Task Preparation and the Switch Cost: Characterizing Task Preparation through Stimulus Set Overlap, Transition Frequency and Task Strength

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Behavioral switch costs are commonly thought to reflect additional control processes necessary to change to a new way of responding to the environment. However, it is not clear whether task switching recruits additional control processes during the performance of task switch, but not task repeat trials. The current set of studies focused on preparatory processes involved in actively setting up a new task. Three experiments examined whether **a.** task switch preparation recruits unique processes, which are not necessary for task repeat preparation, or whether **b.** task switch preparation reflects greater recruitment of general preparation processes.

The aim of the current studies is to identify whether there are unique task switch processes that may be influenced selectively by experimental factors. Several factors influencing task preparation were manipulated to determine whether each factor affects task switch preparation alone or whether each factor affects both switch and repeat trial preparation. First, the overlap in task set was examined to determine whether switch preparation is selectively affected. It was hypothesized that preparation demands would increase on task switch trials when both stimulus sets are the same since set overlap increases task interference. However, it was found that performing two tasks with the same stimulus sets increased task preparation on all trials. Second, transition frequency was manipulated to determine whether switch frequency affects switch preparation. It was found that switch frequency increased general preparation demands on all trial types. Further, it was found that high switch frequency did not increase the expectancy for the switch task type. Third, task strength was manipulated to examine whether transition frequency effects are the same for both the strong and weak task types. It was hypothesized that since the weak task trials already require a high degree of task retrieval to perform, preparation demands would not be further increased by a previous switch trial. It was found that frequent switching increased preparation for the strong task type, but not for the weak tasks. The results from all three experiments support the idea that general task preparation demands are increased on task switch trials.

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1 INTRODUCTION

Switch costs, or the slowed responding and reduced accuracy when switching tasks compared to repeating the same task on the previous trial, are generally found across a variety of paradigms, task demands, and in spite of attempts to eliminate task switch effects. Due to the universal nature of the switch cost, it has been studied intensely over the past decade in hopes of illuminating universal cognitive processes involved in the retrieval, maintenance, decay, and/or control of task demands (Monsell, 2003; Rogers & Monsell, 1995).

Debate continues as to whether switch costs reflect top-down or bottom-up mechanisms. Top-down accounts suggest that extra control processes are necessary for task performance on task switch but not task repeat trials (Rogers & Monsell, 1995). Bottom-up accounts suggest that switch costs are due to repetition priming of previous trial information (Logan & Bundesen, 2003; Allport & Wylie, 2000). It has become increasingly clear that the switch cost cannot be reduced to any one process, but instead reflects a complex combination of sources. To reduce the complexity of these different processing sources, the switch cost has been separated into the following dissociable components, each reflecting activity in a different trial phase (Meiran, Chorev, & Sapir, 2000). First, previous trial decay increases the reaction time on switch trials. This component is largest at small response-cue intervals (RCIs) and shows little effect with RCIs larger than 1000 msec. Second, active preparation is greater for task switch trials. This component is largest at small cue-target intervals (CTIs). For CTIs shorter than 500 msec, this preparatory switch cost reduces with increasing CTI. As the CTI increases further, the switch cost stays relatively constant and does not reduce further. For this reason, the preparatory component of the switch cost is thought to reflect an active control process necessary for task switching that occurs within the first 500 msec of the preparation interval. Third, a switch cost remains even when both the RCI and CTI are long (and both the decay and preparatory components of the switch cost show no further reductions). This "residual" component reflects stimulus associations that are retrieved upon presentation of the target stimulus (Meiran, Chorev, & Sapir, 2000). Stimulus associations reflect previous episodic experience between the target stimulus and the task set, which strengthens the cue-target and the target-response mappings. The residual component reflects the slowed responding on task switch trials that is due to the retrieval of mappings that were strengthened on trial n-1, but are no longer relevant for the current trial (Allport & Wylie, 2000; Wazsak & Allport, 2003). Each of these three switch cost components reflects separable mechanisms contributing to the task switch cost.

1.1 CHARACTERIZING SWITCH PREPARATION

Task switch preparation is the decrease in task switch cost with increasing preparation interval. Meiran, Chorev, & Sapir (2000) found that at short cue-target intervals (i.e. CTIs less than 500 msec), the switch cost shows large reductions with increasing interval. However, after 500 msec of CTI, there is not much more reduction in switch cost as preparation time increases further. This asymptote in the switch preparation function has been attributed to active preparation process(es) necessary for the performance of a task switch, which may be executed in advance of the target stimulus (i.e. during the cue-stimulus interval) (Meiran, Chorev, & Sapir, 2000). Such proposed processes include task-set reconfiguration (TSR) (Monsell, 2003; Monsell & Mizon, 2006), task-set retrieval (Mayr & Kliegl, 2003), goal shifting (Kieras, Meyer, Ballas, & Lauber, 2000), activation of task intention (Goschke, 2000), priming of conceptual task information (Gilbert & Shallice, 2002; Badre & Wagner, 2006), and cue encoding (Schneider & Logan, 2005).

According to many of these theoretical frameworks, switch preparation is viewed as the recruitment of additional control processing or retrieval, which is necessary for performance of task switch, but not task repeat trials. However, Logan & Bundesen (2003) found that switch preparation does not necessarily reflect extra processes performed on task switch trials. They suggested that instead task switch preparation reflects greater cue encoding demands when the cue stimulus changes.

Logan & Bundesen (2003) introduced the use of two cues per task to separate the effects of cue encoding from that of set switch preparation. They found that with two cues per task, a greater preparation effect was found for task repetition than for cue repetition, but preparation was no greater for task switching when compared to task repetition. Therefore, there was no set switching cost, just a cue encoding cost. This result led the authors to conclude that task switch preparation does not reflect control processing, just cue encoding. While this effect clearly seemed to demonstrate that switch preparation does not reflect control processing, other researchers have found a true task switch preparation effect. Mayr & Kliegl (2003) used two cues per task and found clear differences between task switch and task repeat preparation. Recent findings suggest that the reason for these discrepant findings is transition frequency, or the frequency of task repeat trials relative to the frequency of task switch trials (Monsell & Mizon, 2006; Logan & Schneider, 2006). These previous studies found that when repeat frequency is relatively high (25% cue repeat trials, 50% task repeat trials, 25% task switch trials) a standard switch preparation effect is found, however when switch frequency is relatively high (25% cue repeat trials, 25% task repeat trials, 50% task switch trials) the switch preparation effect is reduced or even eliminated (Monsell & Mizon, 2006; Logan & Schneider, 2006).

1.2 IS THERE SWITCH-SPECIFIC PREPARATION? DISTINGUISHING SWITCH-SPECIFIC FROM GENERAL TOP-DOWN MECHANISMS IN TASK PREPARATION

Meiran et al. (2000) described the preparation component of the switch cost as the "active" switch component. This component is often thought to reflect control mechanism(s) necessary for setting up the task on a switch trial (Gilbert & Shallice, 2002; Monsell, 2003; Mayr & Kliegl, 2003; Badre & Wagner, 2006). While some researchers conceptualize switch preparation as reflecting additional process(es) necessary for switching to a new task (Monsell, 2003; Mayr & Kliegl, 2003; Sohn & Anderson, 2001), others feel that task switch preparation recruits the same control necessary for task repeat preparation, but to a greater degree (Gilbert & Shallice, 2002; Badre & Wagner, 2006).

The current set of studies examined whether switch preparation may reflect distinct processes that are not necessary for task repeat preparation. In order to do this, several factors that influence task preparation where manipulated to determine whether these factors specifically affect preparation on task switch trials, or preparation on all trials. Three experimental factors; stimulus set overlap, transition frequency and task strength, were chosen because it was expected that each factor would affect task preparation.

A different pattern of activity is expected for each of the three experimental factors depending on whether the factor affects general preparation or affects switch preparation, specifically. The following hypothesized effects were expected if each factor affects a switch-specific preparation process. First, it was expected that stimulus set overlap would increase stimulus interpretation demands during task switch trials, but not task repeat trials. In this case, a switch to a task with the same stimulus set would result in a larger switch cost than a switch to a different stimulus set. Second, it was expected that transition frequency would affect preparation on task switch trials selectively. If transition frequency affects switch preparation then the preparatory switch cost should be reduced. Previous research found this effect. Monsell & Mizon (2006) found that when switch frequency is high, maintenance for the task repeat trial is reduced over a block of trials and therefore task set reconfiguration becomes necessary during repeat preparation as well as switch preparation (Monsell & Mizon, 2006). Alternatively, if transition frequency affects general preparation demands then both switch and repeat trial preparation should be affected. Third, task strength was manipulated to determine whether previous trial retrieval demands affect general task preparation or switch-specific preparation. If transition frequency affects a switch-specific process then the switch cost should be affected on both strong task trials and weak task trials. On the other hand, if transition frequency affects general task retrieval demands during preparation then transition frequency should only affect strong task trials. On weak task trials, task retrieval demands are already maximal and therefore are not increased further by interference due to persisting activity from a previous switch trial.

The current set of studies aims to determine whether switch preparation involves unique control processes which are not recruited during task repeat preparation. Several experimental factors that are known to influence switch preparation were manipulated to determine whether preparation demands are selectively affected on task switch trials. Although previous studies in the literature have examined switch preparation, no previous studies have directly compared the predictions for theories of switch-specific preparation to predictions for theories of general task preparation. The aim of the current set of studies is to compare the hypotheses to determine whether switch-specific control processes contribute to switch preparation.

1.3 THE USE OF A FOUR-TASK PARADIGM TO EXAMINE SWITCH PREPARATION

Standard task switching paradigms employ two tasks and examine switch costs for blocks of trials in which subjects either repeat one task or switch to the second task. Paradigms using more than two tasks have found that higher-order sequential effects may exist when using more than two tasks (Mayr & Keele, 2000; Dreher & Berman, 2002; Schneider & Logan, 2007). While increasing the number of tasks may produce different sequence effects, increasing the number of tasks does not significantly increase preparation time across the block of trials as long as the blocks are equated for task practice (Meiran, Hommel, Bibi, & Lev, 2002).

The current set of experiments compares task set overlap, switch frequency, and task strength in both two-task and four-task paradigms. This comparison has several advantages to examining effects in the more standard two-task paradigm alone. First, it may be determined whether an increase in preparation demands due to overlapping task-sets is strategic, taking place over a block of trials when stimulus interpretation demands are increased. For example, an overlap in task set may influence task preparation only in the two-task paradigm since cue interpretation is not necessary for task performance when the stimulus sets are different (i.e. the task can be determined by the target stimulus alone, without interpretation of the cue stimulus).

In this case, preparation should be reduced for the two-task paradigm with two tasks of non-overlapping stimulus sets, but preparation should not be reduced for the four-task paradigm when switching between two tasks of different stimulus sets. Alternatively, reduced preparation during the performance of two non-overlapping stimulus sets may be due to decreased interference between the two task sets. This decrease in preparation should occur for both the two-task paradigm and for non-overlapping set switches within the four-task paradigm. The use of the four-task paradigm allows for these two possibilities to be distinguished.

A second advantage of the four-task paradigm is that it allows for higher-order sequential effects to be distinguished. For example, the effect of backward inhibition, or an increased RT when switching back to a previously performed task (i.e. ABA switch RT > ABC switch RT) may be examined to determine whether higher order sequential effects contribute to the increased RTs with high switch frequency. A third advantage to the use of a four-task paradigm is that it allows for testing of the possibility that switch expectancy, or the anticipation of the upcoming switch task, causes switch frequency effects. Recent studies found that a relatively high proportion of task switch trials within a block causes a reduction or even elimination of the task switch preparation effect (Monsell & Mizon, 2006; Logan & Schneider, 2006). In standard task switching paradigms, subjects switch between just two tasks. In this type of paradigm, the upcoming task type can be anticipated when switch frequency is high (i.e. a subject may anticipate a switch to the other task). However, in a 4-task paradigm the subject cannot anticipate the upcoming task type because three different task types are possible. If the switch preparation effect is still eliminated with high switch frequency, then switch frequency effects cannot be due to the anticipation of the switch task.

2 EXPERIMENT 1. THE EFFECT OF STIMULUS SET OVERLAP ON TASK PREPARATION

Previous research has suggested that general task preparation demands, such as cue encoding and task retrieval, contribute to the preparatory switch cost (Mayr & Kliegl, 2003) and may even be entirely responsible for the switch preparation effect (Logan & Bundesen, 2003; Schneider & Logan, 2005). For the current experiment, task preparation demands are varied by manipulating the degree to which task performance is reliant on cue information. If the target stimuli alone can discriminate the appropriate task, then task preparation demands (i.e. cue encoding and task retrieval[1]) will be reduced during the preparation interval. On the other hand, if the cue stimulus is necessary to discriminate the appropriate task, then task preparation demands should increase.

The current experiment examined circumstances in which target stimuli are the same for both tasks to circumstances in which target stimuli are different for the two tasks to determine whether stimulus set overlap affects task preparation demands. The aim of the current experiment is to determine whether increased reliance on cue information for task discrimination

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[1] Task retrieval is sometimes viewed as a general preparation process which contributes to the switch preparation (Altmann, 2002) and is sometimes viewed as a switch-specific process that is necessary for task switch performance specifically (Mayr & Kliegl, 2003). For the present purposes, general preparation and switch-specific preparation are assumed to include different processes. However, no assumptions are made about what processes contribute to each type of preparation.

will affect preparation on all trial types when the stimulus sets are the same or whether the increased reliance on cue information will selectively affect preparation on task switch trials.

It was hypothesized that stimulus set overlap could affect task preparation in a number of ways. One possibility is that non-overlapping stimulus sets would reduce the need for cue information and therefore would reduce task preparation on all trials. In this case, performing two tasks of the same set would necessitate advance preparation because the target stimulus alone cannot distinguish which task should be performed; whereas performing two tasks of different sets would not necessitate advance preparation because the target stimuli for the two tasks are different and determination of the appropriate task to perform can occur at the time of target stimulus presentation. If performance of two tasks with non-overlapping stimulus sets reduces task retrieval after cue presentation, then the preparation effect should be smaller when the stimulus sets are different compared to when the stimulus sets are the same for the two tasks. In this case, performing different stimulus sets would reduce task retrieval demands for all trial types in a block and would not affect switch preparation specifically.

A second possibility is that performing two tasks of the same stimulus set would require less advance preparation because subjects would be in a "mode" to interpret the particular stimulus type and would not need to prepare for the interpretation of a new stimulus type. When subjects perform two tasks of different stimulus sets, then they must reinterpret the meaning of the stimulus type on each trial. In this case, the task preparation effect would be greater for subjects performing two tasks of different stimulus sets than for subjects performing two tasks of the same set. These greater stimulus interpretation demands could affect the preparation of all trial types within a block during the performance of two tasks with different stimulus sets.

A third possibility is that performing two tasks of different stimulus sets would cause greater stimulus interpretation demands, however this would only cause greater preparation demands on task switch trials which required a shift to a new mode of stimulus interpretation. In this case, task preparation should be equivalent on task repeat trials regardless of whether subjects perform two tasks of the same or different stimulus sets. However, task preparation demands should be selectively increased on task switch trials for subjects performing tasks of two different stimulus sets because a task switch would require subjects to shift to a new mode of stimulus interpretation. This possibility suggests that a component of the preparatory switch cost includes readying for the interpretation of a new stimulus type.

The current set of hypotheses provides a novel examination of how target stimulus processing may affect task preparation. Previous theories would predict that preparation reduces interference due to the overlap in stimulus sets (Gilbert & Shallice, 2002; Sohn & Anderson, 2003; Yeung & Monsell, 2003), but these theories do not discuss ways in which stimulus set processing may change the degree of task preparation. For the current study, it is assumed that stimulus set overlap does not just affect stimulus interference, but also affects the amount of task preparation necessary on any given trial.

2.1 Strategic Differences in Task Preparation: Comparison of Set Overlap in the Two-task and Four-task Paradigms

Another aim of the current experiment is to compare the preparation effect in the two-task and four-task paradigms (Figure 1) to determine whether differences in task preparation due to cue encoding demands are caused by strategic differences in task performance for the two paradigms. In the two-task paradigm, task preparation may be reduced when the task sets are different because the target stimuli can be used to determine which task should be performed. In this case, there should be a smaller preparation effect on all trials because advance preparation is not necessary to distinguish the two tasks. This reduced preparation should not occur during the four-task paradigm even when there is a switch to a different stimulus set because each stimulus set is associated with two tasks. In this case, advance preparation is necessary to select the relevant task and the task cannot be determined at the time of target stimulus presentation. Therefore, if task determination occurs at the time of the target stimulus, then reduced preparation for tasks of different stimulus sets should only occur in the two task paradigm and not the four-task paradigm. On the other hand, if stimulus set overlap increases preparation due to increased stimulus interpretation demands for changing stimulus types, this should occur in both the two-task and the four-task paradigms.

2.1.1 Methods

2.1.1.1 Participants:

42 undergraduate students from the University of Pittsburgh were tested. Participants were recruited through the Introductory Psychology Course Subject Pool and were compensated one or two hours of experimental credit upon completion of testing, depending on which version of the task they performed. 22 subjects performed the two-hour, 4-task paradigm and the other 20 subjects performed the one-hour, 2-task paradigm. Subjects signed a consent form that had been approved by the Institutional Review Board at the University of Pittsburgh. Subjects were debriefed about the purpose of the experiment at the end of testing.

2.1.1.2 Materials:

All testing was conducted on pc computers running E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) for experimental presentation and data acquisition.

2.1.1.3 Procedure:

The paradigm was a variant of the standard two-task paradigm used to examine transition frequency effects (Monsell & Mizon, 2006; Logan & Schneider, 2006). Two cues indicated each task. The four tasks were odd/even, low/high, consonant/vowel and before/after. The eight cues were odd, even, low, high, vowel, consonant, before, and after. Target stimuli were the numbers 1-4, and 6-9 for the odd/even and low/high tasks and a, d, e, f and r, o, t, u for the vowel/consonant and before/after tasks.

Half of the subjects performed the full two-hour, four-task version of the paradigm and the other half of subjects performed the one-hour, two-task version of the paradigm. Both paradigm versions were equated for practice within a task. The four-task version consisted of 192 trials per block or 48 trials of each of the four tasks and the two-task version consisted of 96 trials per block or 48 trials of each of the two tasks. Each subject who performed the two-task version received a different set of two tasks to perform throughout the testing session. Some subjects performed two number or two letter tasks and some subjects performed one number and one letter task. There were six combinations of the two tasks that subjects could perform. Each of these combinations was assigned a number 1-6 and was randomly assigned to a subject at the start of testing.

Transition type and CSI varied from trial to trial within a block. The different transition types were cue repeat (cue repetition, task repetition), task repeat (cue switch, task repetition), and task switch (cue switch, task switch) (see Figure 2). CSIs were 100, 300, 500, or 900 msec. Response-cue interval (RCI) randomly varied from trial to trial between 1000 and 1050 msec.

Subjects performed a total of 2 practice blocks and 8 experimental blocks within a testing session. Each block contained 96 trials in the two-task version and 192 trials in the four-task version. Each practice block contained half as many trials as a normal experimental block (48 trials for the two-task paradigm and 96 trials of the four-task paradigm). The trial events were the same for both the four-task and two-task versions.

2.1.2 Results

For the two-task paradigm, two 3-way repeated measures ANOVAs were performed on reaction time and accuracy measures. Both ANOVAs included the factors stimulus-set overlap (2 levels: same set, different set), transition (3 levels: cue repeat, task repeat, task switch), and CSI (4 levels: 100, 300, 500, 900). The first factor, stimulus-set overlap, was a between-subjects factor and the other two factors were within-subjects factors.

For the RT measure, there was a significant interaction between set overlap and CSI [$F(3, 60) = 5.79$, $p = 0.002$]. Subjects who performed tasks with overlapping stimulus sets had a significantly greater preparation effect than subjects who performed tasks with different stimulus sets (Figure 4). There was no interaction between set overlap and transition type [$F(2, 40) = 0.172$, $p = 0.843$] and no 3-way interaction between set overlap, transition, and CSI [$F(6, 120) = 0.799$, $p = 0.573$]. Although set overlap significantly increases overall task preparation time, it does not selectively affect task switch RT. Therefore, set overlap affects general task preparation demands rather than switch-specific preparation. Further, the main effect of set overlap was not significant [$F(1, 20) = 2.83$, $p = 0.108$].

