On the Control of a Control Process: Speed-Accuracy Trade-offs and Task-Switching Costs

by

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Abstract

Previous research suggests the contribution of a unitary supervisory control mechanism in task-switching. Since any change in the response-stimulus interval (RSI) between tasks affects the time available for task-set reconfiguration, switch costs are highly influenced by changes in RSI. However, increasing RSI can not completely remove the switch costs, which has been attributed to automatic control processes. Considering these contributions, speed, accuracy, and their corresponding trade-off (SAT) have been investigated in this study. In Experiment 1 and 2, 28 single-session and 10 multiple-session participants switched between different (or repeated similar) tasks with either short (200 ms) and long (2000 ms) RSIs. Within 8 blocks of 64 trials containing pairs of letter and digit categorization tasks, the contribution of SAT to task-switching was studied by giving the participants either speed or accuracy emphasis instructions at the beginning of each block. Results showed reductions in switch costs during the long RSI trials. However, the long RSI could not remove the residual switch cost. Speed-emphasis instructions resulted in faster responses but higher number of errors in short and long RSIs for both switch and repeat trials in comparison to accuracy emphasis. Moreover, RT switch costs at both short and long RSIs were reduced under speed emphasis, but only for the more practiced participants in Experiment 2. In Experiment 3, actual SAT curves were generated for 9 multiple-session participants using the response signal method. Reconfiguration costs at both short and long RSIs were implicated by shifts in the intercept of the SAT curve for switch trials with incompatible stimuli.

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Introduction

Although people are able to perform different tasks concurrently, to increase the quality of their performances, they usually opt to do just one task at a time. To explore how different tasks might be performed, complex models have been developed by cognitive psychologists. However, as Meiran (1996) noted, much less attention has been focused on an understanding of the process of switching between tasks.

Executive and automatic control processes regulate human cognition while it is involved with completing different tasks. While executive control is intentional, goal-directed, and voluntary, automatic control is associated with performing a certain sequences of actions without any direct (and conscious) control of the ongoing stages. Because of the obvious involvement of control in the co-ordination of behaviour, the manner in which executive and automatic control mechanisms contribute when people rapidly switch from one task to another task has been an important issue in the "task switching" literature. Knowledge about the co-operation of executive and automatic control on simple tasks should be the key to a better understanding of more complex and organized actions.

In addition, the time required to perform a task has been a salient as well as a common dependent variable in cognitive psychology. Typically, reductions in both reaction times and errors are considered as a good indication of ease of processing. However, sometimes reductions in reaction time are accompanied by increases in error rates and vice versa. Indeed, emphasis on either speed or accuracy can result in reductions in the other. Depending on the performance goals, each of these two variables can be traded off.

Typically, such tradeoffs are assumed to be due to strategic influences on decisional processing. Hence, it is an interesting question as to whether control processes, such as those responsible for task switching are susceptible to such tradeoffs. This question will be examined in this thesis.

In addition, speed-accuracy tradeoff (SAT) functions can be studied directly to identify speed-accuracy relations at different times and levels of accuracy. In this thesis, such methods will also be used to examine the time course of control processing in task switching.

Hence, after reviewing some fundamental work in the area of task-switching, different concepts, methods, and models with respect to the speed-accuracy tradeoff will be considered, leading to the proposed work examining aspects of task-switching in conjunction with speed-accuracy tradeoffs.

Review of the Task-Switching Literature

Original Work

Some very early task-switching work was first performed by Jersild (1927). In his study, participants worked their way through lists of items printed vertically down a sheet of paper. Responding was based on either performing the same mental operation for all items (i.e., pure-task lists) or alternating between performing two different types of operations from item to item (i.e., mixed-task lists). Examples of such mental operations were subtracting three from two-digit numbers or giving the opposites of words.

It was not until Spector and Beiderman (1976) that this line of study formally reappeared in the literature. These researchers essentially replicated much of Jersild's original work under more modern conditions in which the stimulus items were presented to the participants individually in successive fashion rather than in one big simultaneous list. The first thing that Spector and Beiderman found (in Experiments 1 and 2) is that a reaction time (RT) advantage for mixed- over pure-task responding that was present in Jersild's (1927) results when the two tasks involved very different kinds of stimuli (i.e., numbers or words) did not occur when the opportunity for previewing the subsequent stimulus items was eliminated by presenting the items for response one by one. Secondly, Spector and Beiderman found (in Experiments 3 and 4) that a RT disadvantage for mixed- over pure-task responding that Jersild (1927) also found when the two tasks involved responding differently to the same stimuli (i.e., subtract three or add three to two-digit numbers) was, indeed, a very robust phenomenon. Namely, in comparison to a 35 ms per item increase in RT for mixed- over pure-task responding observed in

