ms, suggesting that the response rule priming effect on S2 was suppressed.

The cost of an actual response rule switch between S1 and S2 will not be suppressed when preparation is for a repetition in response rule and trial predictability is full.

The results of the analysis of actual switch trials were unexpected. The priming effect was clearly reduced when participants prepared for a response rule switch; however, the overall effect of priming on this switch was beneficial, when it should have lead to at least a small cost to performance of S2 in all cases. Possible reasons for this result are discussed in the interim discussion following Experiment 4.

2.2 Experiment 4: Early-Stage Preparation

Experiment 1 clearly shows a suppression of response rule priming during preparation for a response rule switch that includes full trial predictability. This reduction in the priming effect appears to be complete at the shortest S1-S2 interval, suggesting that this type of suppression begins earlier than 500ms during preparation. However, the design of experiments 1-3 precludes the examination of preparation times shorter than 500ms for several reasons related to sequential response production. One problem with using shorter S1-S2 intervals is due to a specific feature of the *attentional blink* phenomenon (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Amell, 1992; Reeves & Sperling, 1986; Weichselgartner & Sperling, 1987). Attentional blink refers to the observation that when stimuli are presented in very close temporal proximity to each other (less than 500ms), attending to one stimulus (S1) leads to a increase in response time to the second stimulus (S2). Thus, attentional blink may influence performance on the S2 task. The currently used tasks are especially susceptible to attentional blink, which has been found to greatly impair attention for spatial location (Jolicoeur, et al., 2006) Furthermore, previous research has shown that the influence of attentional blink is greater when a response is made to the first stimulus (Shapiro, Arnell, & Raymond, 1997). Therefore, Prime trials would be affected to a greater extent than No Prime trials.

Additionally, when a sequence of tasks is predictable and occurs in close temporal proximity, these tasks may be chunked together into a higher order task that subsumes each individual task and influences performance (Koch, Philipp, & Gade, 2006); that is, the participant treats both responses as a single task rather than treating them as independent, as the current experimental design assumes. In the current paradigm, the S1 task and the S2 task would become linked, with S1 performance affecting S2 responses. In order to minimize this possibility, S1 and S2 were separated by at least 500ms. This also limited the preparation time to greater than 500ms as well.

In order to avoid attentional blink effects and the chunking of S1 and S2 into a single task and yet still observe response rule priming effects at times shorter than 500ms, the previous experimental design was changed to more closely resemble an explicit cuing paradigm for Experiment 4 (Altmann, 2004; Logan & Bundesen, 2003; Meiran, 1996). Within the explicit cuing paradigm, participants perform a task during S1, followed by an interval of 500ms. After this interval, a cue is presented that predicts the response rule that will be used during S2. The cue appears between 100ms and 500ms before the onset of the S2 stimulus. Since participants cannot prepare for the upcoming task until the cue appears, the time available for preparation is also between 100ms and 500ms, but the S1 and S2 tasks are always separated by at least 600ms.

Method

Participants

Participants were 30 undergraduate students (14 male, 16 female) at the University of Virginia ranging in age from 18 to 24. They participated in exchange for class credit.

Tasks

The task design was once again similar to Experiments 1 and 2 with the following exceptions: 1) An additional cue (the word “SAME” or “OPPOSITE”) was centrally presented above the two stimulus boxes for a varying time immediately prior to and during the S2 stimulus. This cue was used by participants to determine which rule to use in order to respond to the S2 stimulus – respond on the opposite side to the S2 if the word “OPPOSITE” appears and respond on the same side as the S2 if the word “SAME” appears, 2) For all participants, trials within a given block were 50% switch trials and 50% repetition trials, 3) Participants were instructed to wait until this additional cue appeared before preparing a response for S2.

Procedure

In order to observe the early effects of preparation on response rule priming, the shortest amount of preparation was reduced to 100ms. Once again, participants performed Prime and No Prime trials, in which they do or do not respond to S1, respectively. Similarly, the level of S2 predictability (full or partial) also varied between blocks.

However, in contrast with previous studies, the additional response rule cue (“SAME” or “OPPOSITE”) appeared prior to the target task. Furthermore the interval of preparation was now the time between the onset of the cue and the onset of S2 Cue – S2 SOA).

This cue appeared 500ms after the offset of S1, and remained on the screen for a variable amount of time (either 100ms, 300ms, or 500ms) prior to the onset of S2 and remained on the screen until a response was made to S2 (Figure 12). This design allowed for a close examination of changes in the priming effect at very early stages of preparation.

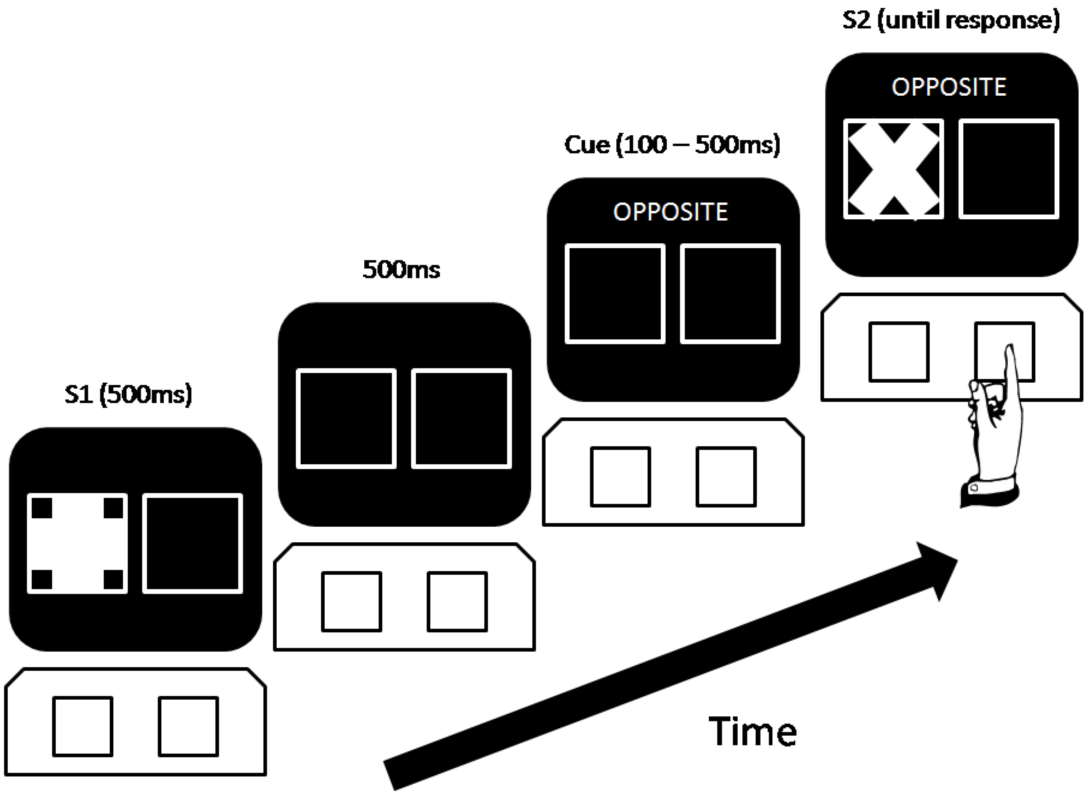

Figure 12. Schematic for a trial in Experiment 4. A response rule cue follows S1 and occurs immediately before S2, allowing only a short time for preparation.

There were two likely ways in which suppression of the priming effect could occur in switch trials. First, the suppression of the previously active task may have been completed prior to any preparation for the subsequent task. If this was the case, then the priming effect would have been reduced as much as possible as soon as preparation begins. Second, the priming effect could gradually reduce over time as response selection for the upcoming task occurred during preparation. Notice that in either case, the difference in priming effect is identical by 500ms.

The results of Experiment 1 support the former scenario, since priming effects were already reduced at the earliest Cue – S2 SOA (500ms) and were not suppressed any further as this interval increased. However, it was possible that suppression of priming occurred gradually, but was still complete by the shortest interval in Experiment 1.

The predicted time course of the priming effect in repetition trials is straightforward. Since preparation for a response rule repetition has no effect on the priming effect, and the beneficial influence of priming during a response rule repetition remains stable across time, this same pattern could occur earlier on as well. Specifically, no interactions between priming and predictability should occur for repetition trials.