For the accuracy measure, there was a significant interaction between set overlap and transition [$F(2, 40) = 8.94$, $p = 0.001$]. Accuracy was significantly worse when subjects performed two tasks of the same stimulus set for both task repeat and task switch trials, but not on cue repeat trials (Figure 5). There was also a significant main effect of set overlap [$F(1, 20) = 5.78$, $p = 0.03$]. Although there was a greater RT preparation effect when the stimulus set was the same, the accuracy was lower for the same set. This finding suggests that reduced accuracy does not reflect the degree of advance preparation, but instead reflects the greater interference of retrieved stimulus-response (SR) mappings associated with the target stimulus when the same stimuli are associated with both tasks. No other accuracy effects including the set overlap factor were significant. Neither the set overlap by CSI interaction [$F(3, 60) = 0.90$, $p = 0.45$] nor the 3-way interaction between set overlap, transition, and CSI [$F(6, 120) = 0.10$, $p = 0.99$] were significant.

For the four-task paradigm, set overlap was examined for switch trials only. This was because the stimulus set repeated on all repeat trials and therefore, set overlap did not vary for repeat trials. Task switch trials, on the other hand, could either switch from the same stimulus set (i.e. number -> number) or could switch from a different stimulus set (i.e. letter -> number). For task switch trials only, the factors of stimulus set overlap and CSI were examined.

The RT data showed a trend toward a significant main effect of set overlap [$F(1, 19) = 3.24$, $p = 0.09$]. There was no interaction between set overlap and CSI [$F(3, 57) = 0.60$, $p = 0.62$]. The results suggest that the reduced preparation during performance of the two-task paradigm for different stimulus sets only occurs when the target stimuli can unambiguously discriminate the task within a block of trials. If the target stimuli are associated with more than one set, then the target stimuli alone cannot discriminate which task should be performed and task preparation is increased over the block of trials.

For the accuracy data, there was no main effect of set overlap [$F(1, 19) = 0.08$, $p = 0.78$], but the interaction between set overlap and CSI was significant [$F(3, 57) = 3.17$, $p = 0.03$]. This interaction reflected the greater improvement in accuracy from the short CSI to the long CSI when the stimulus sets were the same on a switch trial (Figure 6). This suggests that target interference on task switch trials is greater when the target stimuli overlapped in the previous trial, and this interference decreases with more time for preparation.

2.1.3 Discussion

In the two-task paradigm, stimulus set overlap affected task preparation, causing a greater preparation effect when the stimulus sets were the same for the two tasks performed than when they were different. This finding confirms the hypothesis that when the target stimuli alone can discriminate the tasks (i.e. when the two stimulus sets are different), less task preparation is necessary since the target stimuli can determine task selection. One interpretation for this reduction in preparation with different sets is that task selection is delayed until after target stimulus presentation. If this were the case, then performance of two tasks with different stimulus sets should show a longer overall RT than performance of two tasks with the same stimulus sets. This is because task selection would occur after preparation when the stimulus sets are different and would delay the overall RTs. The data did not show this effect. The main effect of set overlap was not significant. If anything, there was a trend toward a longer RT for same set performance. This suggests that task selection is not delayed until after target presentation during performance of different stimulus sets, instead there is an overall reduction in cue processing and associated advance preparation demands.

Although set overlap affected general preparation across all trial types, it did not selectively influence task switch preparation. This finding suggests that the manipulation of set overlap caused a difference in cue processing and advance preparation demands over a block of trials. Further, this suggests that the degree of cue processing and advance preparation is not determined on a trial by trial basis, but instead may be set at the start of a block of trials when less preparation is necessary.

In the two-task paradigm, the accuracy measure did show an interaction between set overlap and transition. Reduced accuracy occurred on both task repeat and task switch trials when the stimulus sets overlapped, but to a greater degree on task switch trials. Although set overlap reduced accuracy more on task switch trials, this effect did not interact with CSI and therefore does not reflect preparatory processing. Instead the greater reduction in performance on both task repeat and task switch trials, may reflect increased interference in retrieved SR associations with the target stimulus when the stimulus sets overlap.

In the four-task paradigm, set overlap and CSI effects were examined on task switch trials only. RT measures did not show an interaction between set overlap and CSI or a main effect of set overlap. If preparation demands depended on the degree of stimulus set overlap from the previous trial, then a switch to the same stimulus set should result in a greater preparation effect than a switch to a different stimulus set. However, no such effect occurred in the four-task paradigm. This suggests that preparation demands may depend on whether task selection can be determined by the target stimuli alone. In the four-task paradigm, two out of the four tasks are associated with each stimulus set, and therefore the target stimuli alone cannot unambiguously select the necessary task. Therefore, the reduction in preparation with different stimulus sets that occurs in the two-task paradigm may be a strategic affect (i.e. the degree of preparation demands is set for a block of trials when the stimulus sets are different for the entire block) and preparation demands do not vary from trial-to-trial within a block (i.e. in the four-task paradigm, the degree of preparation demands does not reduce when the task switches to a different stimulus set).

The RT results in the four-task paradigm also confirm the findings from the two-task paradigm that set overlap does not affect task switch preparation selectively. If set overlap affected switch preparation, then same set switch trials should show a greater preparation effect than different set switch trials. However, no such effect occurred.

Although set overlap does not affect preparation time on switch trials, it does cause a greater improvement in accuracy with preparation on task switch trials. In the four-task paradigm, there is a greater accuracy improvement from the short to the long preparation interval for same set switch trials than on different set switch trials (Figure 6). Although increasing preparation interval did not reduce RT more on same switch trials, increasing preparation interval improved subjects' accuracy more when the stimulus sets were the same on the previous and current trials (same set switch trials). This suggests that accuracy is worse when the target stimulus associations overlap on the previous and current trials (same set switch trials) and that more preparation time alleviates accuracy costs due to stimulus interference. As in the two-task paradigm, greater interference in target associations, as evidenced by reduced accuracy, was found on task switch trials when the task set overlapped. The fact that this reduced accuracy was found in both the two-task and four-task paradigms suggests that target stimulus interference effects are not due to strategic processes. Such processes would be recruited when interference demands increase throughout a block of trials (as in the case of the two-task same set paradigm and the four-task paradigm), but would not be recruited when stimulus set interference is low across a block (as in the case of the two-task different set paradigm). Instead, interference affected accuracy on same set switch trials in both the two-task and four-task paradigms, suggesting that these accuracy effects were due to trial-by-trial fluctuations in stimulus set interference.

3 EXPERIMENTS 2 AND 3: SWITCH FREQUENCY AND TASK STRENGTH EFFECTS ON TASK PREPARATION

Previous studies have found that the preparatory switch cost is reduced and may even be eliminated when switch frequency is high relative to the frequency of task repeat and cue repeat trials (Logan & Schneider, 2006; Monsell & Mizon, 2006). This result suggests that switch frequency selectively influences a switch process and therefore eliminates the preparation difference between switch and repeat trials. Monsell and Mizon (2006) found that in addition to affecting the preparatory switch cost, switch frequency causes a general increase in preparation on both switch and repeat trial types. Further, studies examining higher-order switch effects (or the effect of a previous transition on the n-1 or n-2 trial) found that a switch on the previous trial (n-1) always increases reaction time on the current trial (n) both for switch and for repeat trials (Reynolds, Brown & Braver, 2006) and causes general increases in preparation time for both repeat and switch trial types (Schneider & Logan, 2007). These results suggest that switch frequency manipulations may affect task preparation in a couple of ways. First, preparation state changes caused by the manipulation of switch frequency may selectively influence switch preparation. Second, the increased occurrence of previous switch trials may increase preparation demands on all trial types.

The current experiment examines the effect of switch frequency on switch preparation in a four task paradigm to distinguish between several possible mechanisms. First, Monsell &

Mizon (2006) suggested that manipulating switch frequency could cause changes in the control state. A low switch frequency may cause the control state to remain biased towards the previously performed task whereas a high switch frequency may cause the control state to return to neutral after a task switch trial is performed. Second, Logan & Schneider (2006) suggest that switch frequency effects are caused by cue-transition associations. When a particular transition (i.e. a switch transition) becomes more associated with a particular cue then that transition becomes faster upon presentation of the cue stimulus. Third, switch frequency effects may be caused by the previous transition history. If the current trial was preceded by a switch, this would increase the RT on all trial types. Previous transition history could even account for reduced switch preparation when switch frequency is high. That is, task switch trials could be faster on blocks with a high switch frequency if the trial sampling favored more switch trials preceded by a repeat trial. Fourth, a high switch frequency could cause a subject to expect a task switch trial. In this case, a subject could adopt the following strategy: if the cue stimulus switches then begin to prepare the opposite task as soon as a cue switch is detected.

Two experiments were performed which manipulated switch frequency. The first study examined switch frequency effects on task preparation in both the two-task and four-task paradigms. The second study manipulated task strength in addition to switch frequency to examine how switch frequency interacts with task strength. Previous research found that the infrequent or less-practiced task sometimes produces a smaller switch cost than the more-practiced task but sometimes produces a larger switch cost (Monsell, Yeung & Azuma, 2000). This set of experiments will examine task strength to determine whether task strength affects switch preparation and whether the effects of transition frequency are modulated by task strength.

3.1 EXPERIMENT 2. SWITCH PREPARATION AND TRANSITION FREQUENCY: PREPARATION DEPENDS ON PREVIOUS TASK DEMANDS

The current experiment will manipulate transition frequency to determine whether switch preparation is selectively affected by switch frequency or whether switch frequency causes an increase in general task preparation. Previous research has shown that frequent switching increases general preparation demands and reduces the preparatory switch cost (Logan & Schneider, 2006; Monsell & Mizon, 2006). Braver and colleagues (Brown, Reynolds & Braver, 2006) found that switch frequency increased RT on both trial types, however, the preparation interval was not manipulated and therefore the effects of switch frequency on preparation were not assessed. The current experiment will examine transition frequency and task preparation to distinguish between several different potential mechanisms for these effects and to determine whether switch preparation is selectively affected by transition frequency. Such mechanisms include changes in control state, cue-transition associations, switch expectancy and increases in control demands after a switch trial. Transition frequency will be examined in both the two-task and four-task paradigms. This comparison will provide several advantages to examining switch frequency effects in a two-task paradigm alone. First, it will allow for the examination of higher-order task sequence effects. Second, it will provide a means to determine whether switch frequency effects are due to switch expectancy.

3.1.1 Methods

3.1.1.1 Subjects:

40 undergraduate students from the University of Pittsburgh were tested. Participants were recruited through the Introductory Psychology Course Subject Pool and were compensated one or two hours of experimental credit upon completion of testing, depending on which version of the task they performed. 20 subjects performed the two-hour, 4-task paradigm and the other 20 subjects performed the one-hour, 2-task paradigm. Subjects signed a consent form that had been approved by the Institutional Review Board at the University of Pittsburgh. Subjects were debriefed about the purpose of the experiment at the end of testing.

3.1.1.2 Materials:

All testing was conducted on pc computers running E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) for experimental presentation and data acquisition.

3.1.1.3 Procedure:

The paradigm was a variant of the standard two-task paradigm used to examine transition frequency effects (Monsell & Mizon, 2006; Logan & Schneider, 2006). Two cues indicated each task. The four tasks were odd/even, low/high, consonant/vowel and before/after. The eight cues were odd, even, low, high, vowel, consonant, before, and after. Target stimuli were the numbers

1-4, and 6-9 for the odd/even and low/high tasks and a, d, e, f and r, o, t, u for the vowel/consonant and before/after tasks.

Half of the subjects performed the full two-hour, four-task version of the paradigm and the other half of subjects performed the one-hour, two-task version of the paradigm. Both paradigm versions were equated for practice within a task. The four-task version consisted of 192 trials per block or 48 trials of each of the four tasks and the two-task version consisted of 96 trials per block or 48 trials of each of the two tasks. Each subject who performed the two-task version received a different set of two tasks to perform throughout the testing session. Some subjects performed two number or two letter tasks and some subjects performed one number and one letter task. There were six combinations of the two tasks that subjects could perform. Each of these combinations was assigned a number 1-6 and was randomly assigned to a subject at the start of testing.

Frequency, transition and cue-stimulus interval (CSI) were manipulated. Frequency referred to the frequent transition type on a block of trials. A block of trials had one of the following proportions of transition types:

task repeat frequent: 25% cue repeat/50% task repeat/ 25% task switch,

task switch frequent: 25% cue repeat/25% task repeat/50% task switch

Transition type and CSI varied from trial to trial within a block. The different transition types were cue repeat (cue repetition, task repetition), task repeat (cue switch, task repetition), and task switch (cue switch, task switch) (see Figure 2). CSIs were 100, 300, 500, or 900 msec. Response-cue interval (RCI) randomly varied from trial to trial between 1000 and 1050 msec.

Subjects performed a total of 2 practice blocks and 8 experimental blocks within a testing session. Each block contained 96 trials in the two-task version and 192 trials in the four-task version. Each practice block contained half as many trials as a normal experimental block (48 trials for the two-task paradigm and 96 trials of the four-task paradigm). For the first half of the testing session subjects performed one transition frequency type and then for the second half of the testing session, they performed four blocks of the other transition frequency type. The order that the transition frequency blocks occurred within the testing session was counterbalanced between subjects. Subjects started with a block of practice of one transition frequency, then four blocks of that transition frequency type, followed by another short block of practice for the other transition frequency type and four experimental blocks of that transition frequency type. While the transition frequency was manipulated between the first and second half of the testing session, the task strength was always the same for each task. All four tasks were performed on 25% of trials.

3.1.2 Results

For both the two-task and four-task paradigms, 3-way repeated measures ANoVAs were performed on the factors of transition frequency (2 levels: repeat frequent and switch frequent), transition (3 levels: cue repeat, task repeat, and task switch), and CSI (4 levels: 100, 300, 500, and 900). All factors were manipulated within subjects. Both RT and accuracy measures were examined.

In the four-task paradigm, transition frequency interacted with CSI [$F(3, 57) = 4.226$, $p = 0.009$], reflecting a greater preparation effect when switch trials were frequent (Figure 7). There was also a main effect of transition frequency [$F(1, 19) = 11.760$, $p = 0.003$]. Frequent switching resulted in slower RTs overall. The 3-way interaction between transition frequency, transition, and CSI was not significant [$F(6, 114) = 1.983$, $p = 0.074$]. Although there was a trend toward a significant effect (Figure 8), the preparatory switch cost was not reduced as in previous studies in the literature (Monsell & Mizon, 2006; Logan & Schneider, 2006). It is speculated that the current results might differ from that of previous studies because of paradigm differences such as the amount of practice with each transition frequency and the amount of reward given to subjects. Both of these possibilities will be discussed further later in this section and in the Discussion section. In the current study, transition frequency interacted with CSI for all transition types and this effect was not greater on task switch trials. These findings suggest that transition frequency affects general task preparation and not a switch-specific control process.

For the accuracy measure, switch frequency did not show any significant effects. There was no main effect of switch frequency [$F(1, 19) = 0.096$, $p = 0.760$]. Switch frequency did not interact with CSI [$F(3, 57) = 0.557$, $p = 0.646$] and it did not interact with transition [$F(2, 38) = 2.144$, $p = 0.131$]. Further, there was no 3-way interaction [$F(6, 114) = 1.752$, $p = 0.115$].

In the two-task paradigm, no switch frequency effects were significant. There was no main effect of switch frequency [$F(1, 21) = 0.950$, $p = 0.341$], no switch frequency by transition interaction [$F(2, 42) = 0.018$, $p = 0.982$], no switch frequency by CSI interaction [$F(3, 63) =$

1.550, p = 0.210], and no 3-way interaction [F (6, 126) = 0.823, p = 0.554]. Similarly, there were no significant effects for switch frequency in the accuracy measure. There was no main effect of switch frequency [F (1, 21) = 1.249, p = 0.276], no switch frequency by transition interaction [F (2, 42) = 1.446, p = 0.247], no switch frequency by CSI interaction [F (3, 63) = 0.073, p = 0.974], and no 3-way interaction [F (6, 126) = 0.834, p = 0.546].

The fact that there were no switch frequency effects in the two-task paradigm is discrepant with findings in the literature (Monsell & Mizon, 2006; Logan & Schneider, 2006). To determine why the current results do not replicate previous results in the literature, order effects were examined. In previous studies, subjects performed one transition frequency condition in one testing session and then performed the other transition frequency condition on a different day. In the current experiments, subjects performed both transition frequencies within the same testing session. The order that they performed the conditions was counterbalanced between subjects. Switch frequency effects were examined separately for subjects who performed the frequent repetition blocks first in the session and for subjects who performed the frequent repetition blocks second in the session.

To examine the effects of condition order, the between-subject factor of Frequency Order was added to an ANoVA with the factors transition frequency, transition, and CSI. There was a significant interaction between condition order and switch frequency [F (1, 20) = 41.158, p = 0.000]. This interaction revealed that the frequent repeat condition was not affected by condition order. However, RTs were significantly slower when the frequent switch blocks were performed first (Figure 9). This suggests that practice significantly improves performance for frequent switch blocks but not for frequent repeat blocks. There was also an interaction between condition order and CSI [F (3, 60) = 3.017, p = 0.034]. When subjects performed the switch condition first, the preparation effect was larger than when subjects performed the repeat condition first (Figure 10). This suggests that frequent switching could hinder practice effects and therefore increase preparation time. Consistent with this finding, previous research has also found that greater practice decreases preparation time (Monsell, Chorev & Sapir, 2000; Dreisback, Haider & Kluwe, 2002).

Condition order also showed a significant interaction with switch frequency, and transition [$F(2, 40) = 9.121$, $p = 0.001$]. Switch costs were largest for the frequent repeat condition when this condition was performed first (Figure 11). There were no interactions between condition order, transition and CSI [$F(6, 120) = 1.528$, $p = 0.175$] or between condition order, transition frequency, transition, and CSI [$F(6, 120) = 1.365$, $p = 0.234$]. There was a main effect of switch frequency [$F(1, 20) = 5.016$, $p = 0.037$] and no other switch frequency effects.

The results suggest that switch frequency effects in the literature may be due in part to practice. In the current paradigm, subjects performed a practice block of 48 trials (for the two-task paradigm) before performing four blocks of each frequency condition and both frequency conditions were performed in the same testing session. The practice block was included to reduce any practice effects, however practice still seems to occur over the course of many blocks.

In previous studies, subjects performed only one transition frequency within a testing session and were brought back on another day to perform the other condition. In the current study, both frequency conditions were performed within the same testing session. This difference in testing procedure and the amount of practice that subjects receive with each transition frequency condition is one possible factor that may account for the differences between previous and current transition frequency effects.

Although switch frequency effects were found for the four-task paradigm, condition order effects were examined to determine whether they influenced transition frequency as in the two-task paradigm. Similar to the findings from the two-task paradigm, the four-task paradigm found an interaction between condition order and switch frequency [$F(1, 18) = 19.876$, $p = 0.000$] (Figure 12) and a 3-way interaction of condition order, switch frequency, and transition [$F(2, 36) = 9.575$, $p = 0.000$]. The results suggest that performing the frequent repeat condition second significantly lowers RT, but performing the frequent switch condition second does not significantly lower RT. Also consistent with the two task paradigm results, the switch cost was greater for the transition frequency condition that was performed first and this effect was larger in the frequent repeat condition.

3.1.2.1 RT Costs Affecting Preparation and SR demands: Cue-Target Congruency, Response Congruency and Stimulus Repetition Effects

To separate the effects of interference from several sources (cue stimuli, target stimuli and stimulus repetition) several RT costs were examined. Cue-target (CT) congruency (mean CT incongruent RT – mean CT congruent RT) was examined as an indicator of the degree of cue and/or task interference that occurred during the preparation interval. Since the cues in the current design inadvertently indicate a response, a cue may indicate a response congruent with the response indicated by the target stimulus (e.g. Odd -> 7); while other cues indicate the response that is incongruent to the target stimulus response (e.g. Odd -> 6). Previous studies (Logan & Bundesen, 2003; Logan & Schneider, 2006, Monsell & Mizon, 2006) have found a CT congruency effect using this design. Presently, it is assumed that if a condition requires greater preparation demands then the CT congruency cost should be greater.

Response congruency and stimulus repetition effects were also examined. The response congruency cost (mean response incongruent RT – mean response congruent RT) was examined to indicate interference in SR associations from previously performed tasks. The target stimulus could indicate congruent responses for both tasks relevant for that stimulus (e.g. 8 indicates a 2 (even) response for the odd/even task and a 2 (high) response in the low/high task) or the target could indicate incongruent responses for both tasks relevant for that stimulus (e.g. 7 indicates a 1 (odd) response for the odd/even task and a 2 (high) response for the low/high task). Finally, stimulus repetition effects (mean stimulus switch RT – mean stimulus repeat RT) were examined to indicate priming of previous information.