Experiment 2, these conditions induced a corresponding task-shift loss of 402 ms per item in Experiment 3, which was then reduced to 188 ms per item in Experiment 4 by presenting the operation to be performed along with the stimulus items (i.e., "-"or "+"). This set of findings led Spector and Beiderman (1976) to conclude that a main determinant of a task-shift loss is the degree to which the stimuli unambiguously cue the mental operations required by each of the tasks. Another aspect of the procedure employed by these researchers (which will be important with respect to making comparisons with later work) is that the length of the intervals between their trials was always approximately 4 s.

However, it was still not until 18 years later that this line of study began to be examined in earnest by a number of researchers. The first important work of this time was performed by Allport, Styles, and Hsieh (1994) who initially regarded "voluntary shifting of task set ... to be a prototypical function of executive or intentional control" (p. 431). Prior to the study of Allport et al. (1994), much of the research on cognitive control had focused mostly on either visual spatial attention shifting or the efficiency of maintaining given task sets (such as conflicting stimuli in the form of Stroop interference or divided attention in dual/multiple-tasking performance). Hence, Allport et al. (1994) attempted to examine the possible involvement of a unitary supervisory control mechanism in task switching. Considering the capacity limitation of supervisory control, they hypothesized that manipulations of resource demands should interfere with this control mechanism.

In Experiment 1, using a self-paced "sliding window" to present the stimuli, they had participants switch between cognitive operations (i.e., odd-even and less-more than 5 judgments), perceptual features (i.e., attend to the size of a group of numbers or their values), or both cognitive operations and perceptual features of presented tasks and found identical switch costs in all three cases. In Experiment 2, participants made less-more judgments while switching between perceptual features. The effects of task difficulty were manipulated by varying numerical distance. Again, the results revealed no significant change in switch cost. In Experiment 3, participants shifted between naming colour-word Stroop dimensions and group-value number Stroop dimensions and still no differential shift costs were obtained when shifting either between responding to the non-dominant dimensions (colour and group) or the dominant ones (word and value).

In Experiment 4, participants first read words printed in conflicting colours, or named digit values appearing in various groupings on a screen, or alternated between the two tasks in an initial block of trials. In a second block, the tasks were changed to colour naming and judging numerosity. They found that the stimulus-response mappings from the first block interfered with switching between the second block tasks but only for the first few minutes. In Experiment 5, they manipulated the response-stimulus interval (RSI) time between pairs of trials (20, 550, or 1100 ms) in which either a task switch or non-switch was required and found only a small reduction in switch cost with increases in this RSI. Surprisingly, they also found that there was a higher switch cost in switching to an easy task than switching to a harder one. In this experiment, participants were slower in switching to word naming than to colour naming.

The results of the first three experiments were deemed not to be compatible with unitary control mechanism that reconfigures task sets, unless it could be assumed that such reconfiguration takes place before task processing begins (i.e., in a stage-like sequence). However, the results of the next two experiments are not compatible with that notion either (especially the RSI results because 1100 ms is much longer than the size of the observed switch costs of about 100-400 ms).

Hence, to explain these switch costs, Allport et al. (1994) proposed a concept called "task-set inertia" (TSI), which refers to the costs caused by persistent proactive interference from a previously executed task set. They proposed that task-set inertia is the source of the switch cost. That is, even when the participant is aware that the previous task set is no longer relevant, the original activation does not disappear completely. This residual activation helps to facilitate doing repeated tasks but interferes with switched tasks. Moreover, the interference depends on the introduction of a new stimulus and varies on the basis of the timing of its introduction. Allport et al. (1994) argued that it is more distributed passive reorganization of the cognitive system rather than an active controlled reconfiguration that results in switch costs.

For example, while performing Stroop colour naming, participants have to inhibit strongly the tendency to perform the word naming task. This need for inhibition leads to a slower performance and delays the colour naming response. It also inhibits switching back to word names (i.e., as in negative priming). Therefore, Allport et al. (1994) suggested that it is important to study switch costs as a function of the task being switched from and not the task being switched to.