Results

Two separate ANOVAs, one for repetition trials and one for switch trials, were run on the factors of Predictability (Full and Partial), Priming Type (No Priming and Priming trials), and Cue x S2 SOA (100ms, 300ms, and 500ms). The comparisons of interest were the interaction between Priming and Predictability and the interaction between Priming, Predictability, and Cue – S2 SOA. Response Times for Repetition trials are shown in Figure 13. No interaction was found for either the Prime x Predictability interaction, $F(1, 29) = 2.48$, $p > .10$, *MSE* = 12,531, or Prime x Predictability x Cue-S2 SOA, $F(1, 29) = 2.85$, $p > .05$, *MSE* = 3,554, thus confirming the prediction that priming remains consistent when preparation is for a response rule repetition.

Repetition Trials

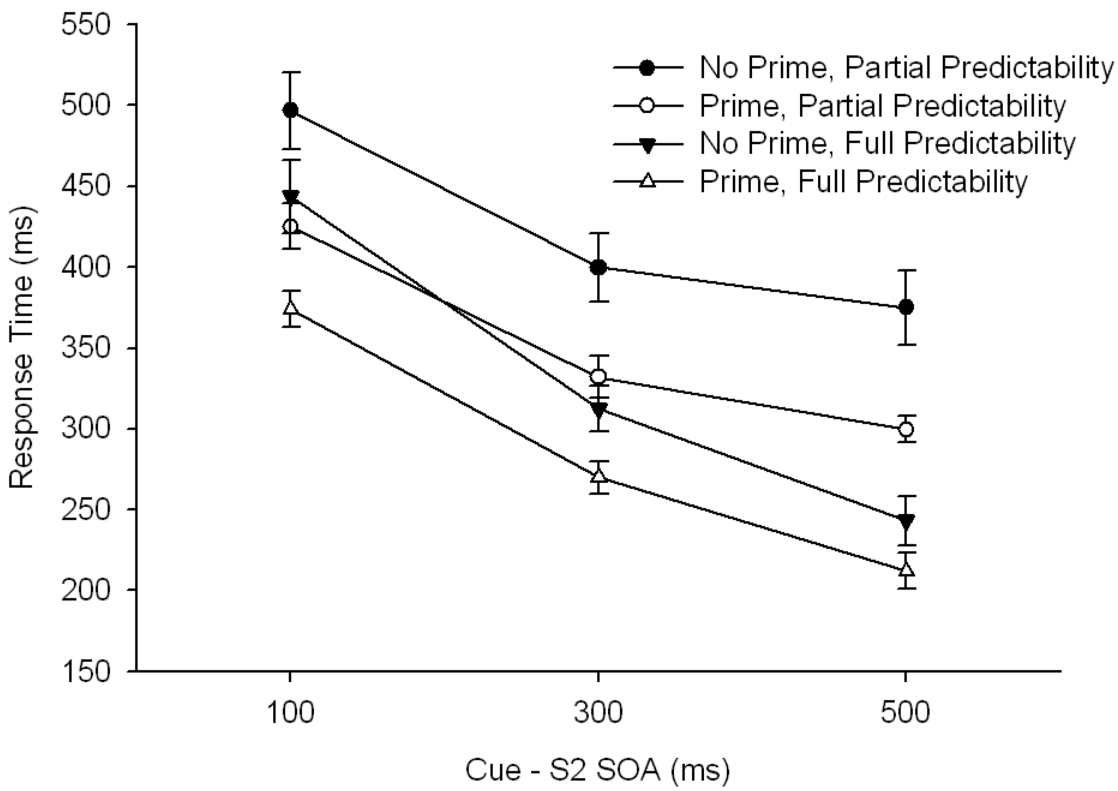

Figure 13. S2 response times for response rule repetition trials at each interval between the response rule cue and S2 for Priming Type and Level of Predictability.

In addition, response times were faster for the full predictability versus partial predictability conditions, $F(1, 29) = 20.21$, $p < .05$, *MSE* = 558,771, faster in Prime versus No Prime trials, $F(1, 29) = 27.81$, $p < .05$, *MSE* = 320,589, and faster for longer versus shorter Cue-S2 SOA, $F(2, 58) = 325.97$, $p < .05$, *MSE* = 732,865. An interaction was found for Predictability x Cue-S2 SOA Interaction such that the beneficial effect of Full Trial Predictability on preparation was greater at the longest (500ms) than shortest (100ms) interval, $F(1, 29) = 15.96$, $p < .05$, *MSE* = 25,151.

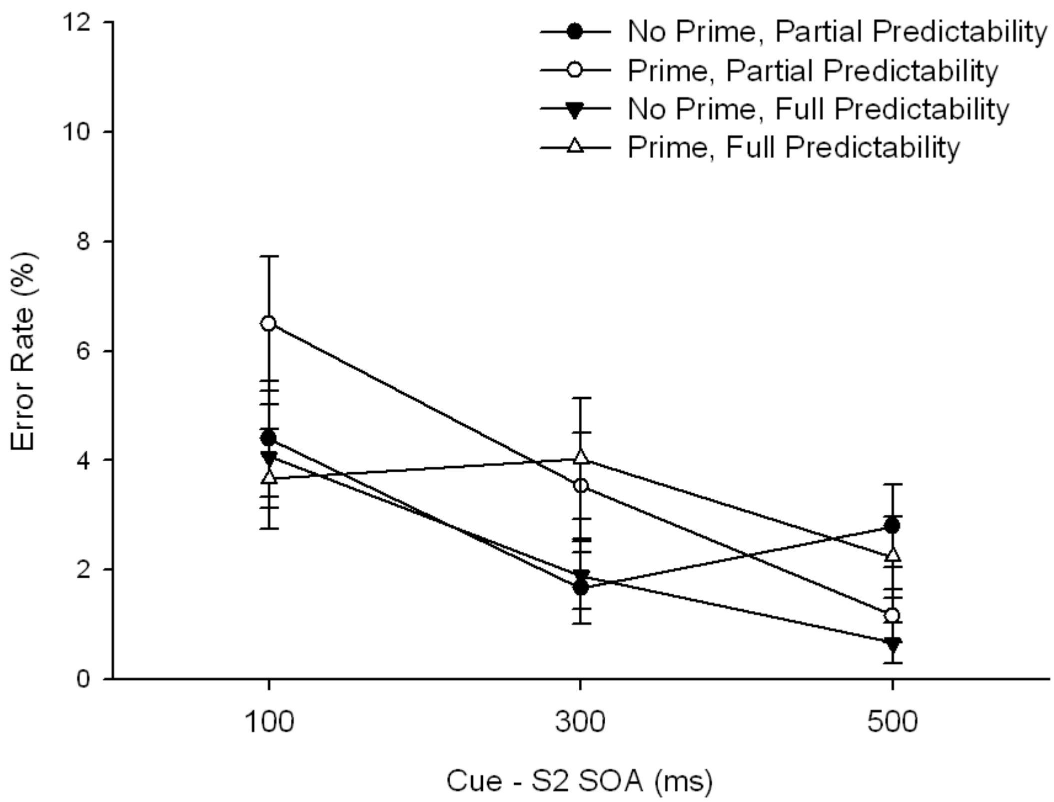

Figure 14. S2 error rates for response rule repetition trials at each interval between the response rule cue and S2 for Priming Type and Level of Predictability.

Error rates were very low for response rule repetition trials (Figure 14). As with response times, the interaction between Predictability and Priming was not significant, $F(2, 58) = .10$, $p > .70$, *MSE* = 2. Predictability x Priming Type x Cue-S2 SOA was also not significant, $F(2, 58) = 3.08$, $p > .05$, *MSE* = 61. The only significant main effect was for only Cue-S2 SOA, such that as this interval increased, error rates decreased $F(2, 58) =$

11.71, $p < .05$, *MSE* = 266. Priming Type came close but did not reach significance at an alpha level of .05, $F(1, 29) = 3.49$, $p > .05$, *MSE* = 79. No other factors or interactions came close to significance (all F's < 1.8, all p's > .19).