Three 3-way ANoVAs were performed for the three factors previously examined: transition frequency, transition, and CSI. The ANoVAs were performed for the three cost measures: CT congruency, response congruency and stimulus repetition. For the CT congruency measure, there was an interaction between transition frequency and transition [$F(2, 38) = 6.138$, $p = 0.005$]. The interaction indicated that the CT congruency effect was largest for switch trials when switching was frequent (Figure 14). There was a large CT congruency effect on all task repeat trials, which is due to the presentation of the other task cue on the previous trial (which thereby primed the incongruent response on the current trial). For switch trials, the CT congruency effect is larger when switching is frequent, suggesting that activation from previous tasks influences the amount of cue interference on the current trial. No other transition frequency effects occurred [main effect of transition frequency: F (1, 19) = 0.132, p = 0.070, interaction between transition frequency and CSI: F (3, 57) = 0.224, p = 0.879, interaction between transition frequency, transition and CSI: F (6, 114) = 0.360, p = 0.903].

For the response congruency measure, a 3-way interaction [F (6, 114) = 2.366, p = 0.034] indicated that when switching is frequent, switch trials show a greater response congruency effect with a longer preparation interval (Figure 15). This suggests that when there is persisting activation from previous tasks (i.e. when switching is frequent), the preparation effect is reduced on switch trials that have incongruent response mappings. This effect may be due to previous task activity that contributes to interference in SR mappings. No other switch frequency effects were significant for the measure of response congruency [main effect of transition frequency: F (1, 19) = 0.019, p = 0.892, interaction between transition frequency and CSI: F (3, 57) = 2.107, p = 0.109, interaction between transition frequency and transition: F (2, 38) = 1.165, p = 0.323]. For the stimulus repetition measure, there were no significant effects for the transition frequency factor [main effect of transition frequency: F (1, 19) = 0.021, p = 0.887, interaction between transition frequency and CSI: F (3, 57) = 2.004, p = 0.124, interaction between transition frequency and transition: F (2, 38) = 0.940, p = 0.399], 3-way interaction between transition frequency, transition and CSI: F (6, 114) = 0.210, 0.973].

3.1.3 Discussion

The aim of the current experiment was to determine whether transition frequency influenced general task preparation on all trials, or whether switch preparation was selectively influenced.

In the four task paradigm, frequent switch trials increased overall reaction times and the preparation effect. However, transition frequency did not influence switch preparation. Although there was a trend toward a 3-way interaction, the preparatory switch cost was not alleviated as it had been in previous studies in the literature (Logan & Schneider, 2006; Monsell & Mizon, 2006). It is speculated that the difference between the current results and previous findings may be due to differences in the experimental procedure. Specifically, previous studies practiced subjects for longer on each transition frequency condition and treated subjects to different conditions on different testing sessions in different days. The current procedure tested subjects on both conditions within the same testing session. The repeat frequent condition showed a practice effect, or reduced RT, when it was tested second whereas the switch frequent condition showed no such practice effect. With more practice, switch frequency effects may look more like those in the literature. Another possible reason for the discrepancy in the current transition frequency effects and those in the literature may be the lack of reward for good performance in the current study. Monsell & Mizon (2006) rewarded subjects for good performance, but the current study did not. It may be that when subjects are rewarded, there is more incentive to prepare the upcoming trial and therefore subjects may expect the more frequent transition.

Future research is necessary to definitively determine the circumstances in which transition frequency affects switch preparation and the circumstances in which transition frequency affects general preparation. Logan & Schneider (2007) have made one step in this direction by independently manipulating cue switching and the number of switches in a three-transition sequence. The authors used a two-task paradigm and cued each trial with one of four words: “REPEAT”, “STAY”, “CHANGE” or “SWITCH”. With the use of these transition cues, the authors were able to independently manipulate a cue switch and a task switch. Further, the cues were not associated with any particular task. They found that a cue switch and an increase in the number of switch trials in a sequence both slowed RTs. These effects were additive. This finding was consistent with the current results in which a high switch frequency slows RTs on both task repeat and task switch trials. Logan & Schneider (2007) were able to separate cue switch and cue-task associations and found general, not switch-specific effects, of transition frequency. Previous studies have found that practice affects cue-task associations. Therefore, discrepancies between the previous and current results may be due to the strength of cue-task associations with practice and not due to switch-specific preparation. Although future research is necessary to determine whether transition frequency selectively affects switch preparation, the current findings, as well as those of previous studies, suggest that transition frequency affects general preparation.

The finding that the switch frequency condition does not show RT improvements with greater practice is consistent with findings in the literature, suggesting that learning is hindered by performing a more difficult task. Logan & Bundesen (2003) had subjects perform a task switching paradigm with two different cue types. The task was cued on every trial with either meaningful words (e.g. Odd-Even) or arbitrary letters (e.g. G). The type of cue was blocked (i.e. subjects saw one block with word cues and one block with letter cues) and the order that blocks were presented was counterbalanced. It was found that performance of both trial types was slower when subjects performed the letter condition first and no learning occurred when the word condition was performed second relative to when the word condition was performed first. This suggests that increased task retrieval demands associated with arbitrary task cues could hinder learning of the task. Similarly, in the current paradigm, retrieval demands may be increased in the switch frequency condition which may hinder learning when this condition is performed first. Therefore, the discrepancy between the current results and previous results in the literature may be due to differences in the amount of practice subjects have with each frequency condition. For the current study, general preparation demands were increased when switch trials were frequent, but there was no specific reduction in the switch preparation effect. Brown, Reynolds & Braver (2006) also found that RTs are increased for all trial types that were preceded by a switch trial. However, this previous study did not manipulate preparation and therefore the effects of switch frequency on preparation were not assessed.

In the two task paradigm, there were no switch frequency effects. Again, this finding is inconsistent with previous results in the literature and also with the four-task results. This inconsistency may be due to practice effects. To assess whether this was the case, condition order effects were examined to determine whether condition order affected transition frequency. Condition order had a strong effect on the frequent switch condition. Frequent switch RT was faster when this condition was performed second. Condition order had little effect on the frequent repeat trials. The results are consistent with the interpretation that condition order produces a practice effect. Further, this finding suggests that more practice is needed in the frequent switch condition than in the frequent repeat condition.

The fact that condition order produced a practice effect in the frequent switch condition for the two-task paradigm (Figure 8), but produced a practice effect in the frequent repeat condition in the four-task paradigm (Figure 11), may suggest that the timeline for practice effects is different in these two paradigm versions. Practice within a task was controlled for by presenting the same number of trials of each task within a testing session for both the two-task and four-task paradigms. Although each task was presented the same number of times, other factors such as fatigue, boredom, or task retrieval demands may have slowed learning in the four-task paradigm.

In the current study, increased switch frequency slowed responding and increased preparation demands. However, transition frequency did not selectively affect switch preparation. These findings suggest that transition frequency effects are not due to changes in control state (Monsell & Mizon, 2006) or to learned cue-transition associations (Logan & Schneider, 2006). Both of these theoretical interpretations suggest that switch preparation is reduced when the proportion of switch trials is high, however the current results did not find this effect. The current results also rule out the interpretation that switch frequency effects are due to switch expectancy. If switch frequency effects were due to the early expectation of a switch trial, then the switch preparation effect should occur in the two-task paradigm, when the upcoming task type could be determined on a switch trial, and not in the four-task paradigm, when the upcoming task could be one of three possible task types on a switch trial.

The current study finds that performing a task switch on the previous trial slows RTs and increases task preparation demands on the current trial regardless of whether the current trial is a repeat or switch. Further, when transition history is examined up to three trials back, higher-order transition effects exist (Figure 13). Switching tasks on a previous trial could lead to performance decrements for a couple of reasons. First, when the previous trial is a task repeat, performing the same task for several trials in a row could prime that task. This would result in a decrease of activation for the primed task upon task retrieval. Due to this decrease in activation, the amount of task retrieval necessary during the preparation interval of the current trial would be reduced. If the degree of task retrieval demands is dependent on the overall amount of activation for both tasks, then a previous task repeat trial would decrease retrieval demands on both task repeat and task switch trials. In this case, task performance would be facilitated if the previous trial was a task repeat due to the reduction in task activation. Another possibility is that when subjects previously switched, both tasks remain active. In this case, control demands would increase if the previous trial was a task switch because the task activation for the currently relevant task would need to overcome activation from other active tasks.

In order to distinguish between these possibilities, two types of current repeat trial task sequences were compared in the two task paradigm. One task sequence contained a greater number of switches, but the current task was more primed (i.e. in the trial type RSSR, the task history would be T1T1T2T1T1 and therefore task T1 should be primed). This type of repeat trial was compared to another type of repeat trial in which the previous trials included fewer switches, and the task was more primed (i.e. in the trial type RRSR, the task history would be T2T2T2T1T1 and therefore task T1 would be less primed than in the other task sequence). The purpose of comparing these two task sequences was to determine whether the current trial RT was facilitated by the amount of task priming that had occurred for the currently relevant task (in which case the RSSR sequence should show faster RT) or whether the current trial RT was slowed by increased control demands when there were a greater number of recent task switch trials (in which case the RSSR sequence should show slower RT). The mean RT was greater for the RSSR condition (mean RT ± SE, 793 msec ± 40 msec) than the RRSR condition (mean RT ± SE, 755 msec ± 37 msec). This finding was not significant [$F(1, 21) = 1.434$, $p = 0.245$]. However, when subjects performed two tasks with the same sets, there was a trend toward a significant effect [$F(1, 7) = 3.712$, $p = 0.095$], but not when subjects performed two tasks with different sets [$F(1, 13) = 0.001$, $p = 0.975$]. This may be because advance preparation was not necessary when the two stimulus sets were different. Although these results are not conclusive, they suggest that the increased RT and preparation demands resulting from a previous switch trial may be due to an increase in control demands due to greater task activation after a task switch trial, and not a decrease in task activation due to task priming on a task repeat trial.

Other higher-order sequential effects have been found in task switching studies which could influence the current results. One common effect is that of backward inhibition. Mayr and Keele (2000) found that switching back to a task performed previously (ABA) results in a greater switch cost than switching to a new task (ABC). During their experiment subjects judged an oddball object based on different stimulus dimensions. The authors suggest that this effect results from the need to overcome previous inhibition when switching back to a task previously performed. In the current four-task paradigm, more than two task were performed so backward inhibition could be assessed. The RT difference between ABA (mean 960.75, SD = and ABC switch trials was not significant [t (19) = 0.458, p = 0.652]. Therefore, it was assumed that backward inhibition did not affect task switching in the current set of studies. Although many task switching studies have found backward inhibition effects, others have not. Recent research suggests that backward inhibition may occur when switching occurs on every trial, but not in other circumstances (Aron, Monsell, Sahakian & Robbins, 2004; Mayr, in press).

3.1.3.1 A Task Activation Model Account of the Effect of Previous Trial Activation on Task Preparation

The current experiment found that the performance of a previous switch trial increases both the overall RT and task preparation demands on the current trial. This slowed performance occurred on the current trial regardless of the current transition type. The findings suggest that a previous switch trial results in persisting task activation which interferes with SR demands on the current trial and therefore increases current trial task retrieval demands.

A model of transition frequency and task preparation effects in the four task paradigm is based on previous models (Logan & Schneider, 2005; Schneider & Logan, 2006). The previous models account for the preparation effect for cue repeat, task repeat and task switch trials. Logan & Bundesen (2003) theorized that preparatory reductions in RT were due to cue encoding demands for all of these trial types and found that adding an additional “set switch” parameter to their model did not provide a better fit to their data. The models by Logan and colleagues have used separate cue encoding parameters for each transition type to account for the preparation effect and a base RT parameter to account for the RT that remains at long preparation intervals. A recent model (Logan & Schneider, 2006) accounted for switch frequency effects by adding separate base RT parameters for the two transition frequency conditions and a constant f (the frequency priming factor) that was multiplied by the cue encoding parameters in the frequent switch condition to account for the differences in cue encoding between the transition frequency conditions.

The current model uses the same basic equation to account for the base RT and the preparatory reduction in RT in the different transition conditions as used in the previous models by Logan and colleagues, however the current model differs from the model presented by Schneider & Logan (2006) in a couple of ways. First, only one base RT parameter is used to account for both transition frequency conditions. Second, a previous trial task switch activation parameter is added to account for the persisting activation from a previous switch trial. Table 1 displays the parameters and the values used for the current model.

The following equation was used to model the condition means for the factors transition frequency, transition and CSI:

$$RT_{model} = [RT_{base} + Pr^{TSn-1} * \mu^{TaskActn-1}] + [\mu^{TSn} + Pr^{TSn-1} * \mu^{TaskActn-1}] * \exp[(-CSI) / [\mu^{TaskActn} + Pr^{TSn-1} * \mu^{TSn-1}]]$$

The parameter names are displayed in color. CSI and Pr^{TSn-1} were determined from the data. The $\mu^{TaskActn}$ parameter represented the task activation that occurs during the preparation interval. Since the preparation effect is different for the three transition conditions, three separate parameters accounted for the task activation on the current trial: μ^{CRn}, μ^{TRn} and μ^{TSn}. These parameters represented the current trial task activation occurring for cue repeat, task repeat and task switch trials, respectively. The other two parameters were constant across all conditions: RT_{base} and μ^{TSn-1}. RTbase represented the overall RT that remains even at long preparation intervals. μ^{TSn} represents the increase in preparation and overall RTs due to a previous switch trial. This parameter was the same for all conditions and the behavioral differences between the two transition frequency conditions were accounted for by the probability of a previous switch trial for that condition. This probability was computed from the data for each condition and this value was multiplied by the μ^{TSn} parameter value. The CSI value represented Cue-Stimulus Interval and this value was also taken directly from the data.

The full model with separate parameters for the task activation on each transition condition is as follows:

$$RT_{model} = [RT_{base} + Pr^{TSn-1} * \mu^{TSn-1}] + [\mu^{CRn} + Pr^{TSn-1} * \mu^{TSn-1}] * \exp[(-CSI) / [\mu^{CRn} + Pr^{TSn-1} * \mu^{TSn-1}]] + [RT_{base} + Pr^{TSn-1} * \mu^{TSn-1}] + [\mu^{TRn} + Pr^{TSn-1} * \mu^{TSn-1}] * \exp[(-CSI) / [\mu^{TRn} + Pr^{TSn-1} * \mu^{TSn-1}]] + [RT_{base} + Pr^{TSn-1} * \mu^{TSn-1}] + [\mu^{TSn} + Pr^{TSn-1} * \mu^{TSn-1}] * \exp[(-CSI) / [\mu^{TSn} + Pr^{TSn-1} * \mu^{TSn-1}]]$$

The full model contains five parameters: RT_{base}, μ^{CRn}, μ^{TRn}, μ^{TSn}, and μ^{TSn-1}. Microsoft Excel's Solver Add-In Function was used to solve the equation, while minimizing the root mean square deviation (RMSD). The RMSD was computed using the following equation: $RMSD = \sqrt{[\sum(x_{model} - x_{data})^2/n]}$. The best fit parameters were determined by minimizing the RMSD across all twenty four data points (transition frequency 2, transition 3, CSI 4). Table 1 displays the best fit parameters. The RMSD using these parameters is 13.7. Figure 16 displays the condition means generated by the model overlaid on the actual condition means from the data.

The current model was compared to the Schneider & Logan (2006) model of task switching to determine which model provides a better fit of the data. Schneider & Logan (2006) used six parameters to model transition frequency effects: $RT_{baseREP}$, RT_{baseSW}, μ^{CRinf}, μ^{TRinf}, μ^{TSinf}, and f. The parameters, $RT_{baseREP}$ and RT_{baseSW}, stood for the base RT on frequent repeat blocks and frequent switch blocks, respectively. The parameters, μ^{CRinf}, μ^{TRinf}, μ^{TSinf}, stood for the cue encoding that occurs on each transition type. The *f* parameter was a constant multiple applied to the cue encoding parameter if that transition type was the frequent transition for the block. The following equation accounted for RT on frequent repeat blocks:

$$\text{RTmodel} = RT_{baseREP} + (\mu^{CRinf}) \text{ *exp}[(-CSI)/ (\mu^{CRinf})] + RT_{baseREP} + (\mu^{TRinf} * f) \text{ *exp}[(-CSI)/ (\mu^{TRinf} * f)] + RT_{baseREP} + (\mu^{TSinf}) \text{ *exp}[(-CSI)/ (\mu^{TSinf})]$$

The equation was modified as follows for frequent switch blocks:

$$\text{RTmodel} = RT_{baseSW} + (\mu^{CRinf}) \text{ *exp}[(-CSI)/ (\mu^{CRinf})] + RT_{baseSW} + (\mu^{TRinf}) \text{ *exp}[(-CSI)/ (\mu^{TRinf})] + RT_{baseSW} + (\mu^{TSinf} * f) \text{ *exp}[(-CSI)/ (\mu^{TSinf} * f)]$$

To compare the Schneider & Logan (2006) model to the current model, these equations and parameters were entered into Microsoft Excel's Solver Add In and the best fit parameters were found by minimizing the RMSD. The minimum RMSD for these equations was 16.5. This value is greater than the minimum RMSD of 13.7 found for the current model. Since the current model uses fewer parameters and incurred a smaller RMSD using the best fit parameters, it is assumed that the current model provides a more parsimonious account of transition frequency effects than the Schneider & Logan (2006) model.

3.2 EXPERIMENT 3. SWITCH PREPARATION AND TASK FREQUENCY: TASK STRENGTH MODULATES THE INFLUENCE OF PREVIOUS TASK DEMANDS

Previous research has found that switch costs are reduced when switching to a less frequent or "weaker" task. This effect is somewhat counterintuitive and has been called the paradoxical switch effect by some (Gilbert & Shallice, 2002) and the asymmetric switch effect by others (Monsell, Yeung & Azuma, 2000). Monsell, Yeung & Azuma (2000) proposed that this effect may occur because the dominant task is suppressed during the performance of the weaker task and therefore the switch cost is greater when switching back to the dominant task since recent suppression must be overcome. Gilbert & Shallice (2002) proposed another account in which the asymmetric switch cost is due to greater task control activation from the previous trial during a current trial switch to the dominant task. According to this account, switch costs are affected by the degree of previous trial activation.

The current experiment manipulated task strength and switch frequency to determine whether previous switch trial effects are due to interference from the task previously performed or whether previous switch effects may be due to slowed control processing after the recent use of control demands (i.e. because control processes are taxed during the performance of a switch trial). In the former case, increased retrieval would be necessary when the previous task produced greater interference (i.e. on previous weak task trials). It is hypothesized that if the previous trial was weak, it required a high degree of retrieval to perform, and therefore previous task activation would be high regardless of whether the previous trial was a switch or repeat trial.

In this case, a previous switch trial should affect RTs when the previous trial type was a strong task, but not when the previous switch trial was a weak task. This finding would suggest that task activity is high when the previous trial is an weak task, regardless of whether the previous trial was a switch or repeat. Further, this would confirm that previous switching increases current trial RT because both previous tasks remain somewhat active. Alternatively, a previous switch trial could result in increased RT regardless of whether the previous trial was a frequent or weak task type. If this were the case, this would suggest that a previous switch trial increases control demands, but this is not due to increased activity from the previous trial type. The previous trial switch effect would occur both when the previous trial was infrequent and when the previous trial was frequent. This possibility suggests that a switch-specific process occurring on the previous trial slows RTs regardless of current trial task retrieval demands. This possibility supports the role of switch-specific processing in task switching. Another possibility is that a previous infrequent trial could result in less previous trial activity since the associations are weaker for the weak task type and therefore are not maintained as long. In this case, a previous trial switch should have a reduced effect when the current trial type is infrequent.

3.2.1 Methods

3.2.1.1 Subjects:

A separate group of 16 subjects were recruited for the third experiment. Subject recruitment, compensation, and testing conditions were the same as specified in previous experiments. Each subject performed a variant of the two-hour four task paradigm.

3.2.1.2 Materials:

All testing was conducted on pc computers running E-Prime software (Schneider, Eschman, & Zuccoloto, 2002) for experimental presentation and data acquisition.

3.2.1.3 Procedure:

All experimental parameters were the same as in Experiment 1, except that the task strength was manipulated in addition to transition frequency. Just as before, subjects performed one practice block and four experimental blocks of each transition frequency condition. The order in which subjects performed the two transition frequency conditions was counterbalanced between subjects. In the current experiment one task was chosen as the frequent (strong) task. In Experiment 1, task frequency was 25% for all four task types. In Experiment 3, the task frequency was 64% for the strong task and 12% for the other three task types. The particular task that served as the frequent (strong) task changed between subjects so that each of the four tasks served as the strong task an equal number of times between subjects. The strong task remained the same for the eight blocks of trials within a subject.