The next important work of this time was a study performed by Rogers and Monsell (1995). In this work, they employed a new methodology for studying task switching phenomena that represented another substantial improvement of Jersild's original method. Rogers and Monsell (1995) identified some problems encountered with Jersild's paradigm that they felt needed to be avoided. First, in alternating blocks, in comparison to pure blocks, workload is higher because participants have to keep two, rather than one task-sets available or "active" in working memory and must also reconfigure them on every trial (i.e., they must maintain the two tasks in a state of readiness). Hence, it is not clear which one of these demands is indexed by the switch costs. Therefore, a comparison of the two separate blocks does not seem to give a good estimation of switch costs. Second, participants may use different task strategies and response criteria for each block. Third, participants might experience different levels of arousal or make lesser or greater effort and so on for blocks that are alternating the tasks, as they are considered more difficult than pure blocks by participants.

As a simple solution, Rogers and Monsell (1995) compared pure and alternating task trials within-blocks where the participant was aware of when to switch (after every nth trial). Except in their final experiment, n was always 2 and there were two tasks (Task A and Task B) for all experiments in their study. Rogers and Monsell (1995) called this the "alternating runs paradigm" because participants are required to switch between tasks predictably at least every two trials (e.g., AABBAABB…). Switch costs, then, were measured by comparing switch trials (i.e., AB and BA) with no-switch trials (i.e., AA, BB). They defined the difference in the RT as the "time cost" and the difference in error percentage as the "error cost" of the switch.

In their experiments, participants were required to classify letters (as constants or vowels) as one task and judge digits (as odd or even) as the other task. The participants were instructed to respond to these two distinctive tasks by pressing left or right keys. The stimuli contained two characters (one task relevant and the other task irrelevant) on each trial, positioned next to each other. The response associated with the irrelevant character was either congruent or incongruent with the relevant response. The position of the relevant character was set randomly to be on left or right hand. In the "no-crosstalk" condition, the irrelevant character was from a "neutral" set (containing non-alphanumeric characters associated with responses in neither task) and therefore, a response only with respect to the appropriate task was expected. In the "crosstalk" condition, one third of the irrelevant characters were from the "neutral" set and the remaining two thirds were an irrelevant paired character (a letter in digit task and a digit in letter task) which itself contained congruent or incongruent response information.

The character pairs were displayed at the centers of four square boxes positioned at the corners of a 5 cm square, one pair was presented in one of the squares for each trial (a 2 X 2 grid) which moved to the next square clockwise after a response and therefore, prompted the participants to respond to the next task. Different assignments of the task to pair positions were counterbalanced over participants. One group of participants were told to perform the letter task when the stimuli were in the two squares on the bottom. Another group of participants received different task-position assignments but with the same clockwise rotation of displaying the pairs.

On the basis of their set of experimental findings, Rogers and Monsell concluded that there are two important factors that seem to be contributing to observed task-switch costs. The first factor is associated with endogenous, or executive control, preparatory mechanisms that are seemingly invoked in order to adopt the appropriate task set (i.e., "to select, link, and configure the elements of a chain of processes that will accomplish a task", p. 208, Rogers & Monsell, 1995). Evidence in support of this contributing factor was that the size of the observed switch costs declined (from an initial cost of about 200 ms) as the time interval between the response to the previous stimulus and the presentation of the next stimulus (the RSI) was increased from 150 to 1200 ms. Rogers and Monsell (1995) suggested that switch costs decrease with increases in RSI because more time for active task-set reconfiguration is available with longer RSIs and they estimated the time course of this reconfiguration process to be around 600 ms because this was about the point at which switch costs stopped decreasing with further increases in RSI in Experiment 3. But note, however, that this phenomenon only occurred when RSIs were blocked in Experiment 3 and not when they were randomized within blocks in Experiment 2 because the latter conditions do not seem to favour the use of advance task-set preparation. (This fact has also been cited as evidence against Allport et al.'s task-set interia notion because any sort of passive dissipation of inhibitory influences related to the task set of the previous trial should not then depend on whether the RSIs are blocked or randomized; Meiran, 1996.)

The second contributing factor to shift costs proposed by Rogers and Monsell (1995) is associated with some kind of exogenous, or automatic control (Sohn & Anderson, 2000), mechanisms that seem to involve stimulus-driven, task-set activation. Evidence in support of this factor were the presence of stubborn residual switch costs of about 50-60 ms at the longest RSIs of Experiments 3 and 4, which Rogers and Monsell suggested might be due to the fact that the completion of task-set reconfiguration processing must be stimulus cued. Some further evidence in support of this exogenous contributing factor was the finding that overall switch costs were much larger in Experiment 3 when the stimuli contained elements that were relevant to both tasks (called cross-talk stimuli by Rogers and Monsell, 1995, but which have also been referred to as both dual-affordance stimuli by Ruthruff, Remington, & Johnston, 2001, and bivalent stimuli by Meiran, 1996, 2000) rather than to just one of the tasks as was the case in Experiment 4. (Note that if task switch costs were due purely to preparatory reconfiguration processes that take place completely in advance to processing the stimuli, the single vs. dual affordance of the stimulus items themselves should not then have any further differential effect, unless, of course, there are differences in the nature of the preparation that is required to respond to each of these types of stimuli.) Moreover, Rogers and Monsell (1995) also found that for these cross-talk stimuli, task-switch costs were reduced when the responses made to a task-switch trial were correct for either task (congruent task-irrelevant stimulus trials) than when they were not.