Switch Trials

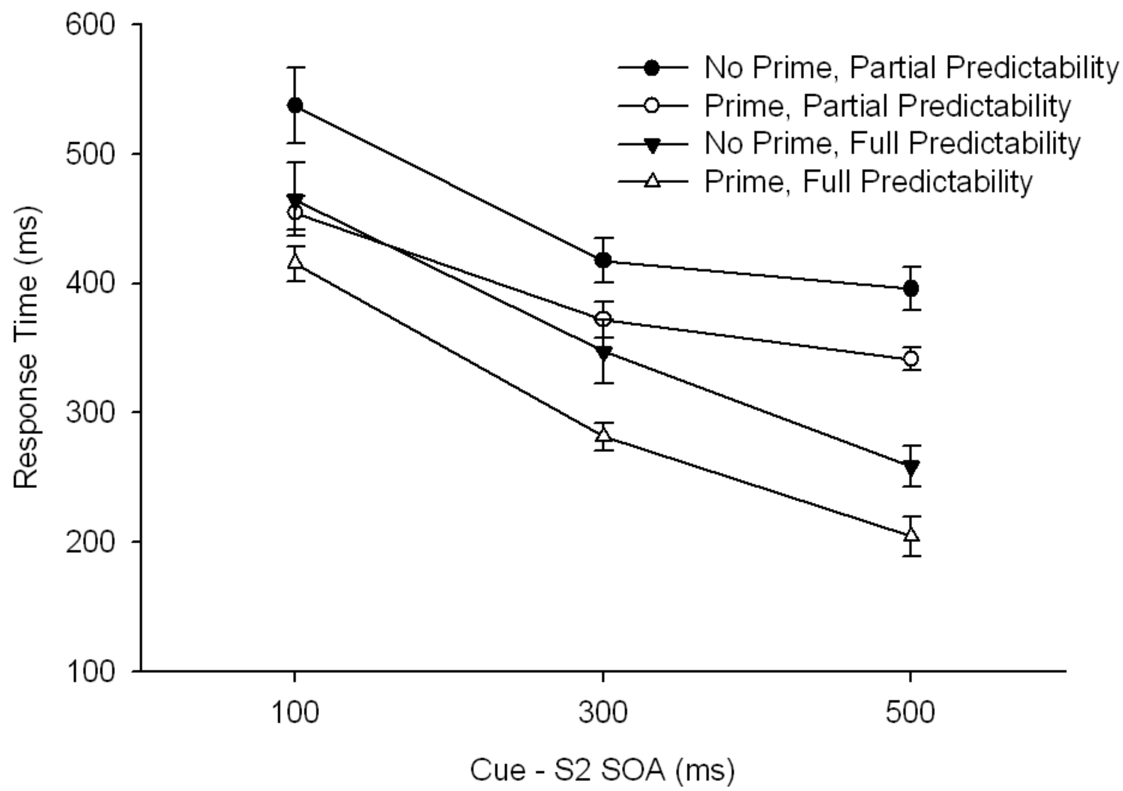

Figure 15. S2 response times for response rule switch trials at each interval between the response rule cue and S2 for Priming Type and Level of Predictability.

As with repetition trials, the comparisons of interest were the Predictability x Priming and Predictability x Priming x Cue-S2 SOA interactions. Response Times for Switch trials are shown in Figure 15. The pattern of results for switch trials was similar to those of repetition trials. No significant interaction was found for either Predictability x Priming, $F(1, 29) = .06$, $p > .80$, *MSE* = 478, or Predictability x Priming x Cue-S2 SOA, $F(1, 29) = 2.57$, $p > .08$, *MSE* = 5,481. Response times were faster for the full predictability versus partial predictability conditions, $F(1, 29) = 26.64$, $p < .05$, *MSE* = 749,026, and faster at longer versus shorter Cue-S2 SOA, $F(2, 58) = 250.00$, $p < .05$, *MSE* = 880,467. A main effect was also found for Prime versus No Prime trials, $F(1, 29) = 23.86$, $p < .05$, *MSE* = 309,643; however, the effect of priming was in the opposite direction from what was expected, with response times faster in Prime trials than in No Prime trials. This unusual result is similar to that found in Experiment 3 for switch trials and will be further examined in the interim discussion. As with repetition trials, an interaction was found for Predictability x Cue-S2 SOA such that the beneficial effect of Full Trial Predictability was greater at the longest (500ms) than shortest (100ms) interval, $F(1, 29) = 12.87$, $p < .05$, *MSE* = 52,314. No other interactions were significant (all F's < 2.6, all p's > .08).

An ANOVA of S2 error rates for switch trials once again found no interaction between Predictability and Prime, $F(1, 29) = .03$, $p > .80$, *MSE* = 1.23, or Predictability x Prime x Cue-S2 SOA, $F(2, 58) = .83$, $p > .40$, *MSE* = 21.43. Unlike response times, error rates showed a performance cost to S2 responses in Prime versus No Prime trials, $F(1, 29) = 18.13$, $p < .05$, *MSE* = 760. A reduction in S2 error rates was found as the interval between the cue and S2 increased, $F(2, 58) = 15.69$, $p < .05$, *MSE* = 377. The interaction between Priming Type and Cue – S2 SOA approached but did not reach significance at an alpha level of .05, with a gradual reduction of errors due to the priming effect as this interval increased, F(2, 58) = 2.86, p > .05, *MSE* = 71. No other factors or interactions were significant (all F's < 2.1, all p's > .16).

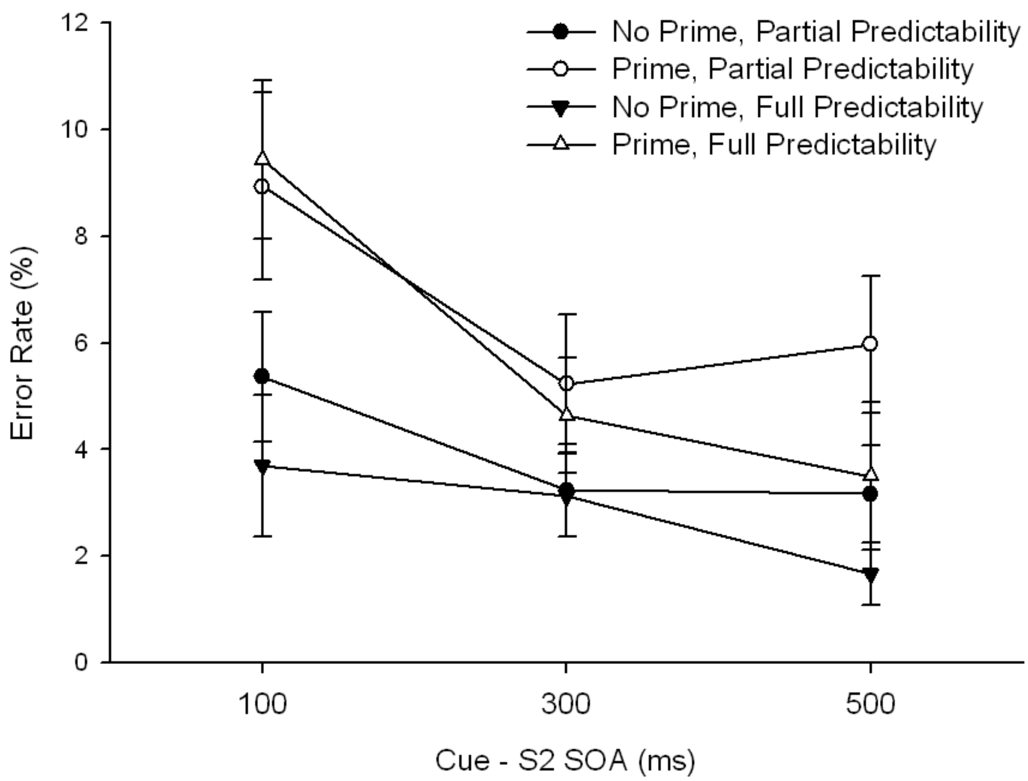

Figure 16. S2 error rates for response rule switch trials at each interval between the response rule cue and S2 for Priming Type and Level of Predictability.

Discussion

S2 response times for both response rule repetition and switch trials remained consistent across all of the early intervals between the cue and S2. This result was expected for repetitions, but not switches. In switch trials, it was predicted that in Full Predictability trials, the priming effect would either be fully reduced before the onset of preparation (Predictability x Priming interaction, but no Predictability x Priming x S1-S2

Interval interaction) or the suppression would occur throughout the early stages of preparation, with the priming effect gradually decreasing over the first 500ms in switch trials will full predictability (Predictability x Priming x S1-S2 Interaction). However, neither of these were found, suggesting that participants did not fully prepare in advance for S2 because the interval for preparation was simply too short. Alternatively, this could simply be due to the unusual priming effect in switch trials, in which a priming benefit rather than cost occurred. Possible reasons for this result, along with that of response rule switch trials in Experiment 3 are further discussed in Interim Discussion for Experiments 3 and 4.