3.2.2 Results

Two 4-way ANoVAs were examined, which included the factors task strength (2 levels: strong (frequent) task, weak (infrequent) task), transition frequency (2 levels: switch frequent, repeat frequent), transition (3 levels: cue repeat, task repeat, and task switch) and CSI (4 levels: 100, 300, 500, 900). All factors were manipulated within-subject. ANoVAs were performed for the dependent measures of RT and accuracy.

For the RT measure, task strength interacted with switch frequency [$F(1, 15) = 6.774$, $p = 0.020$]. There was also a 3-way interaction between task strength, switch frequency, and transition [$F(2, 30) = 5.685$, $p = 0.008$] and a 4-way interaction between task strength, switch frequency, transition, and CSI [$F(6, 90) = 2.445$, $p = 0.031$] (Figure 17). No other effects including the factors of task strength and switch frequency were significant. There was no interaction between task strength, switch frequency and CSI [$F(3, 45) = 0.206$, $p = 0.892$]. The interaction between task strength and switch frequency revealed that there were larger effects of frequent switching in the strong task (Figure 18) and there was little or no switch frequency effect in the weak task condition.

The accuracy results showed a main effect of task strength [$F(1, 15) = 12.926$, $p = 0.003$], but no other task strength effects. There was no interaction of task strength and switch frequency [$F(2, 30) = 0.945$, $p = 0.346$], no 3-way interaction between task strength, switch frequency and CSI [$F(3, 45) = 0.391$, $p = 0.760$], no 3-way interaction between task strength, switch frequency and transition [$F(2, 30) = 0.053$, $p = 0.948$), and no 4-way interaction between task strength, switch frequency, transition, and CSI [$F(6, 90) = 1.186$, $p = 0.321$].

The current RT results suggest that performing an infrequent trial reduces the previous switch effect. However, it is possible that the sampling method was different for the frequent repeat and frequent switch block types. For example, in the repeat frequent blocks, infrequent trials may have been preceded by frequent trials more often; while in the switch frequent blocks, infrequent trials may have been preceded by infrequent trials more often (Figure 21). Upon examination of the trial sampling, it is clear that when repetition is frequent, the weak-task, switch trials are more often preceded by another weak task (73.4% previous infrequent trials) compared to when switching is frequent (4.71% previous infrequent trials). This suggests that the switch frequency effect in infrequent trials may be influenced by the proportion of previous infrequent trials in a block.

To account for this difference in sampling between the two frequency blocks, previous transition effects were examined. Since the previous transition included trials from both transition frequency blocks, the sampling methods for the repeat frequent and switch frequent conditions should not confound the previous transition effects. This allowed for the assessment of whether the previous transition type affected the RTs of either strong or weak task trials. It was found that a previous switch transition increased overall RTs in the strong task condition [$F(2, 26) = 5.735$, $p = 0.009$] (Figure 19) and interacted with current transition in the strong task condition [F (4, 52) = 4.632, p = 0.003] (Figure 20), but these effects did not occur in the weak task condition [ME of previous transition: F (2, 26) = 0.350, p = 0.708, transition x previous transition interaction: F (4, 52) = 1.418, p = 0.241]. These results support the conclusion that a previous switch trial slows RTs during the strong task, but not during performance of weak tasks.

3.2.2.1 RT Costs Affecting Preparation and SR demands: Cue-Target Congruency, Response Congruency and Stimulus Repetition Effects

To provide separate measures of cue interference, target interference and stimulus priming, RT costs were again examined. Cue-target (CT) congruency costs (mean CT incongruent RT – mean CT congruent RT) were examined as an indicator of the degree of interference in cue information that occurred. Response congruency (mean response incongruent RT – mean response congruent RT) and stimulus repetition effects were also examined (mean stimulus switch RT – mean stimulus repeat RT) as measures of SR interference and stimulus priming.

Three 3-way ANoVAs were performed for the three factors: transition frequency, transition, and CSI, for the three cost measures: CT congruency, response congruency and stimulus repetition. For the CT congruency measure, there were no significant effects of task strength or transition frequency [main effect of task strength: F (1, 13) = 1.325, p = 0.270, main effect of transition frequency: F (1, 13) = 0.540, p = 0.476, interaction between task strength and transition frequency [F (1, 13) = 0.156, p = 0.699, interaction between task strength and transition [$F(2, 26) = 0.456$, $p = 0.639$, interaction between transition frequency and transition [$F(2, 26) = 1.461$, $p = 0.250$, 3-way interaction between task strength, transition frequency and transition: $F(2, 26) = 1.132$, $p = 0.338$, interaction between task strength and CSI: $F(3, 39) = 0.234$, $p = 0.310$, interaction between transition frequency and CSI: $F(3, 39) = 1.822$, $p = 0.159$, 3-way interaction between task strength, transition frequency and CSI: $F(3, 39) = 0.505$, $p = 0.681$, interaction between task strength, transition and CSI: $F(6, 78) = 0.410$, $p = 0.870$, transition frequency, transition and CSI: $F(6, 78) = 0.560$, $p = 0.761$], 4-way interaction between task strength, transition frequency, transition and CSI: $F(6, 114) = 0.732$, $p = 0.625$].

For the response congruency and stimulus repetition measures, the factors of task strength, transition frequency and transition were examined. The factor of Cue-Stimulus Interval was not included because there were a small number of observations in some cells. For the response congruency measure, there was a significant main effect of task strength [$F(1, 15) = 16.909$, $p = 0.001$] and a significant interaction between task strength and transition frequency [$F(1, 15) = 10.032$, $p = 0.006$]. The weak task showed a greater response congruency effect when repeat trials were frequent (Figure 22). In the previous experiment, the response congruency effect was greater when switching is frequent. This discrepant finding may be due to the trial sampling in the current study (Figure 21). On the frequent repeat blocks, there were more previous infrequent trials when the current trial was an infrequent switch trial, which could have increased the response congruency effect for weak task trials that occurred within the frequent repeat block. There was also a significant interaction between transition frequency and transition [$F(2, 30) = 3.489$, $p = 0.043$]. There were no other significant effects of task strength or transition frequency [main effect of transition frequency: $F(1, 13) = 0.540$, $p = 0.476$, interaction between task strength and transition [F (2, 26) = 0.456, p = 0.639, 3-way interaction between task strength, transition frequency and transition: F (2, 26) = 1.132, p = 0.338.

For the stimulus repetition measure, there was a significant interaction between transition frequency and transition [F (2, 20) = 3.859, p = 0.038]. The stimulus repetition effect was largest for cue repeat trials and the effect reversed on switch trials in frequent switch blocks (Figure 23). This reversal in the stimulus repetition effect on task switch trials has been found previously in the literature and is thought to reflect lateral inhibition of stimulus priming that was previously associated with another task type. The current finding suggests that the switch trial reversal in stimulus priming effects may occur when there is a buildup of activity from previous task types. There were no other significant effects of task strength or transition frequency [main effect of task strength: F (1, 10) = 3.291, p = 0.100, main effect of transition frequency: F (1, 10) = 0.070, p = 0.796, interaction between task strength and transition frequency [F (1, 10) = 0.970, p = 0.348, interaction between task strength and transition [F (2, 20) = 0.050, p = 0.951, 3-way interaction between task strength, transition frequency and transition: F (2, 20) = 0.371, p = 0.694].

3.2.3 Discussion

The current experiment examined task strength and switch frequency effects to determine whether a previous task switch increases the amount of task activation present in the system on the current trial or whether a previous task switch taxes a switch-specific process such as task-set reconfiguration. The first account leads to the prediction that switch frequency effects should occur for the strong task, but not for the weak task. During the weak task, greater task activation is necessary to retrieve the current task. Because task retrieval demands are already increased, interference due to task activation from previous switch trials do not further increase task retrieval demands. Contrary to this hypothesis, the latter account suggests that a previous switch trial should affect current RTs regardless of the task strength. If previous switching taxes a switch-specific process then this should slow RTs on both strong and weak task types, regardless of task retrieval demands. This suggests that the effects of task strength and switch frequency should be additive with the slowest RTs occurring when the task type is infrequent and the current trial was preceded by a switch trial.

The results from the current experiment support the former hypothesis that the previous transition affects RTs when the current task type is frequent, but not when the current task type is infrequent since a high degree of task activation is required for all infrequent trials regardless of the previous transition. The results suggest that slowed RTs after a switch trial may be due to persisting interference from the activation of previous tasks and this interference necessitates increased task activation. Since retrieval demands are already high during the performance of the weak task, preparation and overall RTs are slowed when the current task type is infrequent, regardless of whether the previous trial was a switch or repeat.

Previous research has found that activation from the previous trial is only greater after a switch trial when the Response-Cue Interval (RCI) is less than 1000 msec (Meiran, Chorev & Sapir, 2000). The current study used a RCI of 1000 msec to avoid this effect of previous trial decay. Although the use of a long RCI should ensure that previous trial activation does not affect the current trial, the current results found a slowing of current trial RTs by a previous switch trial even at this long delay. The fact that a previous switch trial still has a large effect on current trial RT, even at this long RCI, suggests that the persisting interference due to a previous switch trial does not decay with greater time intervals. Further, since previous switching slows RTs several trials into the future (Figure 13), this suggests that the previous switch effect is not due to activation that decays with intervening stimuli. Instead, the persisting interference from a previous switch trial does not decay with time and remains in the system for several trials into the future.

An alternative explanation is that the previous trial switch effect may be due to dynamic changes in association weights, which are dependent on how recently a given task has been performed. This interpretation suggests that a previous switch trial could slow RTs by causing small decreases in association strengths between previously learned items and further suggests that competitor interference resulting from task-stimulus associations may play a role in the previous trial switch effect (Allport & Wylie, 2000; Waszak & Allport, 2003; Waszak, Hommel & Allport, 2005). If this latter interpretation were true, then performance of any given task should depend on how recently the task was performed. To determine whether task recency affected RTs an examination of task sequence effects was perfomed in experiment 2 (p. 39). This post hoc analysis found that task recency did not affect current trial RTs. Previous studies have found that task recency affects current trial RTs when task lag is accounted for (Ruthruff, Remington & Johnston, 2001), however, a more recent examination suggested that task recency effects only occur when the stimuli are different for the two tasks and therefore control demands are low (Sumner & Ahmed, 2006). These findings suggest that previous switch effects are not due to alterations in task-stimulus associations, but instead are due to persisting interference from previous tasks.

In the current study, a previous switch trial increased overall RTs when the current task type was frequent, but did not increase preparation demands for the weak task. This result is counter to the findings of experiment 1 in which switch frequency increased the preparation effect as well as overall RT. It may be that a previous transition does not affect preparation on the weak task because preparation demands are already maximal for this task. If a previous switch affects increases task retrieval demands, then a previous switch would not increase retrieval demands further on weak task trials since task retrieval demands are already high for this task type. Therefore, a previous switch trial would affect strong task trials but not weak task trials.

The current study results found that task strength interacts with transition. The switch cost was larger for strong task trials than for weak task trials. Previous studies have also found that the switch cost is largest in the strong task (Gilbert & Shallice, 2002; Monsell, Yeung & Azuma, 2000). In Gilbert & Shallice's (2002) model of task switching, this paradoxical switch cost was due to increased persisting task activation on strong task trials since the previous weak task type required greater task activation and therefore resulted in increased persisting activation. This increased persisting activation on strong task trials caused a larger switch cost for this task type.

Task retrieval demands are also maximal on task switch trials and therefore it is likely that persisting task activity also accounts for the transition by previous transition effects in the current study. That is, a previous switch trial may have little effect on current trial task retrieval demands during switch trials since task retrieval is already maximal on these trials. The current study found that when current task retrieval demands are high, there is no effect of a previous transition. This result suggests that interference from a previous switch trial increases the retrieval demands on the current trial however, when retrieval demands are already high, interference from previous trial activation does not increase these demands further. In other words, a previous switch trial causes interference which increases task retrieval demands, but only if the present task does not already require maximal retrieval. This interpretation is consistent with previous theories that goal-directed guidance of behavior is needed when tasks are less-automatic or when task interference is present (Botvinick, Braver, Barch, Carter & Cohen, 2001; Miller & Cohen, 2001; Shiffrin & Schneider, 1977; Schneider & Detwiler, 1988). The current findings suggest that goal-directed guidance of behavior is not only affected by previous trial retrieval demands but also because of internal constraints on task retrieval. Future theories of goal-directed guidance of behavior should account for these constraints.

3.2.2.2 Modifications to the Task Activation Model to Account for Task Strength Effects

The task activation model was modified to account for the factors task strength, transition frequency, transition and CSI for the current experiment. The current model added a couple of parameters in addition to those used for the previous experiment. The two additional parameters were μ^{Infn} and μ^{Infn-1}. These two parameters stood for the additional task activation on a current infrequent trial and task activation on a previous infrequent trial, respectively. The first parameter was multiplied by the current task activation for trial n whenever the current task type was infrequent. It was assumed that the weak task would be less practiced and therefore would require greater retrieval during the preparation interval. The second parameter was multiplied by the previous task activation whenever the previous task type was infrequent. It was assumed that the increased retrieval demands from the previous weak task would also increase retrieval demands on the current trial. Conceptually, this mechanism is similar to that used to account for the asymmetric switch cost (increased switch cost to the weaker task) in the Gilbert & Shallice (2002) model.

The current model modified the equation described in the previous section (Section 3.1.3.1, p. 43) to account for the additional parameters and also to fit certain assumptions. The first assumption was that task retrieval demands would be maximal on infrequent trials and therefore task activation would not be influenced by previous switching. Second, it was assumed that a previous switch trial influenced both the base RT and task activation, but only on strong-task, cue repeat trials and strong-task, task repeat trials. On the rest of the conditions (i.e. on switch and weak-task trials), retrieval demands were assumed to be maximal and therefore, a previous switch trial only affected base RTs and not task activation. Third, it was assumed that a switch from a previous weak-task would cause a greater increase in RTs than a previous switch from a strong-task since persisting task activation would be greater for these trials. To account for this third assumption, the proportion of previous weak task trials and previous weak task trials was computed in the following parameters: $Pr^{TSfreqn-1}$ and $Pr^{TSinfn-1}$. Table 2 displays the parameters and the values used for the current model.

The following equation was used to model the condition means for the factors task strength, transition frequency, transition and CSI in the strong task, repeat conditions:

$$RT_{model} = [RT_{base} + Pr^{TSn-1} * \mu^{TSn-1}] + [\mu^{TaskActn} + Pr^{TSn-1} * \mu^{TSn-1}] * \exp[(-CSI) / (\mu^{TaskActn} + Pr^{TSn-1} * \mu^{TSn-1})]$$

The variables, CSI, $Pr^{TSfreqn-1}$, $Pr^{TSinfn-1}$ and Pr^{TSn-1}, were constant for each condition and were determined from the data. The variables, $Pr^{TSfreqn-1}$ and $Pr^{TSinfn-1}$ represent the proportion of previous frequent and previous infrequent trials. The two proportions add to 1 and are multiplied by the Pr^{TSn-1}, or the probability that the previous trial was a switch trial. The $\mu^{TaskAct}$ parameter was different for the three different transition conditions: μ^{CRn}, μ^{TRn} and μ^{TSn}. The other four parameters were constant across all conditions: RT_{base}, μ^{TSn-1}, μ^{Infn-1}, and μ^{Infn}.

The model equation was modified as follows for the strong-task, switch trial conditions:

$$RT_{model} = [RT_{base} + Pr^{TSn-1} * \mu^{TSn-1} + Pr^{TSfreqn-1} * \mu^{TSn-1} + Pr^{TSinfn-1} * \mu^{TSn-1} * \mu^{Infn-1}] + [\mu^{TaskActn}] * \exp[(-CSI) / [\mu^{TaskActn}]$$

For the weak task conditions, the RT_{base} and $\mu^{TaskActn}$ parameters were multiplied by the μ^{Infn} parameter. For all weak task conditions, the model equation was as follows:

$$RT_{model} = [(RT_{base} * \mu^{TaskActInfn)} + Pr^{TSn-1} * \mu^{TSn-1} + Pr^{TSfreqn-1} * \mu^{TSn-1} + Pr^{TSinfn-1} * \mu^{TSn-1} * \mu^{Infn-1}] + (\mu^{TaskActn} * \mu^{Infn}) * \exp[(-CSI) / (\mu^{TaskActn} * \mu^{Infn})]$$

The full model for the task activation including all transition conditions is as follows:

$$RT_{model} = [RT_{base} + Pr^{TSn-1} * \mu^{TSn-1}] + [\mu^{CRn} + Pr^{TSn-1} * \mu^{TSn-1}] * \exp[(-CSI) / [\mu^{CRn} + Pr^{TSn-1} * \mu^{TSn-1}] + [RT_{base} + Pr^{TSn-1} * \mu^{TSn-1}] + [\mu^{TRn} + Pr^{TSn-1} * \mu^{TSn-1}] * \exp[(-CSI) / (\mu^{TRn} + Pr^{TSn-1} * \mu^{TSn-1})] + [RT_{base} + Pr^{TSn-1} * \mu^{TSn-1} + Pr^{TSfreqn-1} * \mu^{TSn-1} + Pr^{TSinfn-1} * \mu^{TSn-1} * \mu^{Infn-1}] + [\mu^{TSn}] * \exp[(-CSI) / [\mu^{TSn}]] + [RT_{base} * \mu^{Infn} + Pr^{TSn-1} * \mu^{TSn-1} + Pr^{TSfreqn-1} * \mu^{TSn-1} + Pr^{TSinfn-1} *$$

$\mu^{TSn-1} * \mu^{Infn-1}] + [\mu^{CRn} * \mu^{Infn}] * \exp[(-CSI) / (\mu^{CRn} * \mu^{Infn})] + [RT_{base} * \mu^{TaskActInfn} + Pr^{TSn-1} * \mu^{TSn-1} + Pr^{TSfreqn-1} * \mu^{TSn-1} + Pr^{TSinfn-1} * \mu^{TSn-1} * \mu^{Infn-1}] + [\mu^{TRn} * \mu^{Infn}] * \exp[(-CSI) / (\mu^{TRn} * \mu^{Infn})] + [RT_{base} * \mu^{TaskActInfn} + Pr^{TSn-1} * \mu^{TSn-1} + Pr^{TSfreqn-1} * \mu^{TSn-1} + Pr^{TSinfn-1} * \mu^{TSn-1} * \mu^{Infn-1}] + [\mu^{TSn} * \mu^{Infn}] * \exp[(-CSI) / (\mu^{TSn} * \mu^{Infn})]$

The full model contains the five parameters introduced in the previous model: RT_{base}, μ^{CRn}, μ^{TRn}, μ^{TSn}, and μ^{TSn-1} plus two additional parameters to account for increased activation on weak task trials: μ^{Infn} and μ^{Infn-1}. The best fit parameters were determined by minimizing the root mean square deviation (RMSD) across the forty eight data points (task strength 2, switch frequency 2, transition 3, CSI 4). The RMSD was calculated using the following equation: $RMSD = \sqrt{[\sum(x_{model} - x_{data})^2/n]}$. Table 2 displays the best fit parameters. The best fit RMSD using these parameters is 23.3. Figure 24 displays the condition means generated by the model overlaid on the actual condition means from the data.

In the current model, it was assumed that previous task activation only influenced current RTs on strong-task, cue repeat and strong-task, task repeat trials. This is because retrieval demands were assumed to be maximal on switch trials and on weak task trials. To account for this, the previous trial task activation was added to the base RT, but did not contribute to task activation. This modification reduced the RMSD on weak task switch trials and also overall in the model. When this assumption was not included in the model the RMSD for the best fit parameters was 24.7.

4 GENERAL DISCUSSION

The current set of studies aimed to determine whether switch preparation involves the same processes as general preparation that occurs on repeat trials, or whether switch preparation involves unique processes necessary for setting up a new task type. Several experimental factors affecting task preparation were manipulated to determine whether switch preparation was selectively influenced. It was hypothesized that if switch preparation recruits additional processes, which are not necessary on repeat trials, then experimental factors that affect a switch preparation process should increase the preparation effect only on switch trials. Several experimental factors were chosen because they have previously been found to affect task preparation and/or the switch cost.

Experiment 1 manipulated stimulus set overlap to determine whether performing two tasks using the same stimulus sets would increase switch preparation. It was found that general preparation demands were increased for those subjects who performed two tasks with the same sets compared to subjects who performed two tasks with different stimulus sets. However, the switch cost was not increased. Further, in the four-task paradigm, switching to a task with the same set as the previous trial did not produce a greater switch cost than switching to a task with a different set from the task previously performed. Therefore, stimulus set overlap increased general preparation demands and did not selectively affect a switch-specific process.

Similarly, experiment 2 found that the factor of transition frequency affected overall RTs and general preparation demands, however switch preparation was not selectively affected. This experiment found that switch frequency effects are due to the increase in overall RTs and general preparation following a task switch trial. These performance costs occur regardless of whether the current trial is a task switch or a task repeat trial. Therefore, task switch preparation is not selectively influenced by previous switching.