Finally, Roger and Monsell (1995) also found that when they extended the runs of repeating task trials to four in Experiment 6, the switch cost did not extend beyond the first trial in a run. This was a result that they felt was compatible with their proposal of a role for exogenous stimulus cuing in task reconfiguration (i.e., because once a task is cued it does not have to be recued until the next task-switch trial) but was incompatible either with Allport et al.'s (1994) TSI hypothesis or with an additional alternative micro-practice hypothesis for the switch cost. According to the TSI hypothesis, a gradual decrease of switch costs would be expected as the inertia dissipated. Therefore, if this hypothesis was correct, the switch costs should have decayed gradually within a serial trial run of successive trials with the same task. The micro-practice hypothesis, on the other hand, also assumes that there should be a gradual improvement in performance on the basis of trial-by-trial optimization of the decision criteria when performing repeated tasks.

Theoretically, Rogers and Monsell (1995) proposed that these endogenous and exogenous components were consistent with the Norman and Shallice's supervisory attention system (SAS; 1986) model of executive control. An endogenous process is an internal executive mechanism that is unitary and intimately associated with conscious awareness. On the other hand, when there is a tendency to perform tasks habitually, "exogenous control" is involved. According to Rogers and Monsell (1995), to complete a task set, the intervention of the executive mechanism (endogenous control) is not always required. Indeed, a suitable task set can be automatically selected by "contention scheduling" process. The process of automatic selection results from two different competitions: (a) Competing strengths of association between stimuli available in the environment and stored task sets, and (b) mutual competition between the task sets themselves. Among the activated task sets, a dominant task set would be selected. Some factors such as frequency of use, recency, and salience affect this selection process. However, when an appropriate task set is not selected, the endogenous SAS comes into play and reorganizes the system to meet current behavioral objectives (e.g., by strongly biasing the contention scheduling process). Overcoming exogenous activation of task sets by the endogenous control mechanisms may result in some failure of control (errors) and also slowing of performance. It happens when an inappropriate response must be suppressed (such as for Stroop interference).

The next important work of this time was a study performed by Meiran (1996). In this work, Meiran examined task-switch costs within a paradigm in which the different tasks being performed were presented randomly within a block (i.e, in an unpredictable sequence) but were always cued in advance using varying cue-target intervals (CTIs). Furthermore, Meiran's method in Experiment 2 and 3 represented an improvement upon traditional task-cuing paradigms (e.g., Sudevan & Taylor, 1987) because the time between the previous response and the current target constant was kept constant so as not to confound the time interval between the task cue and the presentation of the stimulus target (i.e., the CTI) with the time interval between the response to the last trial and the stimulus target presentation (i.e., the response-target interval, RTI; which was also referred to as the degree of remoteness to the previous trial by Meiran, 1996, and is essentially equivalent to Rogers & Monsell's, 1995, RSI without the associated predictability of the upcoming task on the subsequent trial). If the two intervals covary together, Meiran argued that it is not possible to determine whether the observed switch cost represents the time required by a proactive executive preparatory task-set reconfiguration process or represents the influence of a proactive interference (or carry-over) effect of the processing that took place on the previous trial (as per Allport et al.'s, 1994, TSI).

Meiran's (1996) experiments involved two choice RT tasks, an up-down discrimination and a left-right discrimination that used a 2 X 2 grid in which the position of the target stimulus within that grid on each trial could be classified according to either the vertical or horizontal dimensions. For each trial, an instructional cue was given indicating the task to perform (i.e., vertical or horizontal discrimination). Three independent variables were considered in these experiments, including task shift (task shift, task repeat), cue-target interval (short, long), and compatibility (compatible, incompatible). Cue-target interval varied randomly within a block of trials and the instructional cue was a pair of arrows. To unconfound the cue-target intervals with the remoteness from the previous trial, the interval between the previous response and the correct target was kept constant (Experiment 2-3). To do so, the instructional cue was placed either far from the previous response and close to the current target stimulus (short cue-target interval) or close to the previous response but far from the target stimulus (long cue-target interval). Compatible targets led to the same responses in each discrimination task (i.e., an upper left target where respond up and respond left were the same key press). In contrast, incompatible targets resulted in different responses depending on the tasks.