2.3 Interim Discussion for Experiments 3 and 4

As in Experiment 3, the results of Experiment 4 show a benefit-only pattern to S2 response times following a response to during S1 (Priming trials), even when the response rule used during S1 conflicted with that of S2. There are several reasons that may explain why this occurred:

Experiments 3 and 4 used a within trial design and Experiments 1 and 2 used a between block design. In Experiments 1 and 2, trials were blocked such that all trials within a block were all response rule switches (Experiment 1) or all were response rule repetitions (Experiment 2). In Experiments 3 and 4, a given block of trials contained both switch and repetition trials. Previous task switching research has found that between and within block transitions show slightly different effects for repetition and switch trials than pure blocks of each of these different task transitions (Altmann, 2004; Rubin &

Meiran, 2005). The effect of mixing response rule switches and repetitions is still not fully understood, but may involve a change in preparation strategy due to the uncertainty of an upcoming task when compared to blocks of pure switches or pure repetitions. For example, several repetitions in a row may lead participants to prepare for a switch trial, even though the ensuing trial may be another repetition. Furthermore, it is possible that the influence of priming effects is automatically adjusted when priming can lead to both costs and benefits to performance within a given trial block.

Second, the response rule cue used in Experiments 3 and 4 may have combined with the S2 stimulus to create a unique task stimulus that was no longer strongly influenced by the priming effect (Koch & Allport, 2006). According to the Stimulus-Based Priming hypothesis, features of the S1 stimulus become associated with a specific response rule in Prime trials. When these same stimulus features appear in S2, this same response rule is automatically retrieved, facilitating responses in repetition trials and interfering with performance in switch trials. However, when a new response rule cue (the word "SAME" or "OPPOSITE") appears in conjunction with S2, a new compound stimulus is formed that no longer shares the same features as S1 and therefore stimulus-based priming no longer occurs. This possibility is further examined in Experiment 5 by varying the features between S1 and S2.

2.4 Experiment 5: Task inertia or stimulus-based priming?

Although previous research clearly shows that priming effects can affect subsequent performance, there is some contention as to how this influence takes place. According to the Inertia Hypothesis, cognitive processes remain active following task performance and gradually decay over time (Meiran, 1996). Alternatively, the Stimulus-Based Priming hypothesis posits that an association between a task stimulus and the task in which it is used forms during task performance (Allport & Wylie, 2000). This strengthened association does not decay over time, but rather biases performance of the same task when a similar task stimulus occurs at a later time.

The Inertia Hypothesis and the Stimulus-Based Priming Hypothesis offer differing accounts as to whether two competing tasks can remain active at the same time. According to the Inertia Hypothesis, two tasks compete to drive performance regardless of how similar they are to each other. The Stimulus-Based Priming hypothesis asserts that multiple tasks can be active at the same time and only compete when they share the same stimulus features.

Furthermore, determining the source of the priming effect with the current task paradigm may help explain the unexpected results of Experiment 4. In particular, if the response rule priming effect requires a repetition of shared stimulus features between S1 and S2 as mandated in the Stimulus-Based Priming account, then it is likely that integration of the cue and S2 in Experiment 4 prevented the response rule used during S1 from influencing responses to S2. Experiment 5 used a modified version of the paradigm from previous studies in order to compare both of these hypotheses.

Method

Participants

Participants were 49 undergraduate students (21 male, 28 female) at the University of Virginia ranging in age from 18 to 24. There were 26 participants in the Response Rule

Repetition condition and 23 participants in the Response Rule Switch condition. They participated in exchange for class credit.

Procedure

Participants performed two different versions of the experimental paradigm used in Experiments 1 and 2 – a Shared Feature version and an Orthogonal Feature version (Figure 17). In the Shared Feature version, S1 and S2 shared the same spatial features (appeared in either the left or right box on the screen) and both required a judgment of the spatial location of the stimulus in order to make a response.

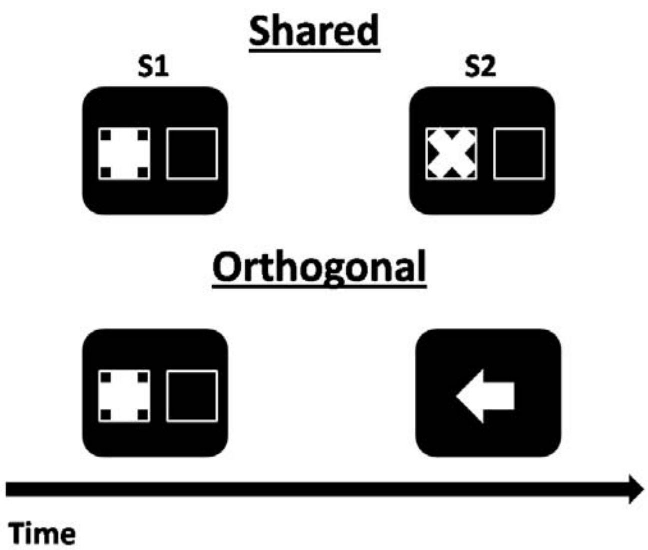

Figure 17. Example of S1 and S2 for Shared and Orthogonal conditions.

In the Orthogonal version, S1 and S2 no longer shared feature similarities. S1 involved the presentation of a white cross in either the left or right box. However, S2 was a centrally presented arrow that either pointed to the left or right, and the response was selected based on the direction that the arrow was pointing rather than the location of the arrow stimulus itself.

The Shared Feature and Orthogonal Feature versions were manipulated in the same fashion as Experiments 1 and 2. Participants either did not respond or responded to S1

(No Prime versus Prime) and S1 either was unrelated to S2 or S1 predicted the features of S2 (Partial versus Full Predictability).

Results

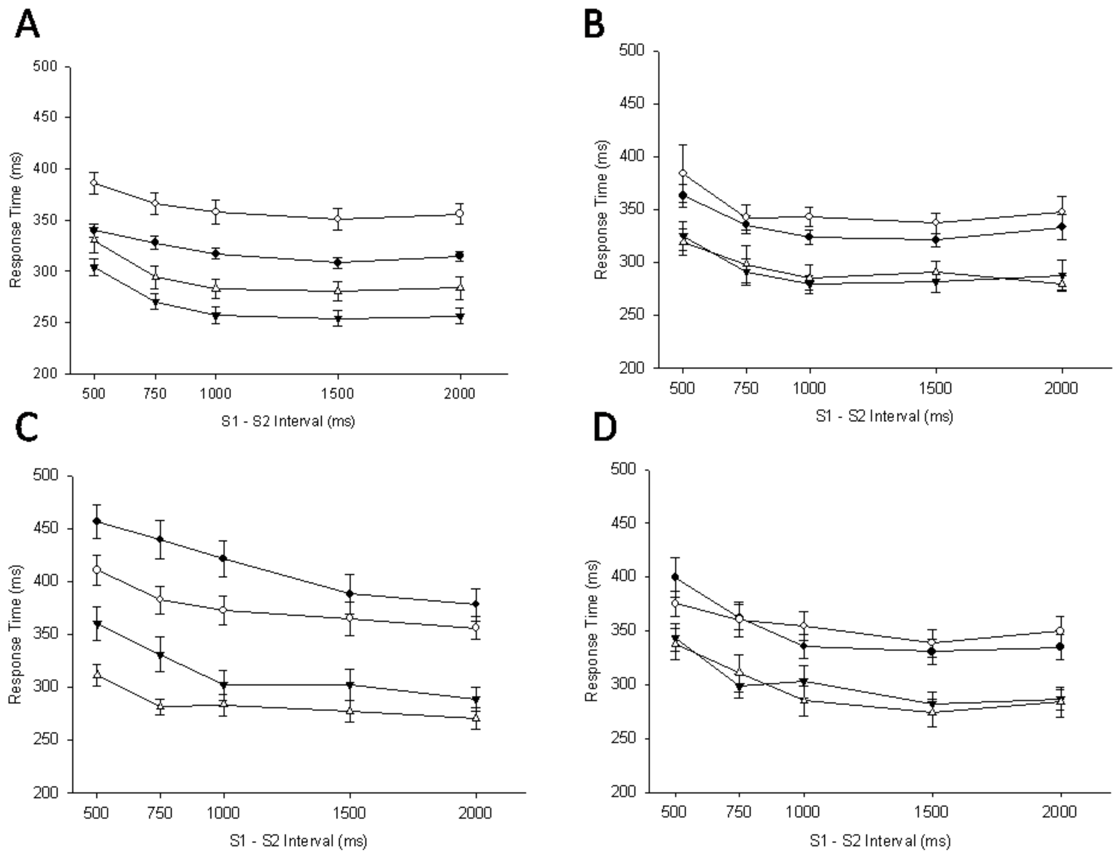

Figure 18. Response Times at each S1-S2 interval for Shared Repetitions (a), Orthogonal Repetitions (b), Shared Switched (c), and Orthogonal Switches (d). Open Circles = No Prime, Partial Predictability, Filled Circles = Prime, Partial Predictability, Open Triangles = No Prime, Full Predictability, Filled Triangles = Prime, Full Predictability.