In experiment 3, task strength was manipulated in addition to transition frequency to determine whether task strength would affect switch preparation. It was hypothesized that if switch preparation involves a switch-specific process, then a previous switch trial should affect current task preparation demands in the same way, regardless of task strength. The current experiment found that a previous switch trial does not affect strong task and weak task trials in the same way. Task retrieval demands are affected on strong task trials, but not on weak task trials. This result suggests that the preparatory switch cost is due to increased general preparation demands rather than switch-specific preparation.

All three experiments found that general preparation demands were affected on all trials and switch preparation was not affected selectively. These findings suggest that switch preparation does not involve switch-specific processing, but instead requires increased general task processing. The results support the conclusion that the interference from previous task activation increases task retrieval demands on task switch trials relative to repeat trials. However, these retrieval demands also occur on task repeat trials to a lesser degree.

4.1 IMPLICATIONS FOR UNDERSTANDING PREPARATION AND TASK RETRIEVAL

The results from experiment 1 suggest that preparation demands are increased when subjects must rely on cue information to distinguish the relevant task set. When subjects performed two tasks with the same stimulus sets, preparation demands were increased relative to when subjects performed two tasks with different stimulus sets. This preparatory difference may be due in part to increased interference in the stimulus-response mappings when the stimulus sets overlap. While stimulus interference could contribute to the preparation effect when anticipatory stimulus set activation occurs (Meiran, 2000a; 2000b), it is more likely that stimulus interference slows RTs upon presentation of the target stimulus and subsequent retrieval of the associated SR mappings (Allport & Wylie, 2000; Waszak, Allport & Hommel, 2003; 2005). Therefore, increased stimulus interference when performing two tasks with the same stimulus sets may contribute to the overall slowing in RTs, however the increased preparation effect on same set trials is due to advance task set selection and not due to interference in SR mappings. The increase in preparation demands when advance task selection occurs instead reflects the advance retrieval and maintenance of task set information.

The finding that set overlap did not affect switch trial preparation in the four-task paradigm, further supports the interpretation that the RT preparation effect does not simply reflect stimulus interference, but instead reflects retrieval of the task set. This interpretation is consistent with many theories of task switch preparation (Altmann & Gray, 2002; Altmann, 2004; Gilbert & Shallice, 2002; Goschke, 2000; Mayr & Kliegl, 2003; Badre & Wagner, 2006). However, it does not lend support (for or against) whether task retrieval includes the readying of SR mappings (Badre & Wagner, 2006; Gilbert & Shallice, 2002; Monsell, 2003) in addition to the retrieval of conceptual task information. One finding from experiment 1 does support the notion that SR mappings are readied during the preparation interval. In the four-task paradigm, accuracy was greatly improved on same switch trials but did not show much improvement on different switch trials (Figure 5). This suggests that preparation reduced interference when switching between same set tasks and therefore suggests that preparation includes the readying of SR mappings. This finding is consistent with previous results that show the same brain regions active during both the preparation and response phases on switch and repeat trials and therefore supports the interpretation that preparation involved the general activation of task information (Brass & von Cramon, 2004; Gruber, Karch, Schlueter, Falkai & Goschke, 2006; Ruge, Brass, Koch, Rubin, Meiran & von Cramon, 2005). The current set of experiments provide further support for the interpretation that both the retrieval of conceptual task information and the readying of SR mappings, occurs on all transition types and not just during task switch preparation.

4.2 PREVIOUS SWITCHING AND TASK PREPARATION DEMANDS

Experiment 2 found that general preparation demands are increased and overall RTs are slowed due to the demands of performing a previous switch trial. The finding that previous switching impairs current task performance is consistent with other findings in the literature (Monsell &

Mizon, 2006; Logan & Schneider, 2006; Brown, Reynolds & Braver, 2006; Reynolds, Braver, Brown, & Stigchel, 2006). But, what about switching makes subsequent task performance less efficient? One possibility is that a previous switch trial results in changes in the control state that leave the system in a "neutral state" between the tasks and less-configured for the performance of the repeated task. Monsell & Mizon (2006) raised this possibility to account for their finding that the preparatory switch cost is reduced when switching is frequent. The current findings did not replicate the 3-way interaction between switch frequency, transition and CSI. Although Monsell & Mizon (2006) originally suggested that changes in control state may occur over a block of trials, the interpretation could be modified to provide an account of the control changes that occur after a switch trial. Even if this interpretation were modified to account for trial-by-trial adjustments in control state it still would not account for higher-order switch effects that occur (Figure 12). If the control state became neutral (or unbiased toward the previous task type) after a switch trial, then an n-1 previous transition should occur, but not higher order switch effects. In experiment 2, higher order switch effects did occur

Another possibility is that previous trial switch effects could be the result of priming of previous trial information (Logan & Schneider, 2007). That is, previous switch trials could decrease current trial RTs because of less priming of current trial task information. In chapter 3.2, the effect of task recency was examined to determine whether priming of task information could occur several trials back in the face of intervening switches (p. 39). A post-hoc analysis found that a task sequence in which the current task type was more primed did not result in faster RTs. This analysis provides support against the interpretation that priming from several trials past reduces the current RT. Although this finding suggests that task priming does not occur in the face of several intervening trials, it is still possible that priming occurs for specific stimuli within the task (Allport & Wylie, 2000; Wazsak, Hommel & Allport, 2003; 2005).

Priming between a specific stimulus and the task with which it has previously been associated results in competitor interference when the stimulus is later presented with a new task type (Allport & Wylie, 2000; Wazsak, Hommel & Allport, 2003; 2005). This competitor interference persists many (even hundreds) of trials into the future and has been found to contribute to switch costs (Wazsak, Hommel & Allport, 2003). It is possible that dynamic changes in the associations between stimuli and tasks could be the cause of previous trial switch effects. However, this interpretation does not provide an explanation for why switching to the strong task is slower than switching to the weak task. If anything, stimuli that were previously associated with the strong task should show less competitor interference because of more frequent association with that task. Further, this interpretation does not provide an explanation for why previous switch effects occur in the strong task type and not the weak task type.

Another account for previous transition effects is that a previous switch trial increases task retrieval demands on the current trial. In this case, a previous task switch increases interference from previous trial types and therefore, increases current retrieval demands. Further, if task retrieval demands for the current task type are already high (e.g. on weak task trials) then task retrieval demands are not increased further by a previous switch trial. This interpretation is confirmed by the current results. In experiment 3, there was an effect of a previous switch on strong task performance, but no effect of a previous switch when the task type was weak (Figure 19). Further, when the task type was strong, the previous switch effect was reduced on current switch trials (Figure 20). This interaction may be because retrieval demands are already increased when switching away from the weak task and therefore a previous switch trial has less of an affect on current trial retrieval demands. This account provides an explanation for both the asymmetric switch cost and previous transition effects and therefore, is a more parsimonious account.

Although task retrieval demands provide a parsimonious account of switch effects, they still do not explain how a previous switch trial slows current trial RTs or how this effect persists several trials into the future. Koch and Philipp (2005) found that previous trial response selection persists into the next trial and contributes to the current trial residual switch cost. The authors examined switch costs in a go-no go paradigm and found that when the previous trial consisted of preparation alone (as in a no go trial), no residual switch costs occurred. This finding led the authors to conclude that response selection is necessary to produce a residual switch cost and further, they suggest that these costs are due to a persisting activation bias for response rules. When previously activated response rules are different from the currently relevant response rules, then lateral inhibition slows responding (and thereby causes a residual switch cost).

The lateral inhibition of persisting, previously relevant response rules could also provide an account for previous switch effects. This interpretation assumes that persisting activation of previous response rules would remain active in the system for several trials into the future. Monsell, Sumner & Waters (2003) found that when task order is random, a previous switch trial slows RTs on several subsequent trials. However, they also found that this slowing was dependent on the response-stimulus interval (RSI) and only occurred at the short RSI (at an RSI of 50 msec). While this study confirmed that a previous switch effect could persist in the face of intervening trials, it is still not clear why this effect decayed so quickly with time. A possible reason for the steep decay in the previous switch effect could be due to the different trial structure that the authors used. Monsell et al. (2003) used an "alternating runs" paradigm in which a cue appeared at the beginning of a "run" followed by two to eight stimuli of the same task type. This structure allowed the authors to examine the effect of a switch on several subsequent trials of the same task type. Since the task type was not cued on every trial, it is possible that subjects abandoned the previous response rule more quickly (i.e. subjects knew that if the new trial did not start with a cue stimulus then they should continue to perform the previously relevant task). Therefore, the previous switch effect may not have persisted as long in this study due to the differences in the paradigm trial structure (Monsell et al., 2003).

Monsell et al. (2003) also found that the effect of a switch trial only persisted for several intervening trials when the task order was random. For predictable task order trials, there was a large switch cost during the first trial of a run, but no effect of a switch on subsequent trials. This finding suggests that when the task order is known, the effect of a switch does not persist (i.e. there is a large switch cost on the current trial, but no further reduction in RT after the first trial). It is not clear why persisting activation occurs during random task order trials, but not predictable task order trials. One possibility is that persisting activation during random task order trials may play a functional role in keeping response rules accessible in case they could become relevant again on future trials. The results from the Monsell study suggest that persisting activation from previous switch trials may occur only when task selection relies on cuing of unpredictable external stimulus events.

Logan and Schneider (2007) examined higher-order switch effects and found that previous task switches slowed responding even when the effect of a current cue switch was controlled for. Further, they found significant main effects of first order switches (trial n switch cost), second order switches (trial n-1 switch cost), and third order switches (trial n-2 switch cost). The preparation effect significantly interacted with the different task sequences and their paradigm used a similar trial structure and timing as the current experiments: CTIs were between 100 and 800 msec and RCIs were 500 msec. These results confirm that persisting task activation affects several subsequent trials in the cued task switching paradigm.

Current studies do not definitively resolve whether previous switch effects are due to the updating of stimulus-response associations or to the persisting activation of previous response rules. Further research is necessary to resolve this issue. Either way, activity would be increased due to interfering task activation after a switch trial. A number of studies now support the finding that a previous switch trial increases the overall activity level in the system and thereby slows RTs (Brown, Reynolds & Braver, 2006; Logan & Schneider, 2007). These results suggest that when the transition sequence consists of mostly switch trials, task interference and task retrieval demands are increased on each trial. Therefore, the overall activity level is greater for sequences that consist of more task switch trials.

Although previous switch effects were robust in the current set of studies, these effects did not occur during the weak task types. A previous switch trial does not affect task performance under conditions that already elicit high preparation demands due to task interference (e.g. when the task type is weak). Experiments 2 and 3 found that preparation demands are affected by a previous switch trial on strong task trials, but not on weak task trials. The results support the conclusion that interference caused by previous switching increases current trial task retrieval demands, but only if the current task does not already require a high degree of task retrieval for performance. On weak task trials, a high degree of retrieval is necessary in order to reduce interference since the SR associations are stronger for competing tasks (Cohen, Dunbar & McClelland, 1990; Cohen & Huston, 1994; Gilbert & Shallice, 2002;

Badre & Wagner, 2006). Because a high degree of task retrieval is already necessary to perform the weak task types, a previous switch trial does not increase retrieval demands further on these trials.

In the current set of studies, conceptual task retrieval is not separated from the activation of stimulus-response associations. In a previous model of task switching, it was proposed that both of these processes occur at different times during the preparation interval (Badre & Wagner, 2006). In future studies, it would be interesting to determine whether a previous switch trial slows one or both of these processes.

4.3 IMPLICATIONS FOR GOAL-DIRECTED BEHAVIOR

Experiment 1 found that the task preparation demands (including the retrieval and maintenance of task information) that occur ahead of task execution are increased when the cue stimulus is necessary for task selection (i.e. when the stimulus sets are the same and therefore the cue is necessary for task selection). When the appropriate task may be selected upon target stimulus presentation (i.e. when the stimulus sets are different for the different tasks), advance preparation is reduced. The results suggest that processes involving the advance retrieval and maintenance of task information are costly, and therefore may only occur when the task must be selected and maintained in anticipation of the target stimulus

Experiments 2 and 3 found that preparation demands increased due to transition frequency, suggesting that task preparation is affected by the persisting interference from previous switch trials. However, in experiment 3, this interference only increased preparation demands when the task was strong and not when the task was weak. The results suggest that the interference due to task associations in the weak task already increases task retrieval demands and therefore a previous switch trial does not increase these demands further. This result provides further support that switching tasks involves the same processes necessary for general task performance and does not recruit unique processes for changing to a new task type. Monsell et al. (2003) found that previous switch effects occur when task order is random, but not when task order is predictable. Therefore, persisting task activity occurs when tasks are cued by randomly occurring stimuli and this interfering activity may play a role in learning the appropriate task associations in an unpredictable environment.

4.4 CONCLUSIONS

The current set of experiments found that task switch preparation requires a greater degree of recruitment of general task preparation and does not recruit specific processes unique for switching to a new task type. Several experimental factors were manipulated to determine whether they influence preparation on all transition types (on both switch and repeat trials) or whether these factors selectively affect switch preparation. All factors influenced general preparation demands and not switch preparation specifically. The current results suggest that greater preparation demands on task switch trials reflect an increase in task retrieval that occurs due to interference in current task activity.

APPENDIX

EXPERIMENT 4: TASK INSTRUCTIONS AND PREPARATION STRATEGY

Another study was performed to determine whether switch frequency effects could be influenced by subjects' strategic differences. Previous pilot results and studies in the literature (Monsell & Mizon, 2006; Schneider & Logan, 2006) found that switch frequency reduced the preparatory switch cost. However, this was not found in the current paradigm. The current study examined whether task instructions could influence subjects' strategy and thereby influence whether switch frequency selectively affects switch preparation.

In a previous pilot study, subjects received "mapping instructions" when learning the four-task paradigm. This set of instructions first taught subjects how to respond to the stimuli for each task. After subjects learned the SR mappings, task cues were introduced into the trial structure and subjects then practiced the task using all four cues. These instructions were presented in a computer experiment. Before testing the current study, it was found that subjects learned quicker when given verbal instructions of how to respond to each task. For the current experiments, subjects were given "verbal instructions" in which the experimenter described the four tasks and how the subject should respond on each task. For both sets of instructions, the practice and experimental procedure was identical (as described in Chapter 3.0). The only difference between the two procedures was the initial set of instructions given to subjects.

For the current experiment, it was hypothesized that when subjects were initially taught with the mapping instructions that they might not form a "task set" when switching is frequent. Instead subjects might adopt a strategy of responding to each cue as if it were an individual task and therefore additional task retrieval demands would be necessary during task repeat trials since subjects would retrieve the task as though the task had switched. This strategy would result in a reduction in the preparatory switch cost when switch frequency is high.

Methods

Subjects:

12 subjects performed the four-task version of the task switching paradigm. Subject recruitment, compensation, and testing conditions were the same as specified for previous experiment. All subjects performed the experiment for two hours.

Materials:

All testing was conducted on pc computers running E-Prime software (Schneider, Eschman, & Zuccoloto, 2002) for experimental presentation and data acquistition.

Procedure:

The same four-task variant of the classic Rogers & Monsell (1995) task switching paradigm, used in Experiment 1, was used again in Experiment 2. All experimental parameters were the same as in Experiment 1, except that the task instructions were different. All subjects received the "Mapping Instructions" through the instruction of an E-Prime computer experiment. Subjects were taught initially taught the stimulus-response (SR) mappings for each task individually. During this initial training procedure, subjects were only presented with target stimuli. Then, after learning the SR mappings, they learned the cues that indicated the task. During the instructions, subjects performed four stimulus-mapping trials with each task and four additional full-trials with each task. After the instructions, subjects performed a practice block, which included 96 trials of all four tasks.

For the rest of the four-task experiments described in Chapters 2 and 3, "Verbal Instructions" were given to a subject using an instruction sheet. The experimenter read through the instruction sheet with the subjects. Subjects were told that they would perform the "Odd/Even, Low/High, Vowel/Consonant, and Before/After" tasks. They were then told that they would first see an instructional cue and then they would see a number or letter stimulus. The experimenter emphasized that the subject should respond to the number or letter stimulus and that the instructional cue only informed them which task to perform. Subjects were then told the response mappings and followed through 3-4 example trials on a chalkboard with the experimenter.

After instructions, subjects performed a practice block of 96 trials. The practice block was identical to that administered to subjects in the "mapping instruction" procedure. All four tasks were practiced and the practice block contained the transition expectancy that the subject would perform during the upcoming four experimental blocks.

Results

Results were examined for the dependent measures of RT and accuracy. 3-way ANoVAs were performed for the factors transition frequency (2 levels: repeat frequent, switch frequent), transition (3 levels: cue repeat, task repeat, task switch), and CSI (4 levels (100, 300, 500, 900). All factors were manipulated within-subjects.

For both dependent measures, there were no significant effects including the switch frequency factor. For the RT measure, there was no main effect of transition frequency [$F(1, 11) = 1.989$, $p = 0.186$], no interaction between transition frequency and CSI [$F(3, 33) = 0.228$, $p = 0.876$], and no 3-way interaction between transition frequency, transition, and CSI [$F(6, 66) = 1.285$, $p = 0.276$]. There was a trend toward a significant interaction between transition frequency and transition [$F(2, 22) = 2.769$, $p = 0.085$]. For the accuracy measure, there was no main effect of transition frequency[$F(1, 11) = 1.002$, $p = 0.337$], no interaction between transition frequency and CSI [$F(3, 33) = 1.001$, $p = 0.404$], no interaction between transition frequency and transition [$F(2, 22) = 0.992$, $p = 0.386$], and no 3-way interaction between transition frequency, transition, and CSI [$F(6, 66) = 1.004$, $p = 0.430$].

Discussion

The current study explored whether the reduction in switch preparation when task switching is frequent may be the result of the task instructions and the resulting strategy that subjects adopt while learning the task. The results suggest that the task instructions do influence switch frequency effects. However, switch frequency did not affect switch preparation in the direction that was predicted. The current set of instructions did not produce a reduction in the switch preparation effect when switch frequency is high.

Subjects overall performance was improved compared to when they received the "verbal instructions" procedure. Overall mean RTs with the "verbal instructions" were 848 msec (SE 88 msec), whereas the overall mean RTs for the "mapping instructions" were 718 msec (SE 101 msec). This suggests that training and subject strategy influence switch frequency effects however, these factors do not fully account for the difference between the findings reported in Chapter 2 and the switch frequency effects found in the literature (Monsell & Mizon, 2006; Logan & Schneider, 2006).

Table 1. Parameter Values Used to Model the Effects of Transition Frequency and Task Preparation.

μ^{CRn}	μ^{TRn}	μ^{TSn}	μ^{TSn-1}	RT_{base}
110.3	175.9	294.2	255.3	683.9

Table 2. Parameter Values Used to Model the Effects of Task Strength, Transition Frequency and Task Preparation.