In general, the results of all of Meiran's (1996) experiments were consistent in showing that there was an interaction between task shift (i.e., task-switch vs. task-repeat trials) and the length of the CTI such that the switch cost (for both RTs and errors) was larger for shorter CTIs. In addition, switch costs were somewhat smaller for response compatible than incompatible trials. Moreover, because these effects occurred even when the time between the response to the last trial and the stimulus target presentation (i.e., the RTI) was held constant, the notion that switch costs at short CTIs are due to an endogenous, executive-based task-set reconfiguration process was supported.

However, the presence of residual switch costs even at the longest CTIs, again supported the presence of an additional non-executive component to the switch cost which Meiran attributed to retroactive adjustment processes. Further evidence for a dissociation between these executive and non-executive components of the switch cost was the additional finding (in Experiment 4) that practice reduced the size of the switch costs at short CTIs but not at long CTI's. In some later work, Meiran (2000) went on to propose that, at least for his two tasks, the two components seem to be related to independent stimulus task-set and response task-set reconfiguration processes (the latter of which is adjusted only after responding to a task-switch trial in a manner that is related to the stimulus-cued reconfiguration completion notions of Rogers & Monsell, 1995). As evidence for this notion, Meiran (2000) showed that the influence of each of the two components on the switch cost respectively depended on the bivalency of either the stimuli or the responses.

More Recent Work

A number of recent studies have focused on further dissociating and determining both the factors that affect and the processes that are responsible for each of the executive and non-executive switch cost components (which are now often referred to as the intentional and the unintentional components respectively). For example, at least one researcher (De Jong, 2000) has suggested that the residual switch cost is due simply to preparation failures.

In his study of residual switch costs, De Jong (2000) considered two classes of hypotheses: the "additional process" (AP) hypothesis and the "failure-to-engage" (FTE) hypothesis. AP occurs when completion of the reconfiguration process during preparation must wait to be triggered by a task-relevant stimulus (as in Rogers and Monsell's, 1995 exogenous component). The second hypothesis, FTE, assumes that residual switch costs happen because of failures to engage in advance preparation for the change of task (i.e., incomplete reconfiguration during preparation).

To distinguish between these two hypotheses, rather than using means, cumulative distribution functions (CDFs) were used by De Jong to study entire RT distributions. The hypotheses were then formalized in terms of mixtures of prepared and unprepared CDFs where task repetitions were assumed to be fully prepared and task switches with short RSIs were assumed to be fully unprepared.

The first experiment investigated the effects of task duration and time on task on task-switching and attempted to examine the changes in CDFs when alternating tasks while manipulating the block lengths. Participants were informed about the length of the block at the start of each new block. Results showed that the residual switch costs could be attributed almost exclusively to failures to engage in advance preparation (i.e., the mixture model provided a good fit to the long RSI task-switch CDFs) in both short and long blocks. Interestingly, responses also tended to be slower in long blocks (especially on switch trials but not significantly so). The decrease in response speed from the first to the second half of long blocks appeared to be the reason for those slower responses.

The results of the Experiment 1 did not support the assumption that people may have trouble holding their intentions to engage in advance preparation at high level of activation for prolonged (rather than short) periods. Responses in long blocks only tended to be somewhat slower which could be attributed to some other factors such as a decline in overall response speed from first to the second half of these blocks. To study further adjustments in control settings in response to different instructions or task requirements, Experiment 2 was conducted. It examined whether participants in Experiment 1 had adapted a conservative strategy to set intention-activation at a level throughout at which they could sustain for prolonged blocks. Using a between-subject design, two groups of participants were assigned to two short and long block groups.

Results on switch trials showed a decline with RSI (also seen in Experiment 1), sizable residual switch costs (especially in long blocks), and faster responses in short than long blocks. This experiment, also showed that failures to engage in advance preparation (called "trigger" failures by De Jong, 2000) in long trial blocks were more prevalent than in short trial blocks (i.e., the "prepared" mixing parameter was smaller), when short blocks were not intermixed with long blocks.

However, a number of other researchers regard the residual switch costs as being due to a repetition priming benefit from repeating the same task on the last trial (which is essentially analogous to Allport et al's, 1994, TSI notion). The interaction of top-down and bottom-up factors in responding to stimuli was studied by Ruthruff et al. (2001). They used the alternating runs experimental paradigm of Rogers and Monsell (1995) and also a task-cuing validity paradigm. They designed four possible conditions of manipulating task expectancy and task repetition including expected repetitions (e.g., BBAAB*B*), expected switches (e.g., BBAA*B*), unexpected repetitions (e.g., AABB*B*), and unexpected switches (e.g., AABBA*B*).