The results of Experiment 5 support the Stimulus-Based Priming hypothesis. Four separate ANOVAs were run on the factors of Predictability Level (Full versus Partial), Priming Type (No Prime versus Prime), and S1-S2 Interval (500ms, 750ms, 1000ms, 1500ms, 2000ms) on the S2 response times for Shared Repetition, Orthogonal Repetition, Shared Switch, and Orthogonal Switch trials (Figure 18a – 18d). It was predicted that the analyses of Shared Repetition and Shared Switch trials should be identical to previous analyses of Repetition and Switch trials. Specifically, Shared Repetition trials should show a benefit to increased predictability, a benefit to priming, and no interaction between the two. Alternatively, Shared Switch trials should show a benefit to increased predictability, a cost to priming, and an interaction between predictability and priming such that increased predictability decreases the cost of the priming effect.

According to the Task Inertia Theory of priming effects, Orthogonal Repetition and Orthogonal Switch trials should show the same pattern of data as Shared Repetition and Shared Switch trials, respectively. If Stimulus-Based Priming is driving the priming effect in the current series of studies, then both the Orthogonal Repetition Trials and Orthogonal Switch Trials will show a benefit of Predictability level, but no Priming effect and thus no interaction between Predictability and Priming.

To summarize, the important analyses in the current Experiment are the priming effect (the Prime factor) and the Predictability x Priming interaction. The Prime factor should be significant for all conditions if the Task Inertia hypothesis is correct but only for Shared Repetition and Shared Switch trials if the Stimulus-Based Priming hypothesis is correct. The Predictability x Prime interaction should only be significant for Shared Switch trials, where the priming effect should be reduced when both full trial predictability and preparation for a response rule switch occurs.

Shared Repetition trials

Response times for Shared Repetition trials are shown in Figure 18a. As in the previous experiments, response times were faster in Prime versus No Prime trials, $F(1, 25) = 42.07$, $p < .05$, *MSE* = 152,053. An interaction was found for Predictability x Priming such that the beneficial effect of the Prime trials was slightly smaller with Full Trial Predictability than Partial Trial Predictability, $F(1, 25) = 6.12$, $p < .05$, *MSE* = 8,815. S2 response times were faster overall for the full predictability versus partial predictability conditions, $F(1, 25) = 176.80$, $p < .05$, *MSE* = 524,129, and faster a longer versus shorter S1-S2 intervals, $F(4, 100) = 29.86$, $p < .05$, *MSE* = 27,769. A significant Predictability x S1-S2 Interval interaction was also found showing that full trial predictability benefitted more from long S1-S2 intervals than partial trial predictability, $F(4, 100) = 3.48$, $p < .05$, *MSE* = 2,154. No other interactions were significant (all F's < .2, all p's > .9).

Orthogonal Repetition trials

Response Times for Orthogonal Repetition trials are shown in Figure 18b. No difference was found between No Prime versus Prime trials, suggesting that no priming effect occurred in Orthogonal Repetition trials, $F(1, 25) = 2.86$, $p > .1$, *MSE* = 10,058. As expected, no interaction was found between Predictability and Priming, $F(1, 25) = 2.40$, $p > .10$, *MSE* = 6,389. There were overall response time benefits to Full versus Partial Predictability, $F(1, 25) = 92.26$, $p < .05$, *MSE* = 325,484, and long versus short S1-S2 Interval, $F(4, 100) = 13.50$, $p < .05$, *MSE* = 30,450. None of the other interactions were significant (all F's < 2.41, all p's > .1).

Shared Switch trials

Response times for Shared Switch trials are shown in Figure 18c. An ANOVA found that S2 response times were slower in Prime versus No Prime trials, $F(1, 22) = 18.87$, $p < .05$, *MSE* = 146,138. However, there was no Predictability x Priming interaction, $F(1, 22) = .27$, $p > .60$, *MSE* = 1,642. Furthermore, S2 response times were faster for the Full Trial Predictability versus Partial Trial Predictability conditions, $F(1, 22) = 117.93$, $p < .05$, *MSE* = 1,063,779, , and faster at longer versus shorter S1-S2 intervals, $F(4, 88) = 34.36$, $p < .05$, *MSE* = 52,658. An interaction was also found for the Priming Type x S1-S2 Interval interaction such that the costs associated with the priming effect were reduced at long S1-S2 intervals, $F(4, 88) = 4.45$, $p < .05$, *MSE* = 1,795. No other interactions were significant (all F's < 1.30, all p's > .28).

The results of the Shared Switch condition do not adhere to predicted results; specifically, the priming effect should be reduced when full predictability is available (Predictability x Priming Type interaction). In order to further investigate this result, paired sample comparisons were run on the size of the priming effect at each S1-S2 interval for Full and Partial Predictability trials (Table 2) Although there was no interaction between Predictability and Priming, the cost of the Priming effect in switch trials is reduced faster (non-significant at 1000ms) for Full Trial Predictability than for Partial Trial Predictability (non-significant at 1500ms).

Table 2.

The mean size and paired-sample t-score for priming effects (No Prime – Prime) in Shared Switch trials at each S1-S2 interval and Predictability type. Bolded values are those that are significantly different from zero.

Shared Switch Priming Effects (No Prime - Prime trials) at each S1-S2 Interval

	Partial Predictability			Full Predictability		
	Mean (SD)	**t-score**	**sig**	**Mean (SD)**	**t-score**	**sig**
500ms	**-46 (61)**	**3.59**	0.00	**- 48 (61)**	**3.77**	**0.00**
750ms	**-57 (66)**	**4.08**	0.00	**- 50 (72)**	**3.31**	**0.00**
1000ms	**-49 (82)**	**2.88**	0.01	- 18 (62)	1.42	0.17
1500ms	-23 (74)	1.48	0.15	- 25 (75)	1.59	0.13
2000ms	-22 (58)	1.83	0.08	- 18 (48)	1.80	0.09

Orthogonal Switch trials

Response Times for Orthogonal Switch trials are shown in Figure 18d. As with Orthogonal Repetition trials, an ANOVA found no difference between No Prime versus Prime trials, $F(1, 22) = .02$, $p > .90$, *MSE* = 64 and there was no Predictability x Priming interaction, $F(1, 22) = .63$, $p > .40$, *MSE* = 1,619. There were overall response time benefits to Full versus Partial Predictability, F(1, 22) = 55.40, p < .05, *MSE* = 331,249, and long versus short S1-S2 Interval, F(4, 88) = 49.33, p < .05, *MSE* = 47,666 A Predictability x Priming Type x S1-S2 Interval Interaction was also found and may be attributable to an increase of the influence of trial predictability on the priming effect as more time is allocated for preparation, F(4, 88) = 7.19, p < .05, *MSE* = 3,183. None of the other interactions were significant (all F's < 2.1, all p's > .09).

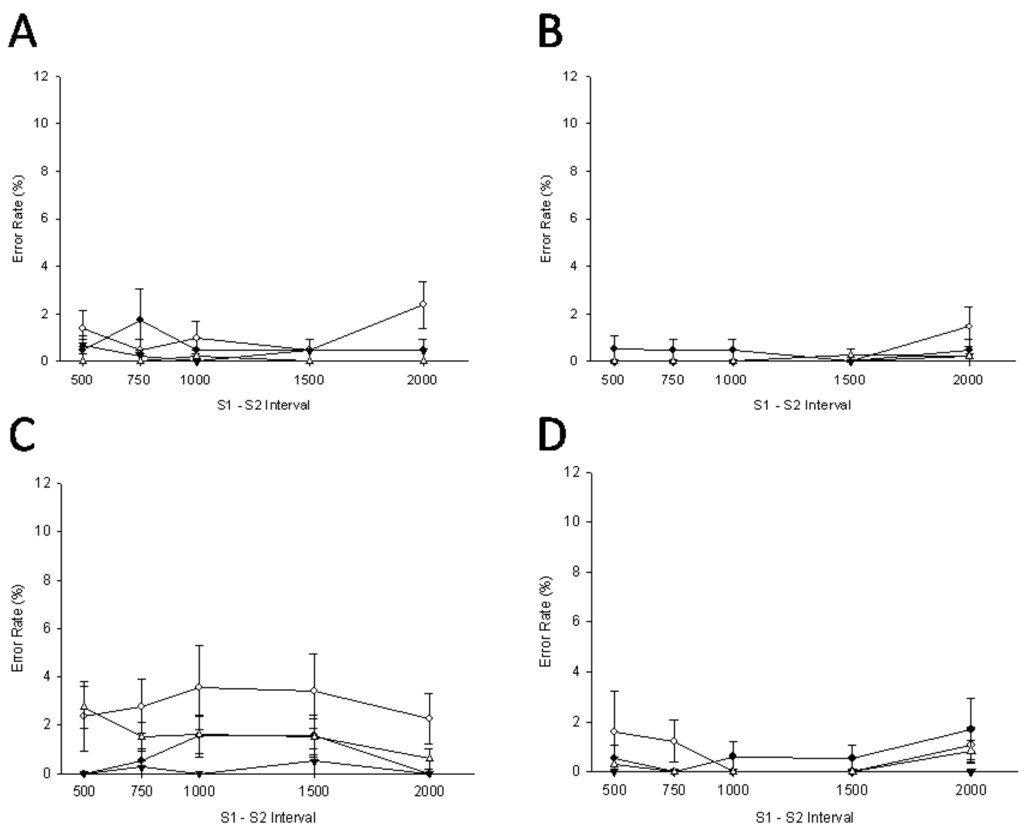

Figure 19. Error rates at each S1-S2 interval for Shared Repetitions (a), Orthogonal Repetitions (b), Shared Switches (c), and Orthogonal Switches (d). Open Circles = No Prime, Partial Predictability, Filled Circles = Prime, Partial Predictability, Open Triangles = No Prime, Full Predictability, Filled Triangles = Prime, Full Predictability.