μ^{CRn}	μ^{TRn}	μ^{TSn}	μ^{Infn}	μ^{TSn-1}	RT_{base}	μ^{Infn-1}
185.4	239.8	288.8	1.1	39.0	646.8	3.1

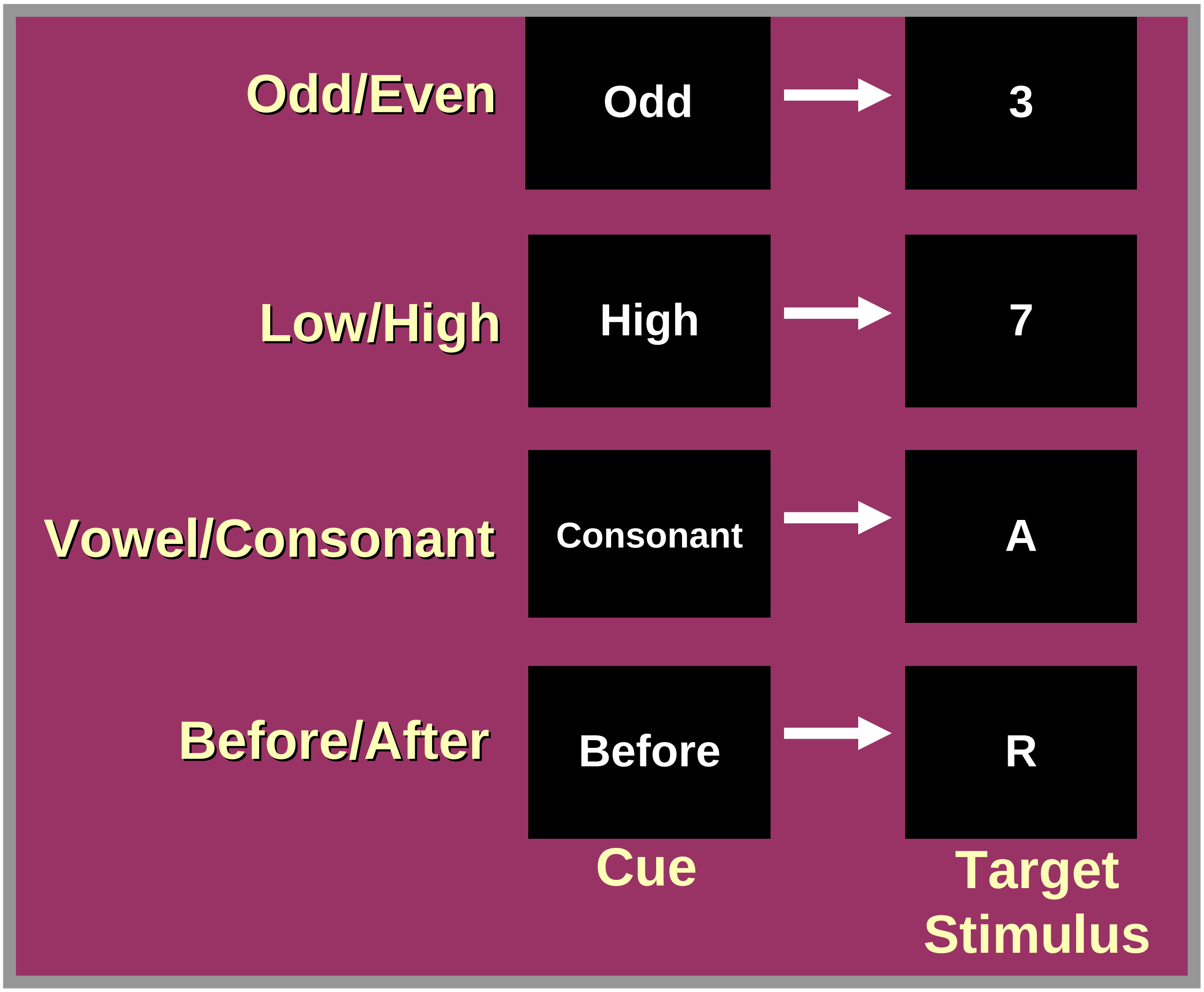


Figure 1. Four possible tasks used in the two-task and four-task paradigms. For the two-task paradigm, each subject performed two out of the four tasks. The two tasks were randomly assigned to subjects and the same two tasks were performed in all blocks. For the four-task paradigm, subjects performed all four tasks in all blocks.

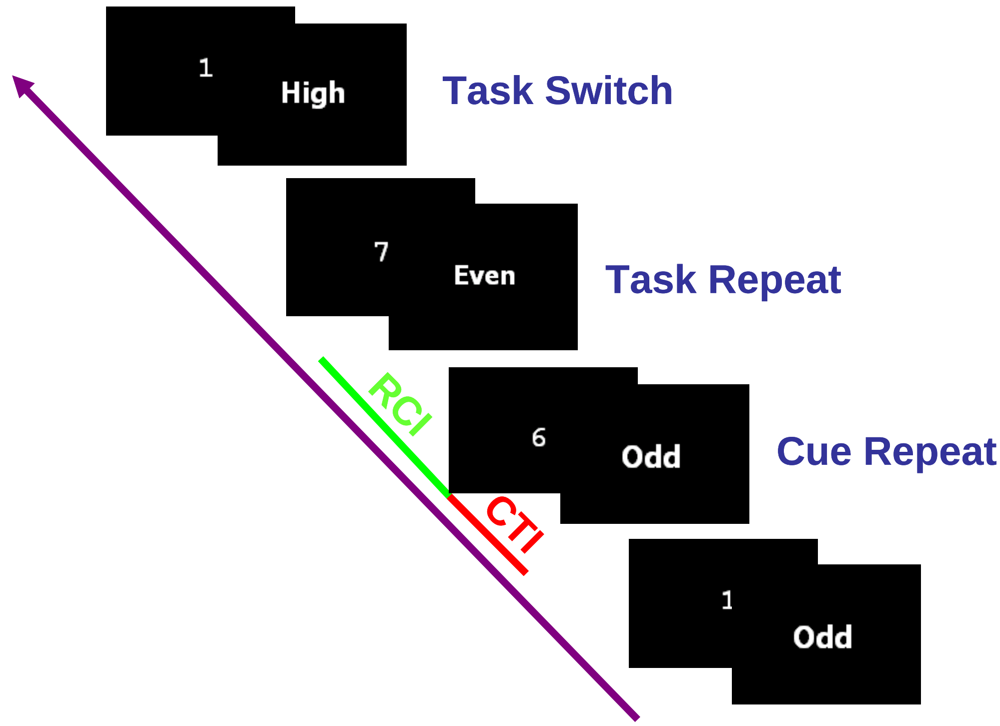


Figure 2. **Paradigm Design.** Example cue and target events for each transition type. Each cue and target stimulus were separated by a variable Cue-Target Interval (CTI). The response on trial n and the cue on trial n-1 were separated by a variable Response-Cue Interval (RCI).

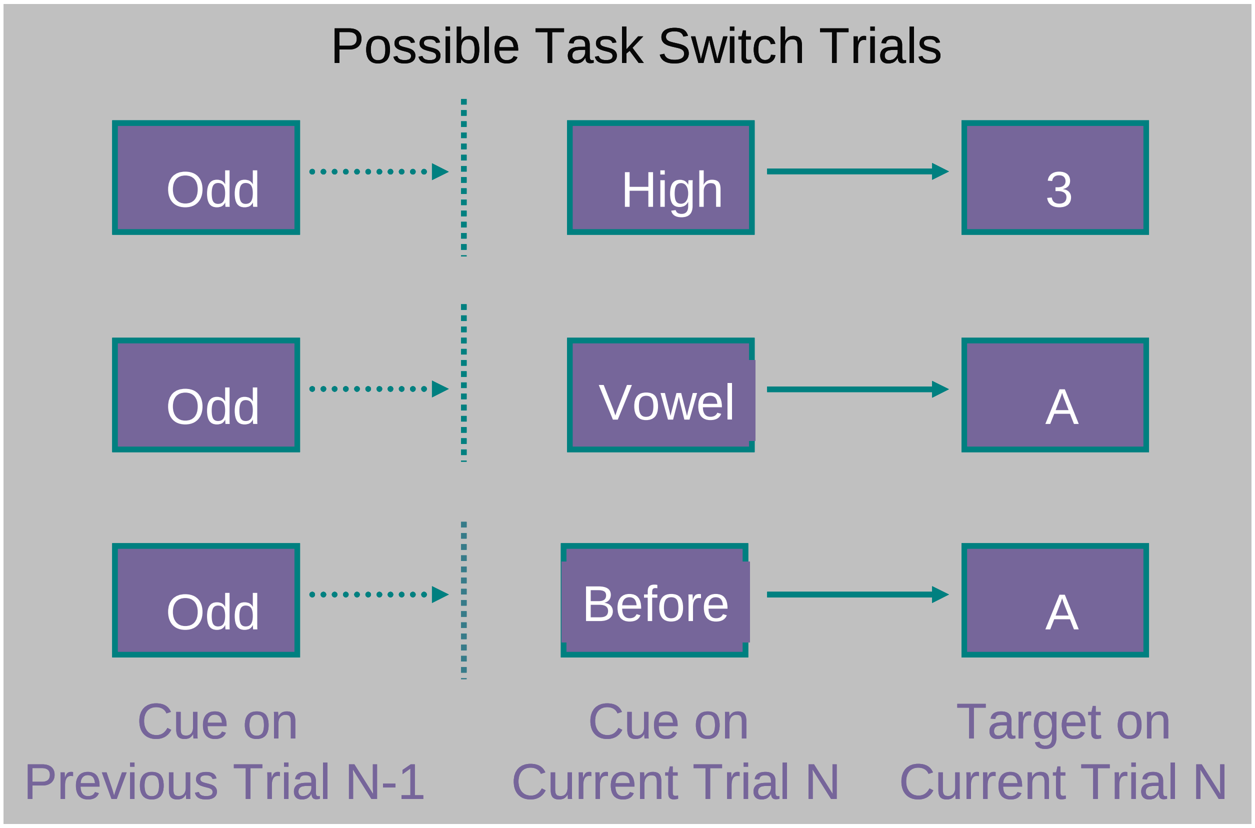


Figure 3. 4-Task Paradigm. Upcoming Switch Type. In the 4-task paradigm, there are three possible tasks that may be presented on a switch trial. In the switch frequent condition, the upcoming switch type cannot be anticipated.

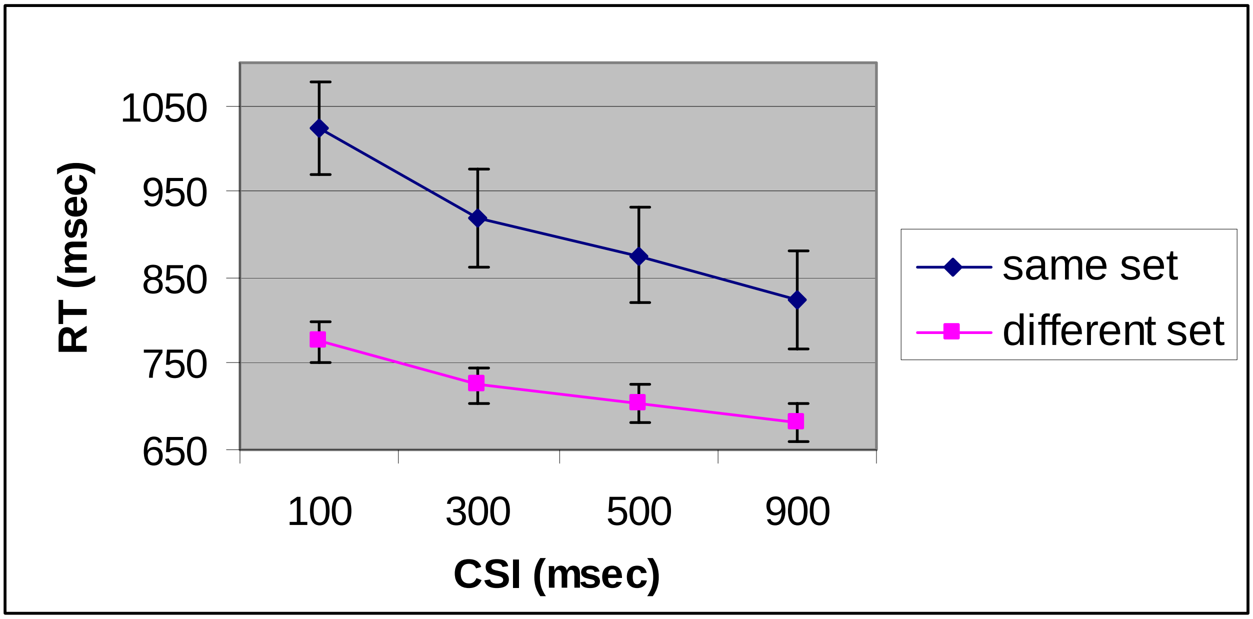


Figure 4. Set Overlap by Preparation Interval. The preparation effect is greater when subjects' perform two tasks with the same target stimuli (same set) than when subjects perform two tasks with different stimulus sets.

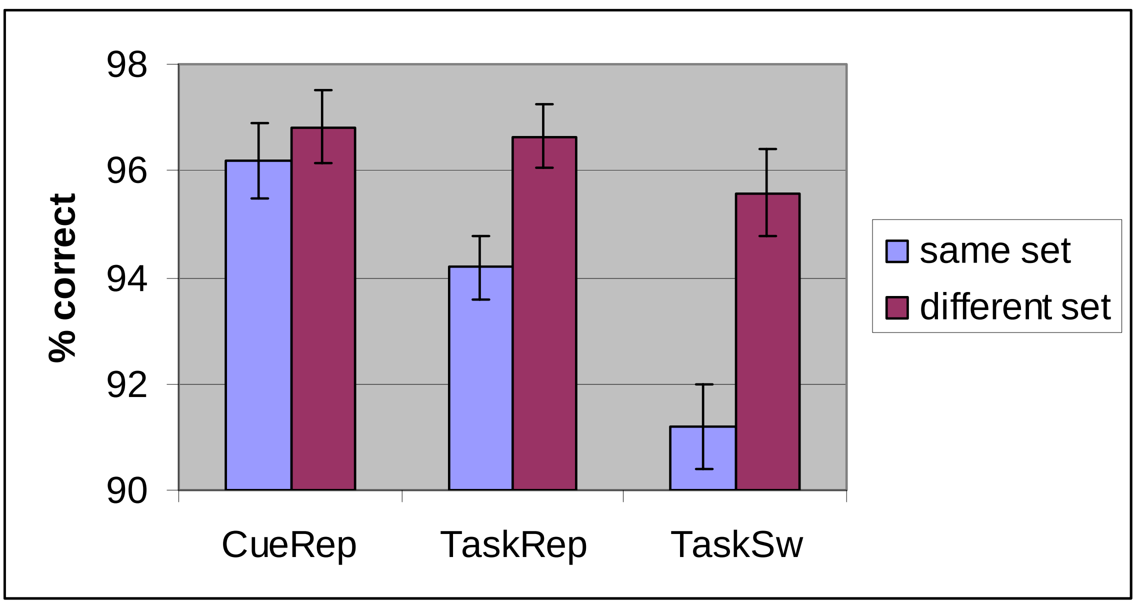


Figure 5. Set Overlap by Transition Accuracy. Performance was significantly worse for two tasks of the same set on task repeat and task switch trials.

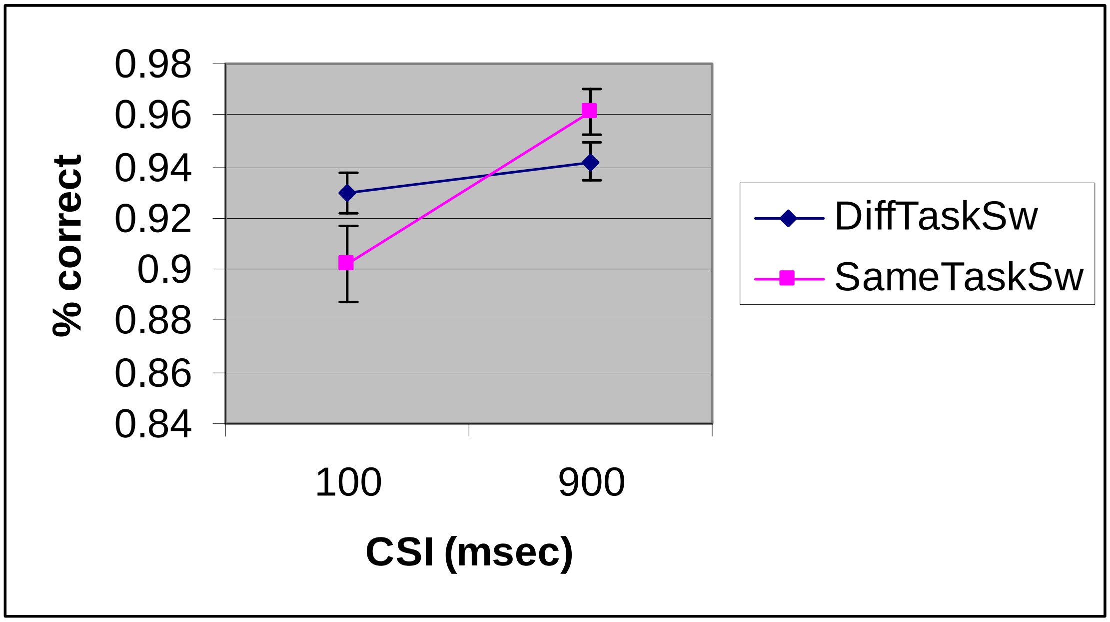


Figure 6. Four-Task Paradigm Task Switch Trials: Set Overlap by Transition Accuracy. Performance on task switch trials showed a greater improvement with preparation when the stimulus set overlapped than when the stimulus set was different.

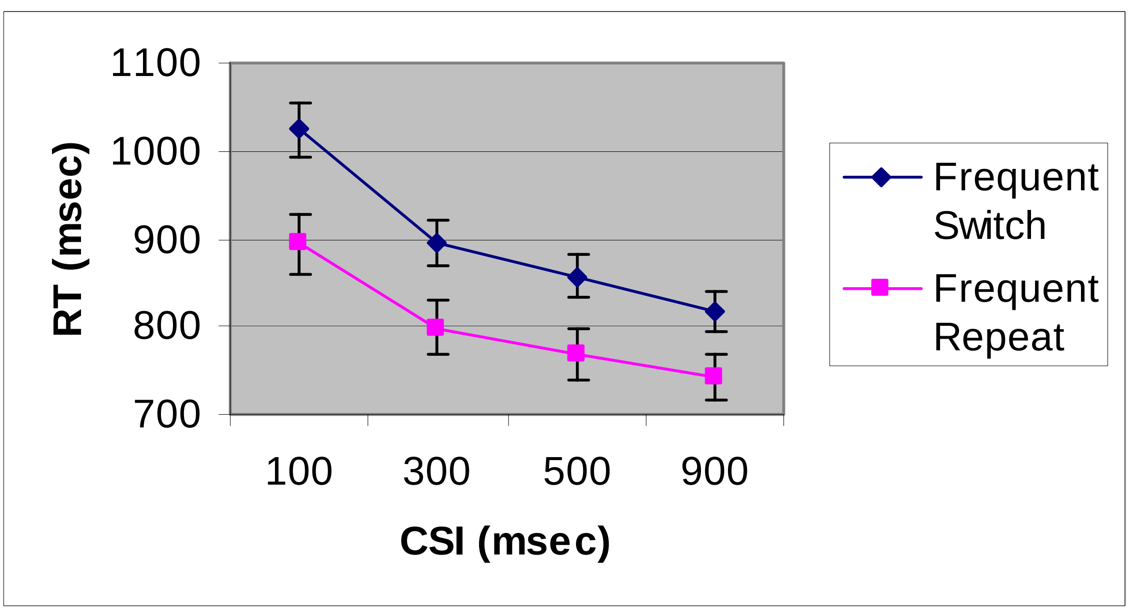
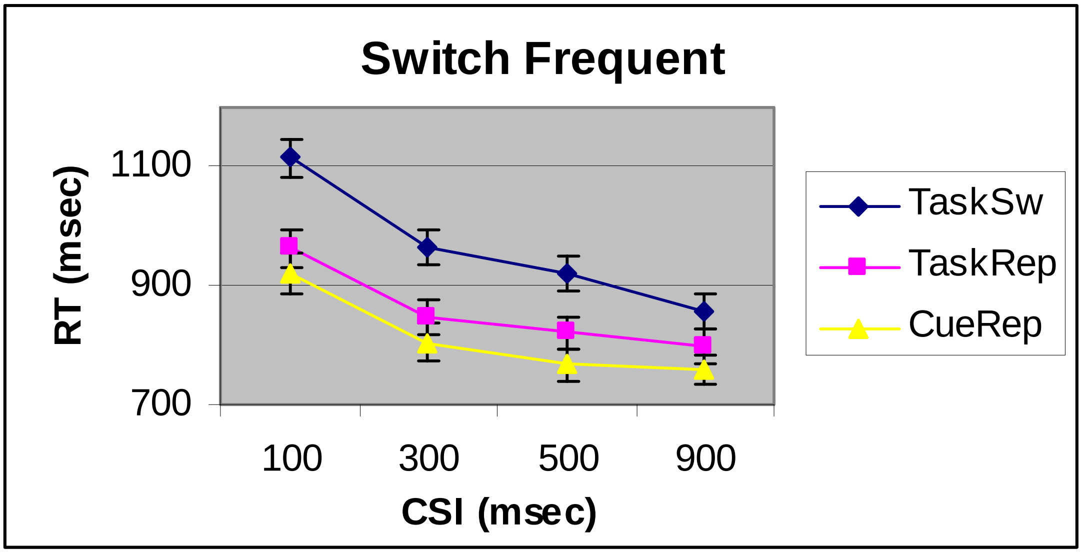


Figure 7. Four-Task Paradigm: Transition Frequency and Preparation Interval RT Interaction. The preparation effect was larger when task switch trials were frequent.