In Experiments 1 and 2, participants were instructed to prepare for the task that was most likely to occur in the upcoming trial using single-affordance letters (Task A) and colour patches (Task B) as stimuli with either two (Experiment 1) or four (Experiment 2) possible responses for each task.

In those experiments, a 2,500 ms interval between the response to a stimulus and the onset of next stimulus (RSI) was set, which contained a 1,000 ms interval between a response and the start of next trial, a 1,000 ms display of a fixation marker (+), and a 500 ms interval before the onset of the upcoming stimulus. Having this relatively long interval (2,500 ms), participants were expected to get fully prepared for the next trial.

To see whether the results of Experiment 1 and 2 could be generalized to task-switching scenarios with more than two tasks, Experiment 3 was conducted with three tasks and showed no evidence that task switching effects depend on the difficulty of task-set disengagement. In all three experiments, an underadditive trend between expected-unexpected tasks and task switching was found, which they deemed to be consistent with an activation suppression model where the activation of recently performed task is deliberately suppressed if it is not expected to occur on the upcoming trial (which would slow down unexpected task-repeat trials).

In order to generalize the previous experiments to different ranges of levels of expectancy, Experiment 4 was conducted. Performances on certain (100% likely to occur) tasks to neutral (50% likely to occur) were compared using the same procedure in Experiment 1-3. However, Ruthruff et al. also considered the fact that the task-repetition variable is binary whereas task recency varies continuously. Reanalysing and transforming the data (for all four experiments) to a linearized relation between RT and task lag (the number of trials since the task was last performed) resulted in no systematic trends toward either underadditivity or overadditivity of task switching and task lag but were additive.

The executive and automatic components of control and their effects when people switch rapidly between different tasks were also examined in a study by Sohn and Anderson (2001). They assumed that the effects of task repetition without foreknowledge of repetition can only reflect exogenous automatic control processes. As well, although switch costs are very resistant to complete elimination, they can be decreased by manipulating certain types of factors. For example, when RSI between two tasks increases, even when task foreknowledge is not available, switch costs decrease. Both inadequate preparation for a task switch compared with task repetition and persisting activation from a previous task set have been proposed to be the reasons for residual switch costs. However, Sohn and Anderson (2001) believed that considering these two different influences on the switch costs as completely independent and separate processes can not be correct because a dissipating repetition benefit effect can occur while the next task is prepared (i.e., the two processes can occur simultaneously). Hence, with foreknowledge of task repetitions and switches, switch costs are expected to decrease with RSI due to both types of processes, whereas with no foreknowledge only repetition benefit effects on the switch cost should be evident.

The issue of independency of the preparation and repetition effects was examined in their Experiments 1 and 2. Specifically, Experiment 1 was designed to study the effects of foreknowledge conditions using different types of blocks (all repetition, all switch, and mixed). The results showed both that the foreknowledge effect increased and the switch cost decreased with increasing RSI. Moreover, both repeat and switch trial RTs in the foreknowledge conditions were also greater than in the no-foreknowledge conditions at short RSIs indicating the inability to prepare affects both switch and repetition trials. In addition, increasing the RSI reduced switch costs more in the foreknowledge conditions than in the no-foreknowledge conditions.

Experiment 2 was designed to generalize the results of Experiment 1 with much longer RSIs. The results were similar to the first experiment. The foreknowledge effect increased and switch cost decreased with RSI. Moreover, in both experiments, practice caused a reduction of the switch cost at all RSIs and especially in the foreknowledge condition. Thus, the preparation component may be more affected by practice, which then supported the fact that the residual switch cost may be the result of more automatized repetition priming-type benefits.

Other researchers have focused on the factors that affect and the processes that are responsible for the intentional, preparatory component of the switch cost. In order to test the hypothesis that LTM (long-term memory) retrieval is associated with the intentional component of task switching, Mayr and Kliegl (2000) predicted a switch cost increase as a function of primary task-set retrieval demands (Experiment 1) and found longer switch costs in tasks with high retrieval demands (i.e., retrieval of episodic information as this was considered more difficult) than in tasks with low retrieval demands (i.e., retrieval of semantic information). However, also in support of Allport et al.'s (1994) findings and the concept of TSI, switch costs were somewhat longer when switching away from an episodic (harder) task than switching from a semantic (easier) task.