Figure 19a – 19d shows the error rates for each of the trial types. In general, error rates were very low. The only ANOVA that showed a significant effect for error rates was the Priming Type in Shared Switch trials (Figure 19c), $F(1, 22) = 21.04$, $p < .05$, *MSE* = 373. In this case, S2 errors were higher in Prime trials than in No Prime trials, further corroborating the priming cost associated with a response rule switch when the features of S1 and S2 are shared.

Discussion

The result of primary interest in Experiment 5 is clear. When the features of the task stimulus changed between S1 and S2 (location of a cross in S1 and direction of a centrally presented arrow in S2), the influence of a response to S1 no longer directly influences response times to S2. This finding clearly supports the Stimulus-Based Priming account rather than the Task Inertia account of the priming effects observed in this task paradigm.

As predicted, when features are shared between S1 and S2, priming from the S1 response (Prime trials) lead to a response time benefit to S2 when a response rule repetition occurred and a response time cost when the response rule switched. Furthermore, the size of the priming benefit remained stable across all S1 – S2 intervals for response rule repetitions but the cost of priming in switch trials gradually dissipated over time – a finding consistent with the previous experiments. However, unlike in Experiment 1, full trial predictability did not reduce the overall response rule priming costs to a greater degree compared to partial trial predictability. Even though there was no apparent overall reduction in this cost, the rate of this reduction was faster under full versus partial trial predictability. As shown in Table 2, the performance cost associated with priming was fully eliminated by 1000ms with full trial predictability but not until 1500ms with partial trial predictability. This difference in results between Experiment 1 and Experiment 5 leads to a small conflict in interpreting the influence of trial predictability on priming effects – the results of Experiment 1 suggest that full trial predictability leads to an overall suppression of priming costs whereas Experiment 5 shows simply a faster reduction in priming costs on response rule switch trials.

Chapter 3

3.1 General Discussion

3.1.1 Interpretation of findings

There were two goals underlying this series of experiments. The primary goal was to examine the interaction between conscious and automatic influences on performance by examining the relationship between conscious preparation for task performance and the automatic influence of response-related priming effects. The results demonstrated that these priming effects can be eliminated during preparation for an upcoming task when the upcoming trial is fully predictable and a switch in response rule is anticipated. Based on the result that response rule priming effect was greatly reduced under full trial predictability, it is likely that the influence of a previously performed task is suppressed during response selection for the subsequent task.

Current research in motor imagery suggests that imagined motor actions and actual motor actions are functionally similar and share many of the same neural substrates. Decety (1996). For example, the actual and imagined actions share very similar time courses (Decety, Jeannerod, & Prablanc, 1989; Kosslyn, Ball, & Reiser, 1978). Additionally, imagined and actual actions share similar locations of brain activity (Decety, Philippon, & Ingvar, 1988; Roland, Skinhoj, Lassen, & Larsen, 1980). Shared brain areas include primary motor cortex, supplementary motor cortex, and cerebellum – areas associates with motor action planning and the coordination of movements.

Decety (1996) suggested three future approaches to the study of the functional equivalence of motor imagery and actual motor action: a comparison of motor imagery to preparatory processes, examination of differences in explicit and implicit motor imagery, and the role of attention in motor imagery. An additional important component of determining the functional equivalence between actual and imaged actions is the indirect consequences of both. If, as Mayr and Keele (2001) and Schuch and Koch (2003) contend, response selection indirectly and involuntarily leads to the suppression of competing response rules, then the imaged selection of a response via full trial preparation should also reduce this type of priming effect. The current hypothesis assumes not only that overt actions are functionally and structurally similar to imagined actions, but also that advance preparation for an upcoming task is a form of imagined action. This view is supported by recent neuro-imaging research showing analogous brain areas are active during both imaged and prepared actions (Michelon, Vettel, & Zacks, 2006)

The important distinction between partial and full trial predictability in the current experiments is the ability to internally select a response for the anticipated upcoming task stimulus. Therefore, if imagined selection of a response suppresses the priming effect, then the response rule priming effect will only be reduced when full trial predictability occurs. Some evidence for this view was found in the current experiments. In particular, the cost of conflicting response rule priming was reduced overall when response selection could take place during preparation (Experiment 1, preparation for a switch in Experiment 3). At the very least, the effect of the conflicting response rule is reduced at a faster rate when response selection can take place during preparation (switch trials in Experiment 5).

A large variety of psychological models categorize the drives behind human actions into two distinct groups: voluntary or involuntary. These distinctions include procedural and declarative motor learning (Cohen & Squire, 1980; Squire, 1992; Willingham, Salidis, & Gabrieli, 2002), dorsal and ventral stream visuomotor translation (Milner & Goodale, 1995; see Creem & Proffitt, 2001 for a review), and indirect versus direct stimulus-response translation (de Jong, 1995). A common theme among these dichotomies is that although both processes contribute to overt task behavior, they do so completely (or almost completely) independently from one another.

The presented research suggests that there are specific modes of processing at which automatic and controlled action systems interact. Specifically, the voluntary selection of a response suppresses the influence of automatic control systems. The current work provides one example of this interaction and is a starting point for further research.

Experiments 1 – 5 provide evidence of interaction between automatic and controlled processes, but only in the limited case of a spatial two-choice response task. It remains unclear whether this same result will occur in more complicated tasks.

A further question is whether the interaction of different action systems during response selection represents the integration of information from both systems and therefore the end of their independent processing for task performance. To clarify, it is currently unclear whether automatic response priming and conscious response selection share a singular response selection processing stage or if they both have independent response selection processes and influence performance only at the final stages of response production (Hommel, 1998). In the former case, one may consider response selection to be the final stage of task processing at which both automatic and controlled systems combine their information and cease to function as separate action systems. When this integration occurs, any conflict between them must be completely resolved. Thus, in the current experiment, by allowing response selection to occur during preparation prior to a task rather than following the presentation of the task stimulus, information from both automatic and controlled action systems have already combined – the additional cognitive “work” associated with resolving response conflict takes place prior to an upcoming task rather than during it.

If instead automatic and controlled action systems have separate response selection processes and influence actions only at the final stages of response production, then according to the current results, the response selection stage simply acts as a conduit between both systems, allowing some crosstalk between them that can lead to an early suppression of the influence of the priming effect on response activation.

3.1.2 Evaluation of the Current Task Paradigm

Another goal of this research was to design a new experimental paradigm that could be used to isolate the specific contributions of varying levels of preparation and priming effects to task response times. This new technique for determining priming contributions to task switching costs shows that the benefit of a task repetition and the cost of a task switch are differentially affected by the duration between task trials and the type of advance preparation that takes place. However, there are a few potential criticisms of this new experimental paradigm that must also be addressed.

First, it may be argued that the predictability manipulation in the current experiments changes the S2 task from a choice to a simple response task. The distinction between simple and choice response time tasks has been acknowledged since the time of Donders (1868). Simple choice tasks merely involve detecting the presence of a single stimulus and then responding to the existence of this signal. Alternatively, choice response tasks require that a distinction is made between two or more stimuli and that a response be selected and executed based on this distinction. Responses on a choice task are generally slower than simple choice responses by between 100ms and 150ms. The S2 task in the current experiments is in the form of a choice response task in which a stimulus can appear in one of two locations (Experiments 1-5) or pointing in one of two directions (Experiment 5) and one of two responses is selected based on these features. This remains true when partial trial predictability is available, since only the response rule is known in advance and a response cannot be selected until the S2 stimulus appears. However, with full trial knowledge, the specific S2 features and the appropriate response rule are known in advance and therefore the appearance of S2 acts more like a "GO" signal prompting an already prepared response. Therefore, one could argue that S2 is a choice response task in the partial trial predictability trials and a simple response task in full trial predictability trials.