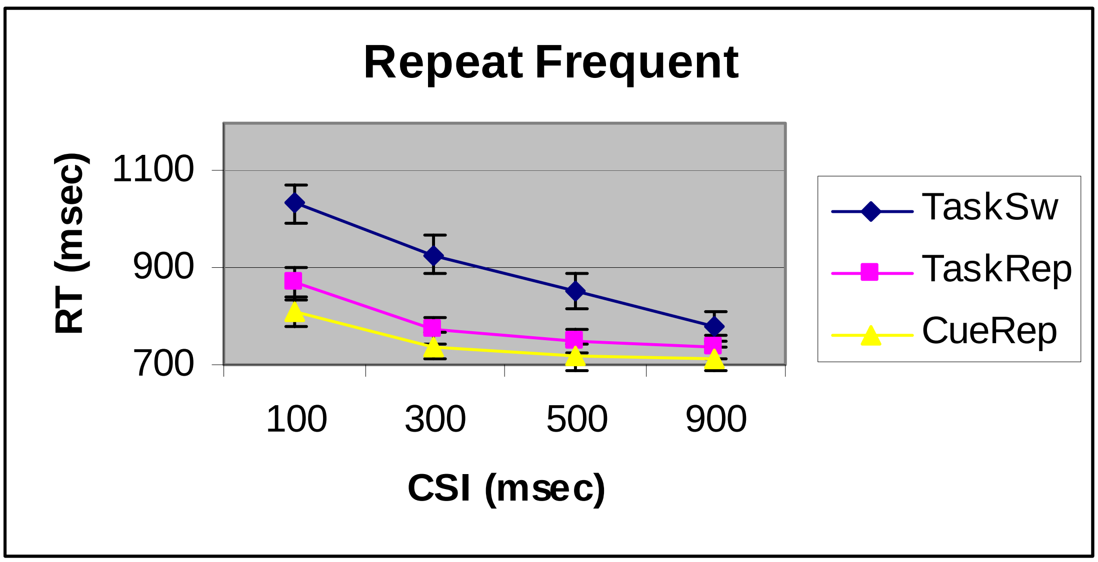


Figure 8. Four-Task Paradigm: 3-way Transition Frequency, Transition and Preparation Interval RT Interaction.

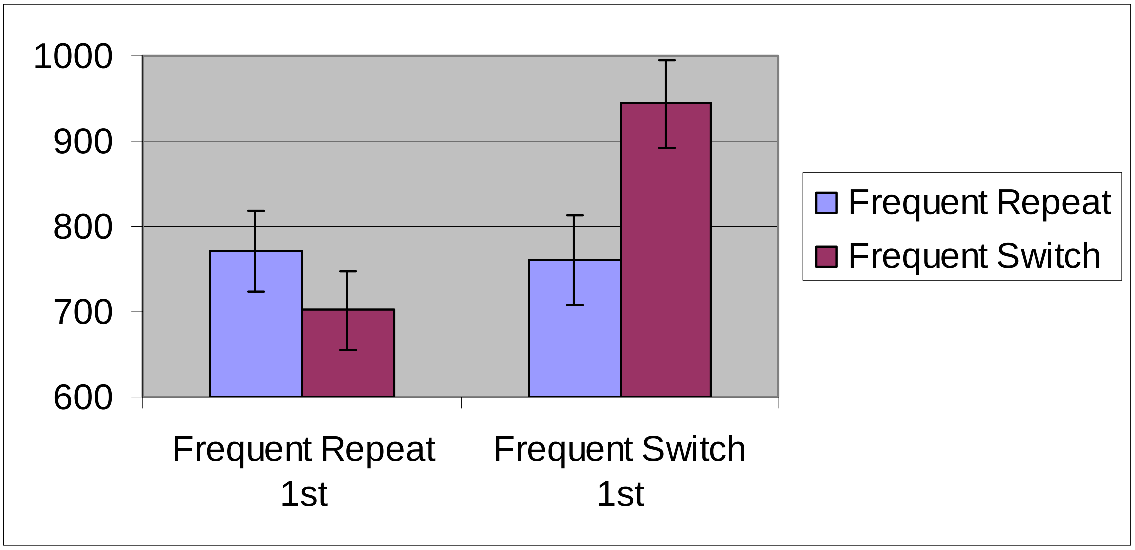


Figure 9. Two-Task Paradigm: Frequency Order and Transition Frequency. RT is significantly slowed during frequent switching when this condition is performed first. However, when switch frequency is performed second, practice significantly decreases RT.

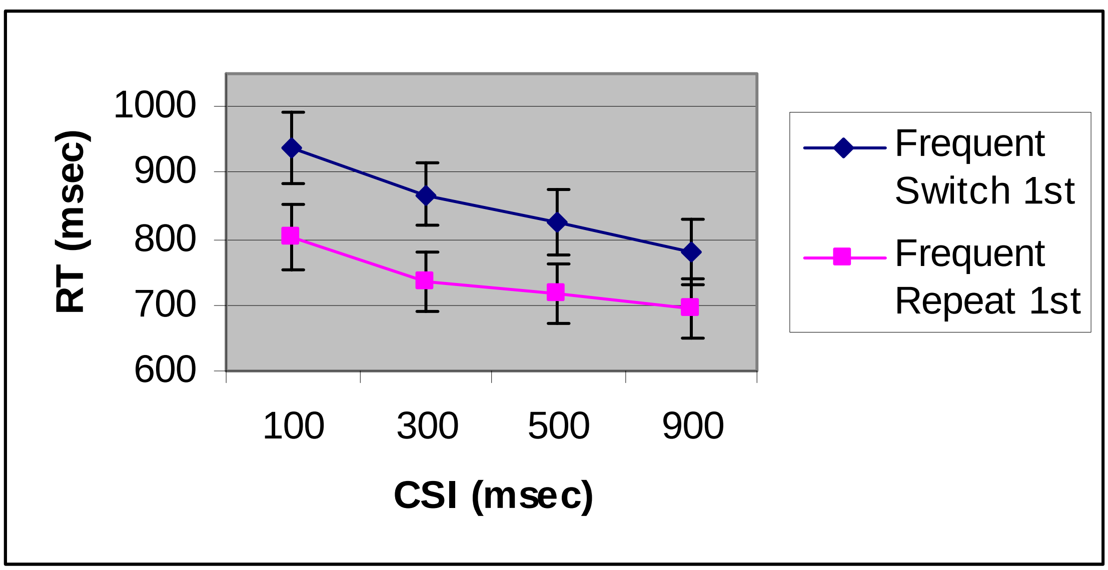


Figure 10. Two-Task Paradigm: Frequency Order and CSI. The preparation effect is larger when subjects performed the frequent switch condition first.

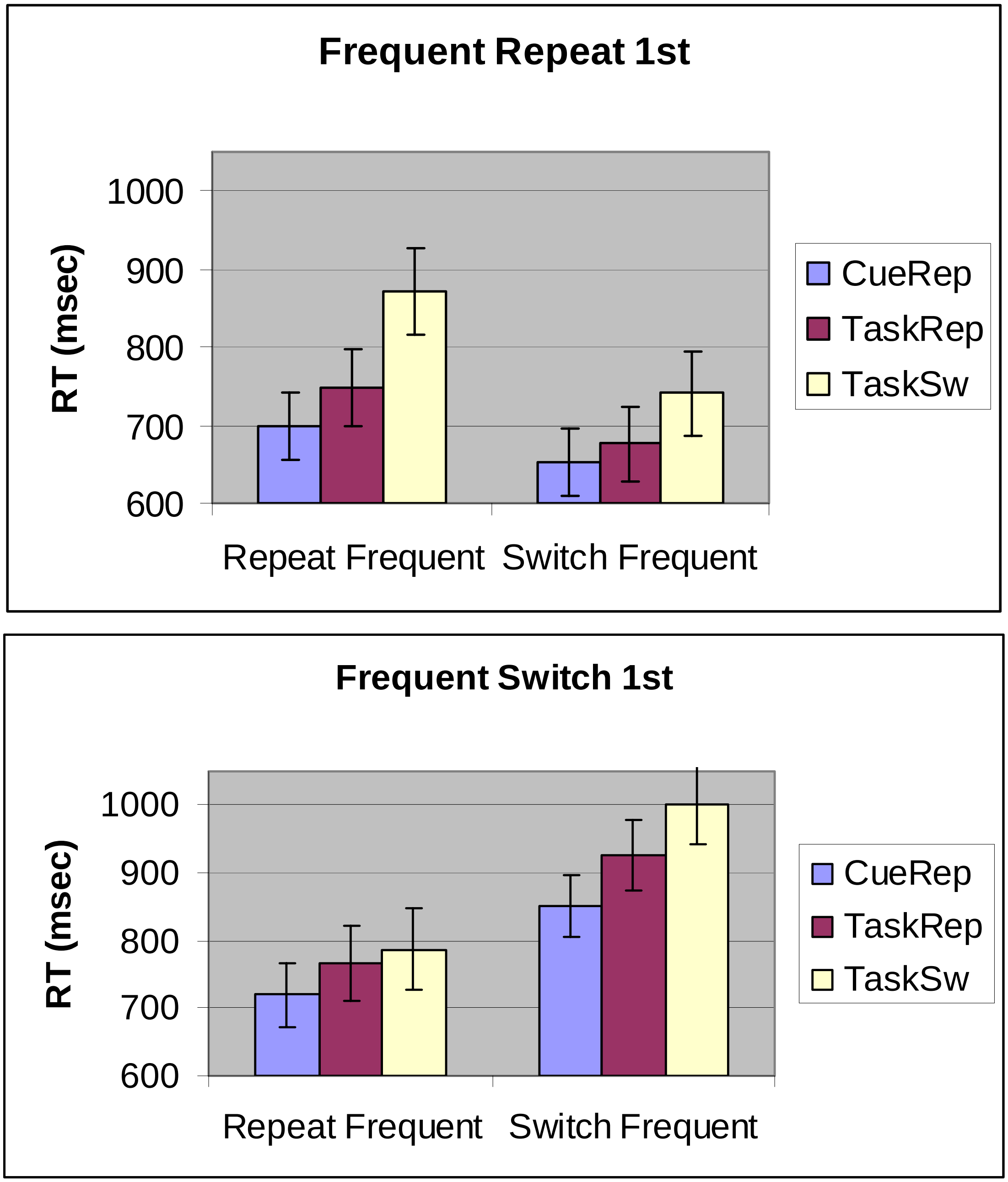


Figure 11. Two-Task Paradigm: Frequency Order, Transition Frequency and CSI. The switch cost is larger for the frequent repeat condition when frequent repeat blocks were performed first.

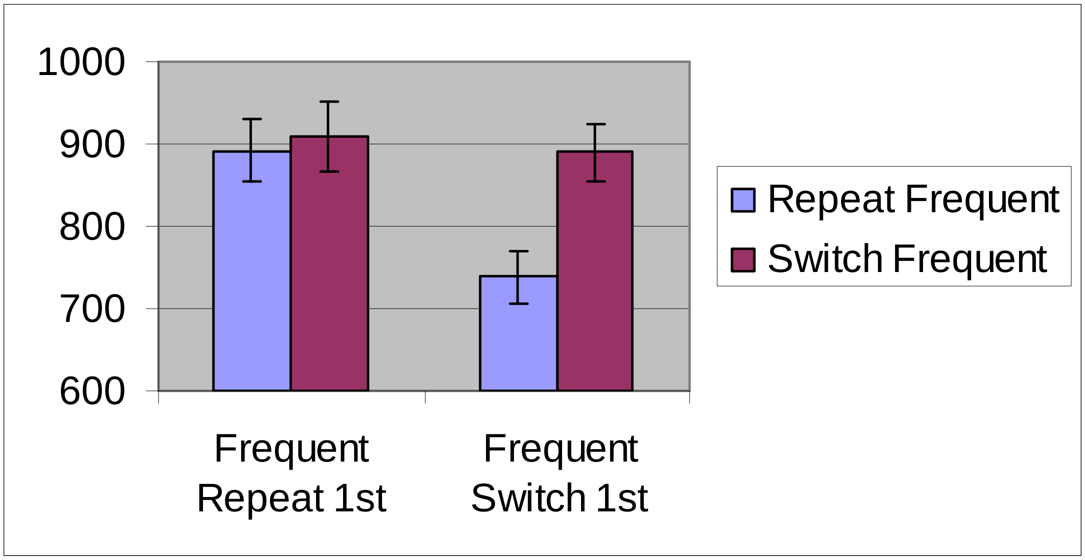


Figure 12. Four-Task Paradigm: Frequency Order and Transition Frequency. In the four-task paradigm, overall RTs are reduced when the repeat frequent blocks are performed second. Overall RTs are not reduced by frequency order in the frequent switch condition.

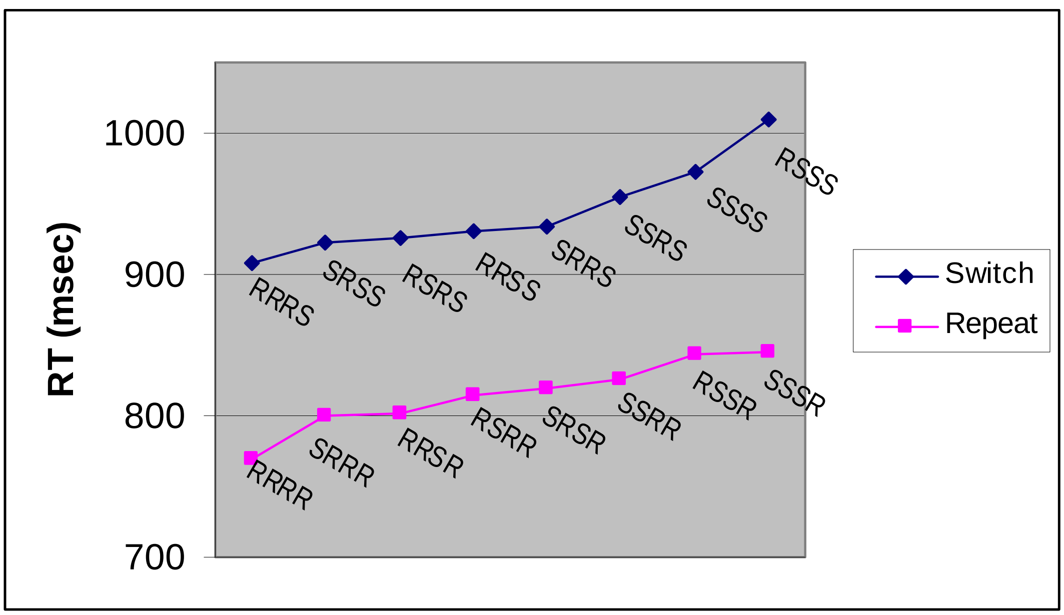
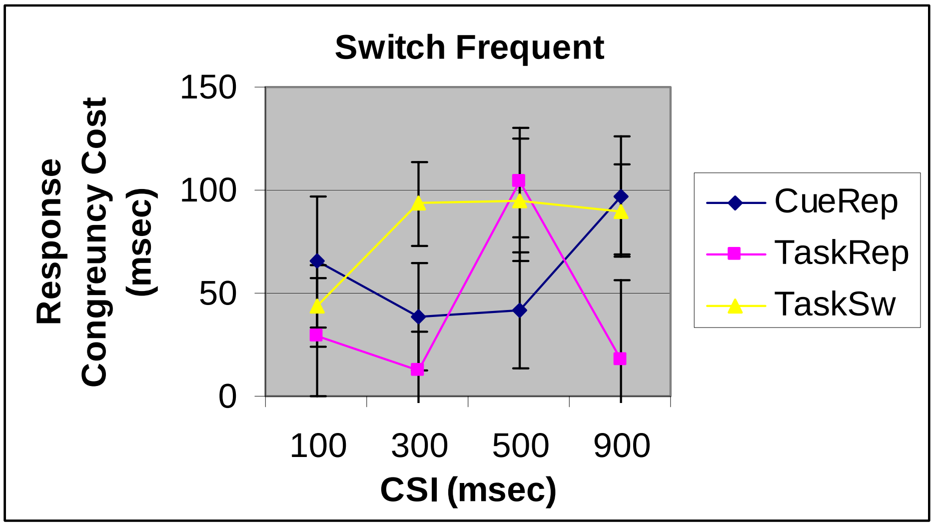


Figure 13. Four-Task Paradigm: Transition History. Higher-order transition effects occur. The RT on the current trial is still affected by a previous transition three trials ago.

Figure 14. Four-Task Paradigm: Cue-Target Congruency. Cue-target congruency is increased on switch trials when switching is frequent.



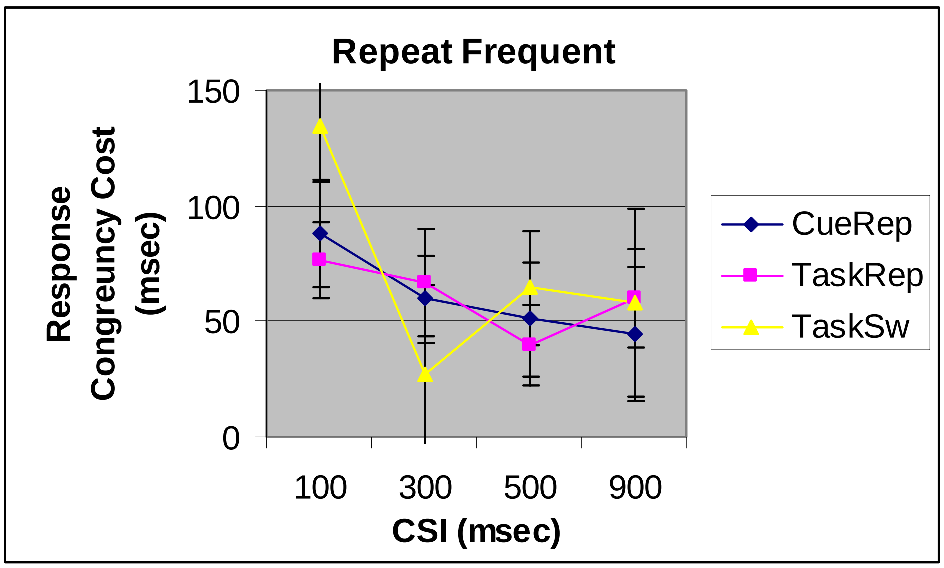
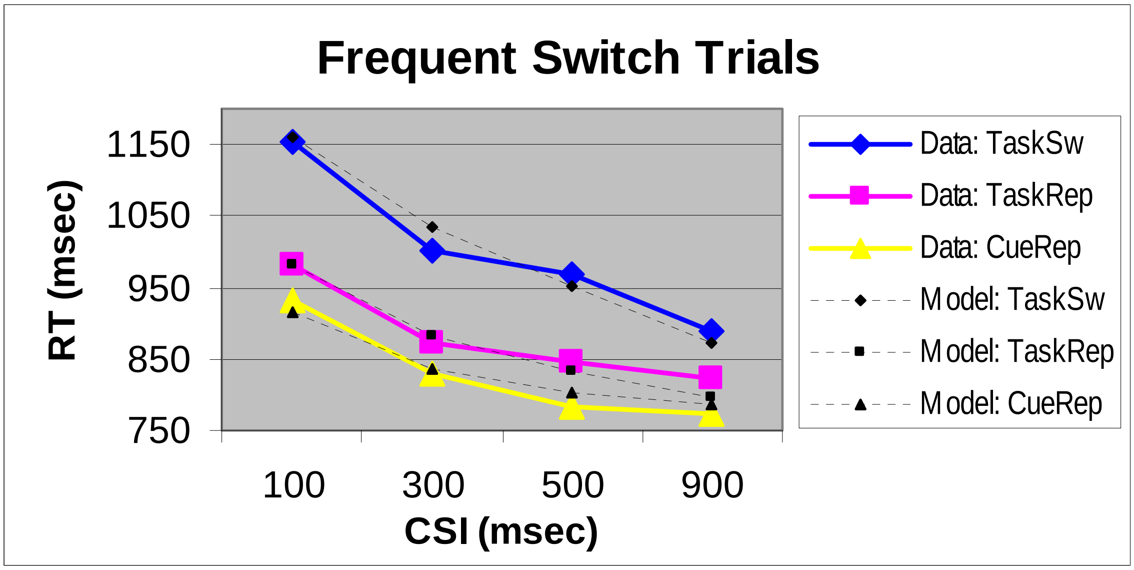


Figure 15. Four-Task Paradigm: Response Congruency. Cue-target congruency is increased on switch trials when switching is frequent.