In Experiment 2, they distinguished and showed how the obtained difficulty effect is specific for retrieval demands rather than on just overall difficulty of the primary task (i.e., the retrieval demand effect on switch costs is not because of the general difficulty of episodic task).

Manipulating preparatory intervals and the amount of information given as task cues were investigated in Experiment 3. Three different switching situations that were designed to isolate "passive" and "proactive" modulations of switch costs were investigated. The two intervals defined by Meiran (1996) as the response cue interval (RCI; the time between the response to the preceding trial and the cue), and the cue stimulus interval (CSI; the interval between the cue and the next stimulus) which together constitute the passive-decay time were manipulated in this experiment. As it was expected, results showed that the retrieval-demand effect on switch costs was reduced for long preparatory intervals (CSIs) but not for long decay intervals (RCIs). As a matter of fact, it was also reduced or eliminated when explicit information about task rules was provided as part of the stimuli.

In a similar fashion, Goschke (2000, Experiment 2) added a distraction (asking the participants to either repeat task-relevant cue words or task-irrelevant words) during a 1500 ms preparation interval. Goschke (2000) hypothesized that the latter condition affects preparation by blocking retrieval of the next task set and indeed, switch costs were much larger in that condition. Moreover, in an initial experiment involving RSIs of 14 or 1500 ms, he also found greater switch costs when incongruent (rather than congruent) stimuli were presented on the previous trial in for which the greater preparation at larger RSIs could not diminish the effect. Goschke (2000) argued that this effect occurred because greater effort was needed to inhibit the previous, irrelevant task set when response conflict was high on the previous trial.

From these findings, Goschke (2000) then concluded that active preparation plays a more important role in switch costs reductions than does passive decay of the previous task set. However, he did not deny the contribution of passive dissipation and believed that the switch cost is a reflection of both proactive interference and advance reconfiguration. Indeed, it seems that switch costs can be influenced by various separable processes including retrieval of relevant task-set representations from memory, persisting activation of the previous relevant task set, and inhibition of the previous irrelevant task set.

In this regard, an important approach to the role of preparation was advocated by Mayr and Keele (2000) who proposed that intentional shifts between tasks are always accompanied by direct inhibition of the previous task set in order to prevent it from having any further influence. They argue that such a process (which they termed backward inhibition) is necessary for adaptive behavioural reasons because task sets themselves involve high-level control settings that are fairly resistant to deactivation; a situation which then is likely to result in proactive interference-based switch costs (c.f., Allport et al. 1994). Furthermore, Mayr and Keele (2000) proposed that it is the residual switch that reflects the role of such processes because it might simply represent the cost of overcoming such inhibition (i.e., after all other possible advance reconfiguration has occurred).

Their main experiments involved "odd-man-out" tasks that involved switching between three stimulus dimensions across trials. Using a task-cuing paradigm that was analogous to Meiran's (1996), evidence for the notion of backward inhibition was provided by showing that switch costs were larger when the task being switched to had just previously been switched from itself (called lag-2 repetitions, i.e., ABA) than when the task being switched to had been abandoned less recently (i.e., ABCA). Mayr and Keele (2000) proposed that this effect occurs because more recently abandoned task sets have not fully "recovered" from inhibition and, hence are harder to re-activate (indeed, these results are hard to explain otherwise).

Finally, in some fairly recent work, Arbuthnott and Woodward (2002) showed that, as in Mayr and Kliegl (2000), switch costs were larger for task cues involving recently learned associations (i.e., shape labels) than for task cues involving pre-existing task-cue associations (e.g., verbal labels). Interestingly, these researchers also demonstrated (using a well-controlled, three-task switching paradigm) that strength of the task-cue association did not affect the size of the switch-cost difference between Mayr and Keele's (2000) lag-

2 repetition trials (referred to by Arbuthnott & Woodward, 2002, as alternating switch trials) and the other switch trials.

Speed-Accuracy Tradeoff

Time Pressure

In studying human judgment and decision making, Maule and Svenson (1993) differentiated between two approaches: "structural" and "process" approaches. In the structural approach, the relation between input (the available information about each choice alternative) and output (the final judgments and decisions which individuals deal with in different situations) are studied. The process approach, on the other hand, concerns different stages of judgment and decision processes in terms of the underlying psychological processes over time.

Another way to classify decision-making approaches is to distinguish between the prescriptive, normative, and descriptive approaches. The prescriptive approach studies how people evaluate and use information to make the judgments, the normative approach involves formalizations about how rational decisions should be made which do not consider the human characteristics, and the descriptive approach studies the process of "choosing" in people's real lives.