The argument that the predictability factor is actually changing the task from a choice response task to a simple response task is a valid one. However, this does not change the key manipulation in the current experiments; namely, that in full trial predictability trials, a response is selected during the preparation period and this does not occur in partial trial predictability trials. Furthermore, the simple response time paradigm generally instructs participants to either make (or withhold) a single response depending on the presence of a specific stimulus or stimulus feature and therefore does not require the selection of one response over another response.

To summarize, it may be argued that when a response is selected prior to the S2 stimulus, the S2 task becomes a simple response task, with different response properties than those of a choice response task. However, the inverse may also be true – the difference in response properties between a simple and choice response task in this case may be attributed to the ability to select a response in advance during the simple but not the choice response task. In either case, the key manipulation of the current experiments - whether partial or full trial predictability is available for preparation - remains.

Additionally, there is a risk that the observed interaction between Predictability and Priming is due to a statistical scaling effect. At a conceptual level, the key comparison in all of the experiments presented here is the difference in response time between No Prime and Prime trials, which represents the priming effect. The level of predictability of the task at S2 was then varied in order to examine the effect of preparation on this difference. Since Full Trial Predictability lead to overall faster response times than Partial Trial Predictability, there is some concern that the priming effect is not comparable across level of predictability because of the scaling effect. Specifically, the response time difference between No Prime and Prime trials at the low end of the response time scale in the Full Trial Predictability trials does not mean the same thing as the same difference between Prime and No Prime trials at the high end of the response time scale in Partial Trial Predictability trials. This criticism originates in the notion that response time is on an ordinal rather than interval scale – e.g., the difference between response times of 200ms and 250ms is not the same as the difference between 600ms and 650ms.

Within the research domain of task switching, the scaling effect is largely ignored and the differences in raw response time are often the comparison of interest (Rogers & Monsell, 1995). In the current experiments, we used a similar strategy in order to maintain comparability with previous work. However, it is still necessary to address the response time scaling issue. Therefore, we provide an alternative analysis in which the data are transformed in order to minimize the possibility that the comparison of interest – the interaction between Priming Type and Level of Predictability – is not simply a statistical artifact. The transformation analyses were performed on the data from

Experiments 1 and 2. These experiments were chosen for two reasons: 1) The data from Experiments 1 and 2 best exemplify the effect of Predictability on Priming in response rule switch (Experiment 1) and repetition (Experiment 2) trials, showing that preparation with full predictability reduces the priming effect when compared to preparation with partial trial predictability, but only in switch trials. 2) The large difference in response times for the factor of Predictability in Experiments 1 and 2 makes the Predictability x Priming interaction especially vulnerable to scaling issues.

In order to reduce the possibility of a scaling issue, the following transformation was applied to the data in Experiments 1 and 2: the response times for all participants were pooled and all extreme response times (below 250ms and above 450ms) were removed from the data. An ANOVA was then performed on the natural Log of the response times for the factors of Priming Type (No Prime versus Prime), Predictability (Partial versus Full Trial Predictability) and S1-S2 Interval (500ms, 750ms, 1000ms, 1500ms, and 2000ms). Tables 3 and 4 show the results of the ANOVAs for Experiments 1 (switch trials) and 2 (repetition trials), respectively[1].

[1] Special thanks to Michael Kubovy for his important contribution in finding an appropriate transformation for addressing the scaling effect in the current data

Table 3.

ANOVA for transformed data from Experiment 1. Bolded numbers represent significant results.

Factor	SS	*df*	MS	F	*p*
Prime	**0.61**	**1**	**0.61**	**18.29**	**<.005**
Predictability	**48.91**	**1**	**48.91**	**1477.00**	**<.005**
S1-S2 Interval	**2.12**	**4**	**0.53**	**15.99**	**<.005**
Prime x Predictability	**0.26**	**1**	**0.26**	**7.89**	**<.005**
Prime x S1-S2 Interval	**0.49**	**4**	**0.12**	**3.66**	**0.01**
Predictability x S1-S2 Interval	0.09	4	0.02	0.69	0.60
Prime x Predictability x S1-S2 Interval	0.01	4	<.005	0.09	0.98
Error	145.10	4382	0.03		

Table 4.

ANOVAs for transformed data from Experiment 2. Bolded numbers represent significant results.

Factor	SS	*df*	MS	F	*p*
Prime	**6.88**	**1**	**6.88**	**229.51**	**<.0005**
Predictability	**48.59**	**1**	**28.59**	**1621.99**	**<.0005**
S1-S2 Interval	**4.30**	**4**	**1.07**	**35.86**	**<.0005**
Prime x Predictability	0.06	1	0.06	1.97	0.16
Prime x S1-S2 Interval	0.10	4	0.02	0.81	0.52
Predictability x S1-S2 Interval	0.15	4	0.04	1.28	0.28
Prime x Predictability x S1-S2 Interval	0.06	4	0.02	0.48	0.75
Error	185.60	6195	0.03		

The analyses with the transformed data confirm the results of Experiments 1 and 2. As in the original analysis of response times, the transformation yielded a Prime x Predictability interaction for response rule switch trials, but no Prime x Predictability interaction for response rule repetitions. Ultimately, the scaling issue is not fully resolved in the current research, but the confirmation of the same result following the data transformation suggests that the original interpretation holds.

3.1.3 The Source(s) of Task Switching Costs

In addition to a better understanding of the interaction between controlled and automatic performance processes, the response rule priming effects observed in the current experiments provide unique insight into the sources of task switching costs. Task switching costs are commonly measured as the response time difference in task performance following a repetition versus a switch in task.

It is commonly asserted that task switching costs primarily represent the increases in response time and error rates associated with a change in task and that task repetitions are an appropriate baseline to which these performance costs may be assessed (Rogers & Monsell, 1995). Further, any changes in switch costs following a manipulation of the task switching procedure, such as providing advance knowledge or varying the duration between task trials are assumed to reflect a change in task switch trials rather than task repetition trials. However, more recent research suggests that task switch costs represent a combination of both a cost to switching task and a benefit to a task repetition (Sohn & Anderson, 1999; Waszak, Hommel, & Allport, 2005)

One of the most controversial phenomena within the task switching literature is the existence of the residual task switching cost – despite having knowledge of the upcoming task and plenty of time to prepare for this switch, a small but reliable switch cost remains (Rogers & Monsell, 1995). The residual switch cost has been attributed to an inability to fully reconfigure the cognitive system for a new task in advance (Rogers & Monsell, 1995), interference from the previously used task rules (Allport & Wylie, 1999; Meiran, Chorev, & Sapir, 2000), and the failure to prepare at all on some but not all task switch trials (de Jong, 2000). In each of these cases, there is the implicit assumption that the failure to eliminate the task switching cost is a failure to abolish the performance costs associated with switching tasks and has nothing to do with performance in the baseline comparison group of task repetitions.

Although it remains unclear whether sequential repetitions or changes in response rules from trial to trial can be considered analogous to repetitions or changes in task, both share many similarities that likely rely on the same underlying cognitive processes. Consider the data for switch costs from Experiment 1 and repetition benefits from Experiment 2. The difference in response times between these two priming effects yields the common measurement of switch costs (switch RTs – repetition RTs). When participants are able to predict not only an upcoming task, but also the specific task stimulus, then residual switch costs are close to 0 when the interval between S1 and S2 is 2000ms (Figure 20).