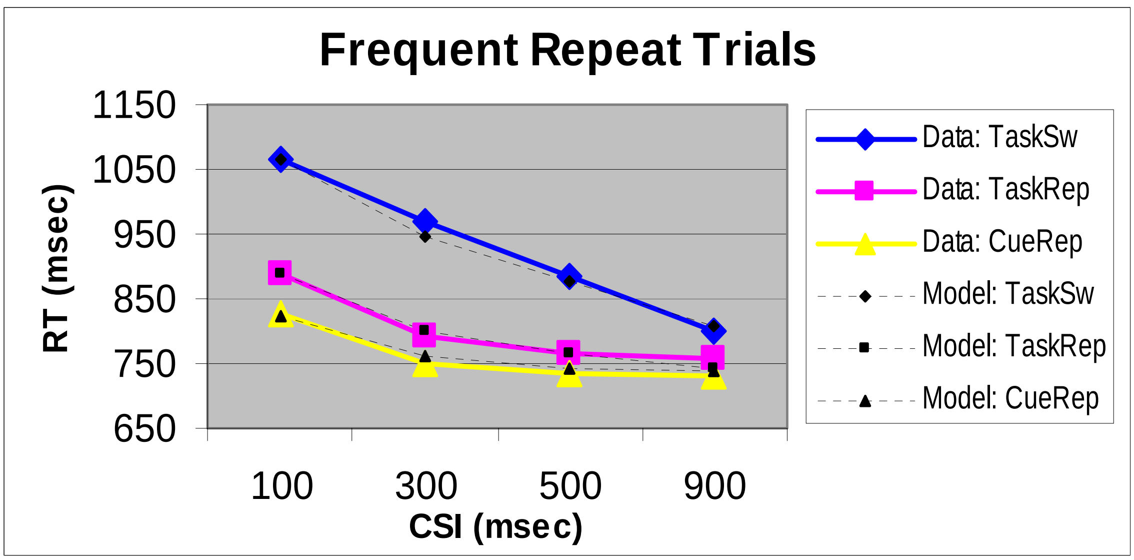


Figure 16. Four-Task Paradigm: Transition Frequency, Transition and CSI Effects Generated by the Model of Task Activation. The values generated by the model are overlaid on the actual data values.

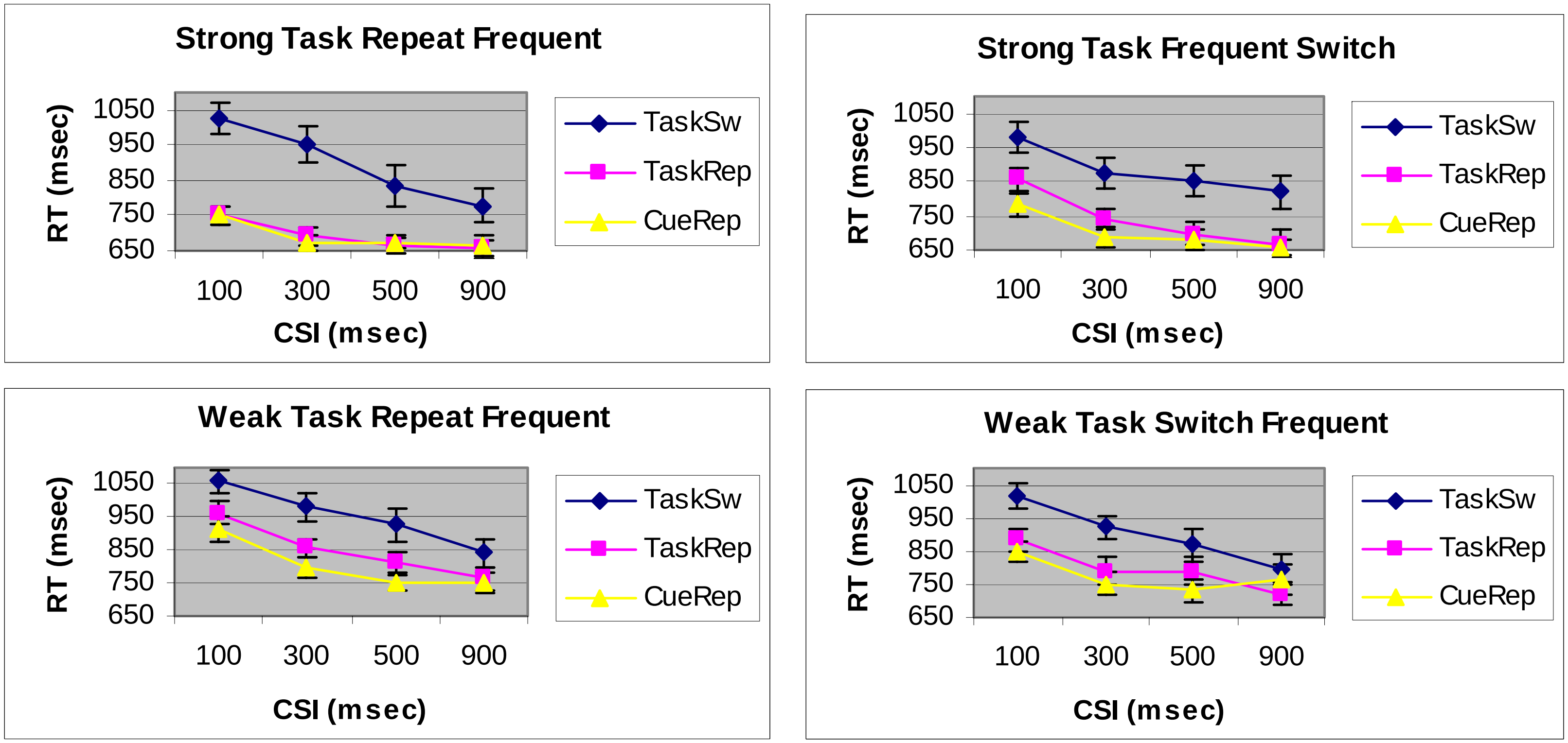


Figure 17. Experiment 3: Task Strength, Transition Frequency, Transition and CSI Interaction.

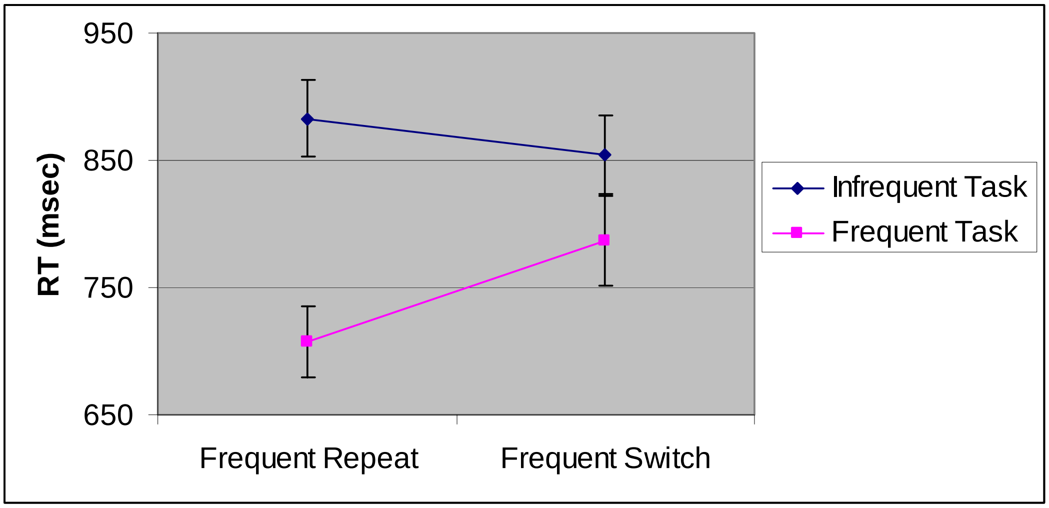


Figure 18. Task strength by Transition Frequency RT Interaction. In the strong task, RTs were slower for the frequent switch blocks. In the weak task, there was little or no switch frequency.

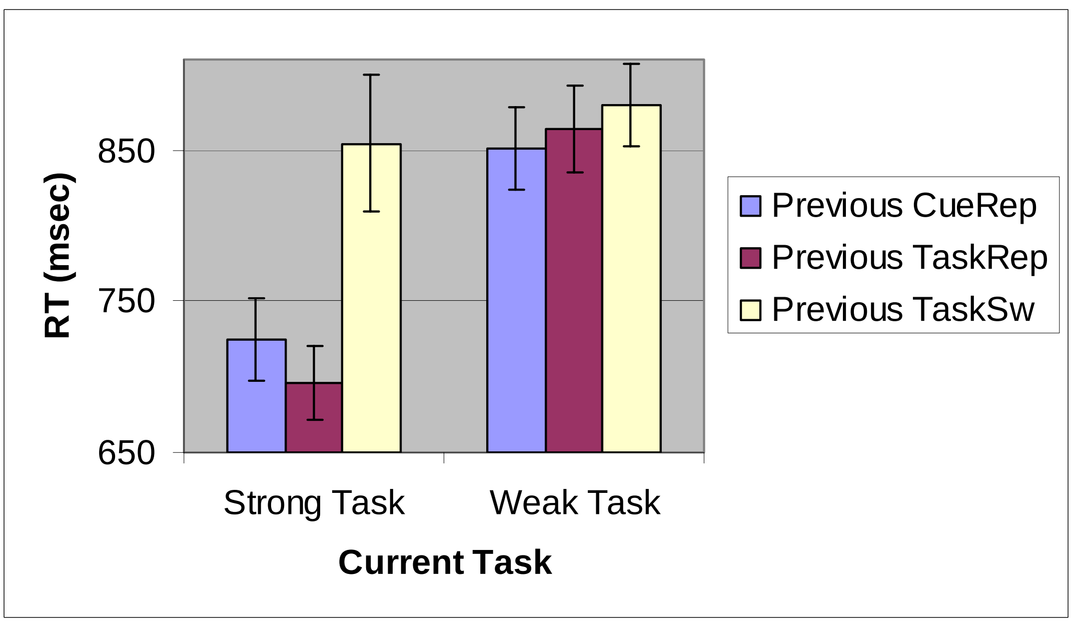


Figure 19. Task strength by Previous Transition RT Interaction. In the strong task, RTs were slower when preceded by a task switch trial. In the weak task, a previous switch trial had little or no effect on the current trial RT.

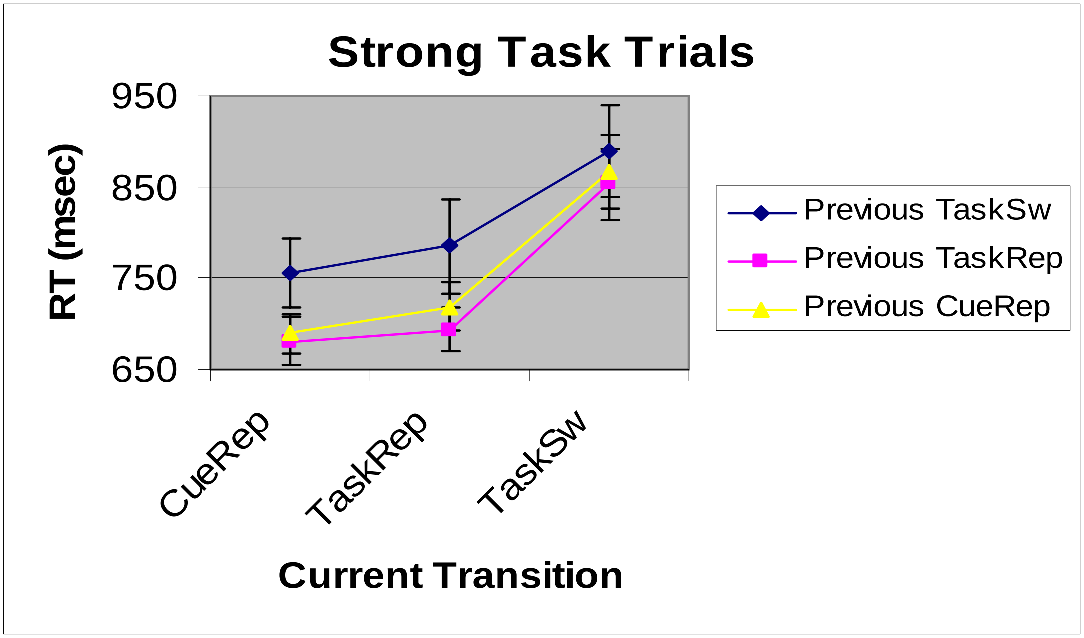


Figure 20. Strong task Trials: Current Transition by Previous Transition RT Interaction. In the strong task, there was little or no previous trial switch effect when the current trial was a switch trial.

Figure 21. Example of Task Sampling Within the Repeat Frequent and Switch Frequent Blocks. The upper row illustrates an example of the transition history while the lower row illustrates the corresponding task history. R and S refer to repeat and switch trials. F, I1, I2 and I3 refer to the strong task and the three weak task types.

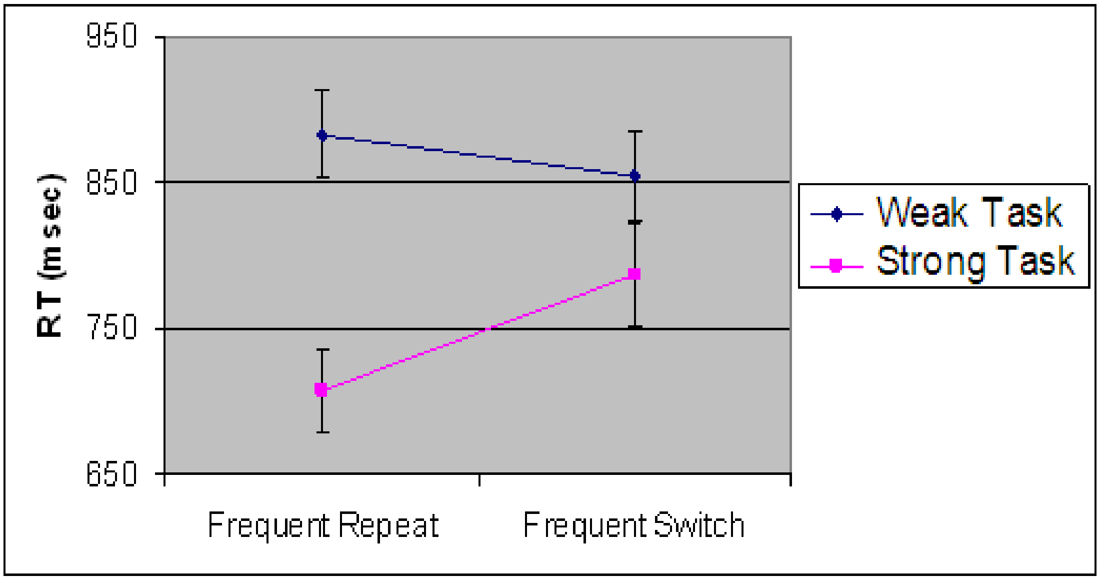


Figure 22. Task Strength and Transition Frequency Interaction in the Response Congruency Measure.

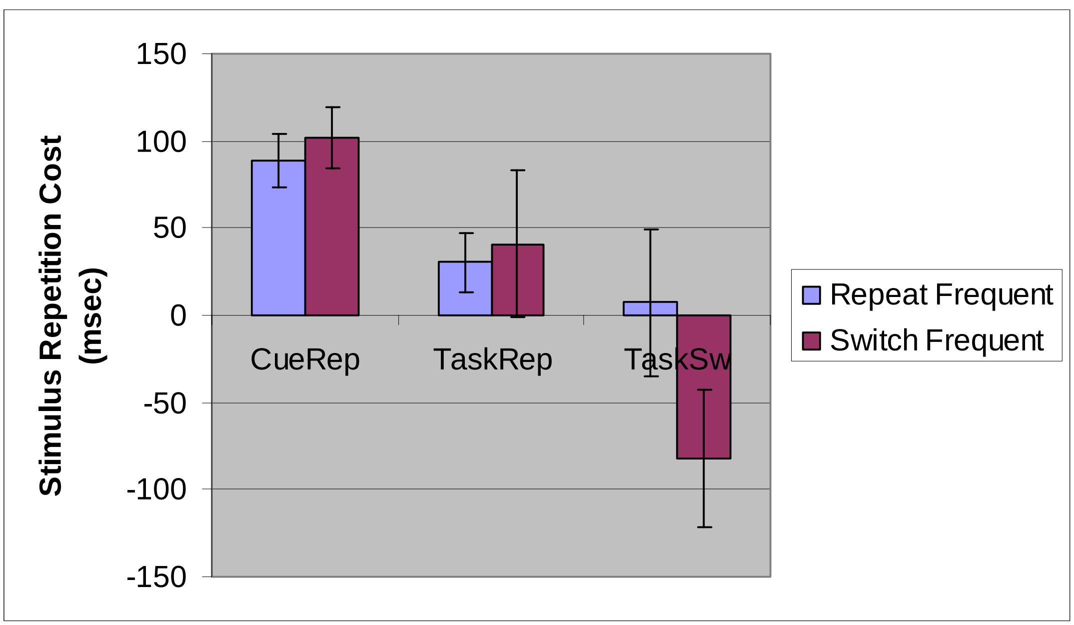


Figure 23. Transition Frequency by Transition Interaction in the Stimulus Repetition Measure.

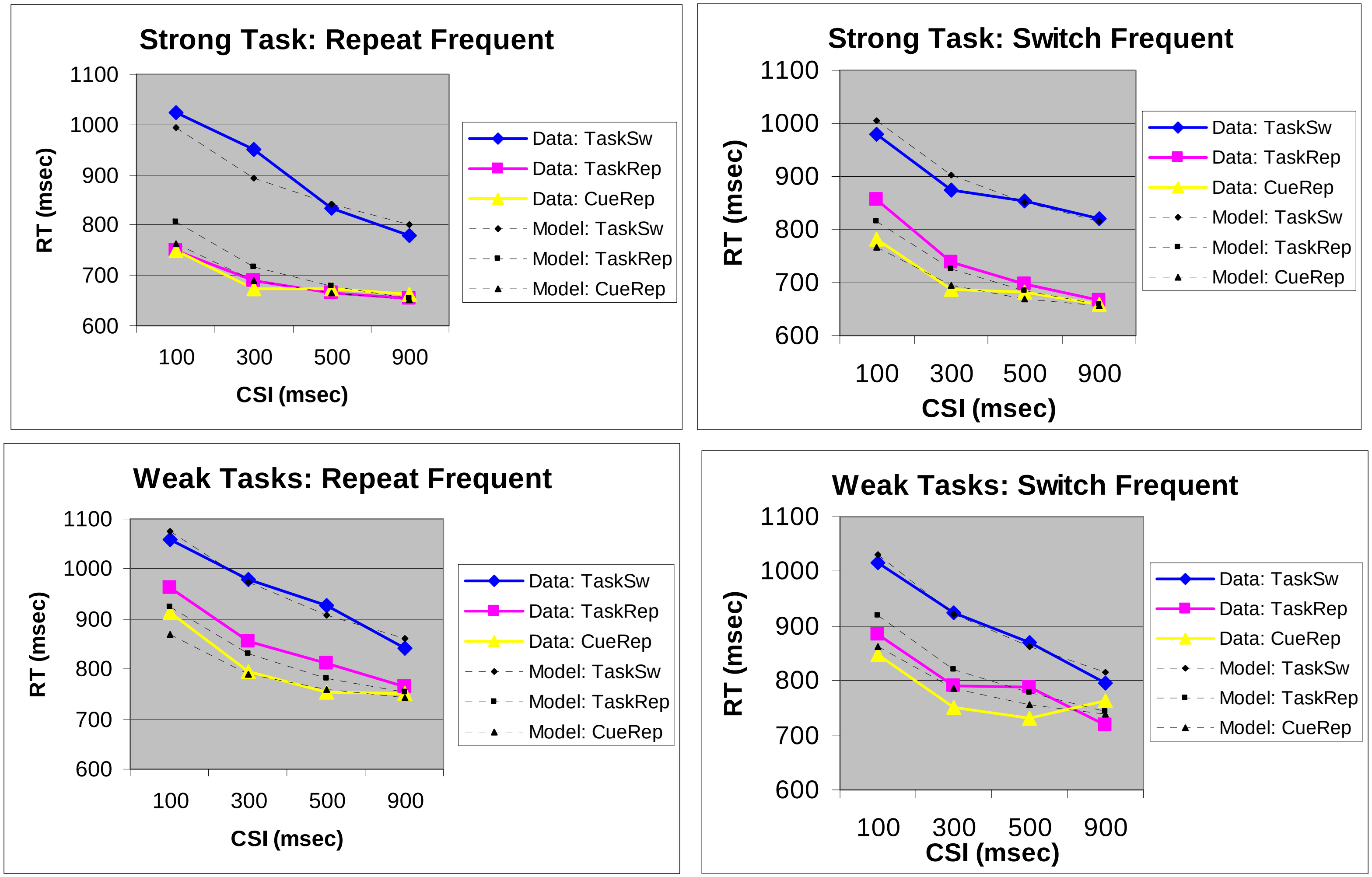


Figure 24. Four-Task Paradigm: Task strength, Transition Frequency, Transition and CSI Effects Generated by the Model of Task Activation. The values generated by the model are overlaid on the actual data values.

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