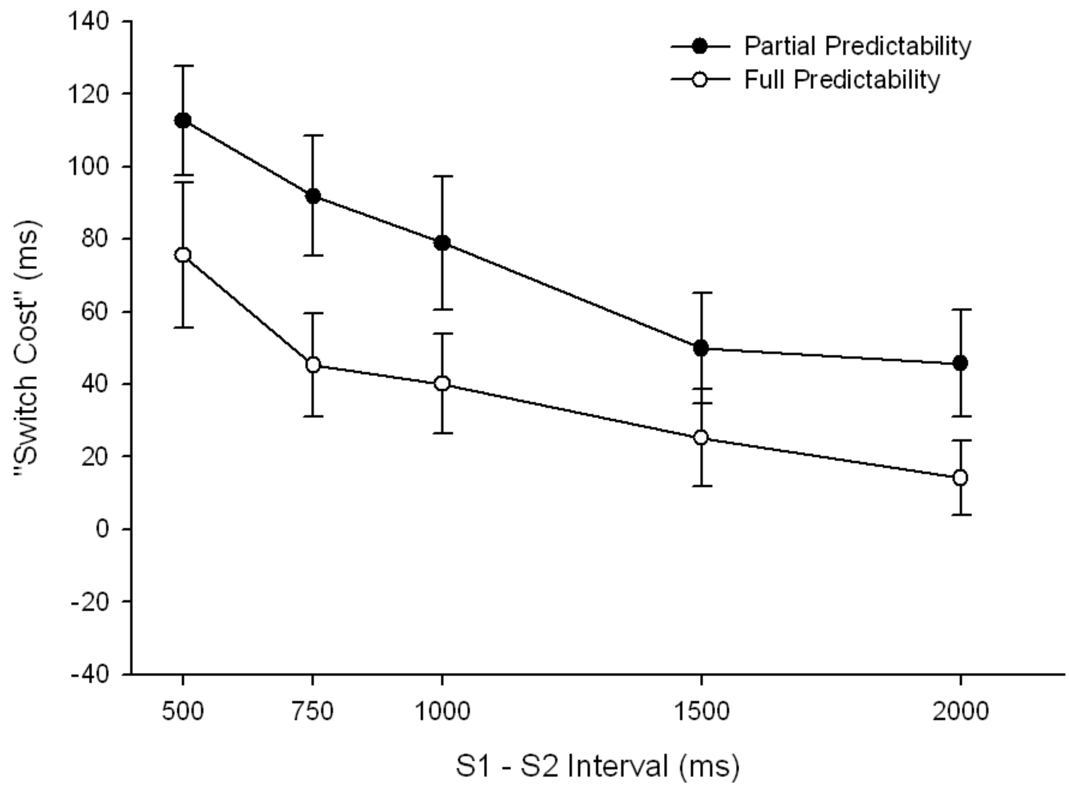

Figure 20. Task switch costs calculated as the difference between priming costs in switch trials from Experiment 1 and priming benefits from Experiment 2. This switch cost is therefore a combination of priming effects in both switches and repetitions.

In fact, if the response time benefit of a response rule repetition is removed when calculating the task switching cost, then this cost is overall greatly reduced (Figure 21). In fact, the switch cost associated with response rule priming completely disappears by 750ms when full trial predictability is available. This elimination of the residual shift cost strongly suggests that the residual switch cost may be completely attributable to the enduring priming benefit of response rule repetitions rather than a remaining and inescapable performance cost associated with switch trials.

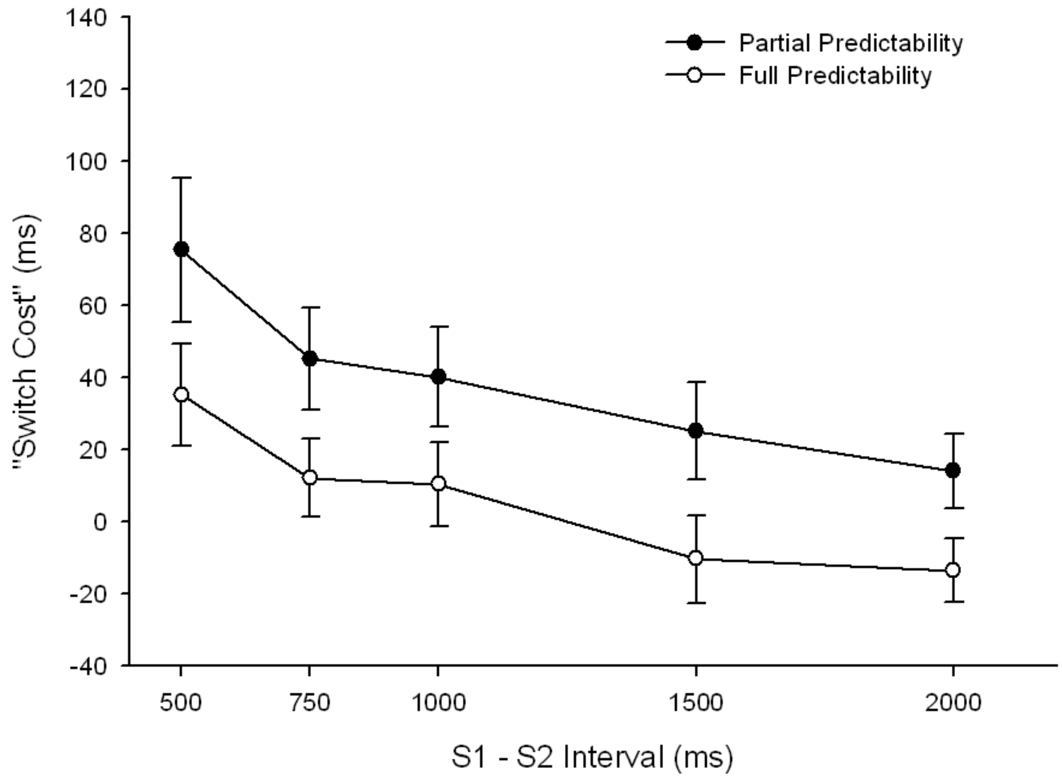

Figure 21. Task switch costs calculated as only the difference between priming costs in switch trials from Experiment 1.

3.1.4 The Double Cost of False Preparation

Advance knowledge of an upcoming event improves reaction times to that event. However, at the current time, less is known about the effect of incorrect preparation on subsequent task performance. The results of Experiment 3 suggest that incorrect advance preparation can be detrimental to performance. Conventionally, the cost of incorrect preparation is attributed to the readying of a response that interferes with the correct response. The current research shows that incorrect preparation is more damaging than this alone. As shown in Experiment 3, the incorrect preparation for an upcoming task can also influence priming effects. Preparation for a switch in task with full trial predictability also suppresses the beneficial influence of a trial repetition. Therefore, preparation for a change in task when an actual repetition occurs leads to a “double cost” to task performance – cognitive processes must be reconfigured for the correct task *and* the priming benefit associated with a task repetition is lost. In such a case, it is likely more beneficial to not prepare at all.

This finding complements the results of Schuch and Koch (2003), which found that the suppression of a previously used response rule may occur during the response selection stage for an anticipated upcoming task and does not require the actual response execution for the task. In their study, Schuch and Koch found that this suppression, or backward inhibition, takes place when the subsequent task stimulus appears but an actual response on the task is withheld. The current results extend this finding, showing that backward inhibition can take place even prior to the onset of the subsequent stimulus. Rather, all that is needed for inhibition of the priming effect from the previous task is the anticipation of a switch in task and the specific task stimulus that will occur, even if this anticipation is incorrect.

3.1.5 Conclusion

These current studies address the importance of conscious and automatic influences on task performance. Conventionally, these influences are conceptualized as independent from one another. However, at least in the case of sequential task performance, it is more fruitful to consider the situations in which these different systems intersect. From a research perspective, no model of performance would be complete without a clear understanding of the interaction between automatic and conscious influences. The experiments presented here suggest that a likely candidate for this “system crossroad” is the selection stages of response production. In particular, some work is being done during response selection that serves to resolve any conflict between cognitive systems that would individually lead to different behaviors.

There are also pragmatic implications for this new line of research. In recent years, there has been a resurgence of interest in modeling the basic cognitive processes underlying general task performance. This is partially driven by the evolving changes in technology over the last few decades that have made the role of task switching on performance increasingly relevant. Currently, it is commonplace for individuals to be quickly alternating between many tasks in the workplace. Consider your own interaction with computers at the workplace – workers often have several programs active at the same time, such as e-mail, a word processor, a web browser, and a database application. Switching between each of these programs often involves changes in the way you are interacting with the computer. As such, changes in the response rules that you use in each program are accompanied by a cost in performance. Therefore it is important to understand ways in which these costs can be minimized and productivity may be maximized.

The experiments presented here are the beginning of a line of research focused on the integration of separate cognitive systems that all contribute to action performance.

Although the experiments we present suggest a specific circumstance for the interaction between conscious and automatic performance systems, the results are not fully compatible between all of the experiments. For instance, Experiment 1 shows an overall greater suppression of automatic priming influences when the conscious performance system is able to select a response. However, in Experiment 5, this suppression is not greater, but simply occurs at a faster rate. Further, in Experiments 3 and 4, the priming influence is less clear in response rule switch trials leading to an apparent performance benefit to the response conflict. These discrepancies are due to the large variety of factors that can influence performance effects such as the similarity between task features that was examined in Experiment 5. The complexity of modern performance research should not be viewed as an off-putting characteristic of this subject matter, but rather an exciting challenge for future research to explore.

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