Maule and Svensen (1993) also made distinctions between "static", "sequential", and "dynamic" situations. In static situations, decisions are made on the basis of the different information available at the moment of the choice. In sequential situations, there are progressive changes in decisions on the basis of the former decisions, and in dynamic situations, the inputs to the decision system are continuously changing.

In terms of the elements of well-defined decision problems, the three elements identified by Maule and Svensen (1993) are (a) the objectives of the choice situation, (b) the available choice alternatives, and (c) the information about each alternative. The adopted strategy in information-processing when making a decision among a set of alternatives would be to reflect upon a number of different decisions on the basis of the order, type, and amount of information processing requirements.

One of the resources in decisional information processing is time. Different amounts of time available serve to increase or decrease the time pressure and, hence, behaviour. Having a shorter time available than the estimated time needed would create high time pressure. On the contrary, longer time available results in less or no time pressure (Svensen & Benson, 1993). As well, different managements of time when making different decisions and doing different tasks would result in different results.

Miller (1960, cited in Maule & Hockey, 1993) described different mechanisms of adjustment that are needed for doing cognitive tasks. Among them, the three mechanisms of filtering, omission, and acceleration have been the focus of research on decision making under time pressure. Filtering occurs when certain low priority categories of information are neglected while continuing to process others. Omission involves completely ignoring the aspects of task information. In this way, all task-related processing are stopped temporarily. Acceleration occurs when mental activity is speeded up in order to meet increasing task demands.

Time pressure can arise a consequence of deadlines. A person who believes a task needs to be done within a certain deadline is motivated to use cognitive and energetic resources to meet these demands, which itself affects cognitive processing. This notion generates the assumption that the acceleration of information processing under time pressure overloads the capacity of the cognitive system, which could lead to errors and systematic biases. Indeed, the effect of time constraints and deadlines may be considered as stressors which result in some costs and benefits.

Experiences gained from earlier identical, or similar, situations lead to the construction of a subjective appraisal of the task demands. This appraisal involves a comparison between the resources needed and the resources available. The problem occurs when the demand component is exceeded. At this stage, the person doing the task has to either increase the available resources (e.g., through mobilization of energetic resources) or decrease the demand on those resources (e.g., through simplifying the decision strategy).

RT, Accuracy, and SAT

RT and accuracy are the two of the most important dependent measures in cognitive psychology (Meyer, Irwin, Osman, & Kounios, 1988). RT is most typically defined as the time elapsed between the onset of a stimulus and the initiation of a response (Sanders, 1998). However, because RT is involved in every response and errors occur only occasionally, RT is considered more salient than accuracy. Indeed, RT is frequently used since it is an obvious and convenient dependent variable (Pachella, 1974). Moreover, it could be argued that duration is the only property of mental activity which can be studied directly (Pachella, 1974).

Accuracy, refers to either the correctness (e.g., percent correct) or the consistency (e.g., standard deviation of a response). The former is measured by the proportion of correct responses or number of errors. Sanders and Moray (1991) characterize errors as actions which are not intended (by the actor) and not designed (by a set of rules) that lead the task or system outside the acceptable limits. In some situations, such as flying a plane, accuracy would be a critical issue.

Typically, more efficient information processing results in a decrease in RT and/or increase in accuracy. However, RT and accuracy are actually highly dependent on each other. In any response process, an optimal balance of speed and accuracy is considered based on the priorities. The mutual dependence of RT and accuracy is evident when more emphasis on accuracy will result in increases in RT and conversely, more emphasis on speed typically causes accuracy to decrease. Miller (1960, cited in MacGregor, 1993) indicated that when the organism increases the response rate, it results in the costs of incomplete information processing and higher error rates.

Hence, the comparison of only the RTs obtained from different cognitive experimental conditions and concluding that one of them is "harder" because the reaction time was longer than the other, is misleading unless we know that the error rate in the two conditions is the same or is greater in the slower condition than the faster condition. Relying on just RT to interpret the results of cognitive studies, was strongly criticized by Wickelgren (1977) who believed that knowing a mean RT without knowing its position on the corresponding speed-accuracy tradeoff (SAT) curve is meaningless. Thus, studying RT in conjunction with accuracy (i.e., the whole SAT function) provides much greater knowledge about information processing dynamics than studying either the reaction time or accuracy aspect of performance separately.

Trading off accuracy for speed or vice versa can be expected in presumably any task. This fact has been known for a long time. However, systematic experimental work on the phenomenon only began in the 50s and 60s (e.g., Fitts 1966; Howell & Kreidler 1963, 1964; Ollman 1966; Pachella & Pew 1968, all cited in Wickelgren, 1977). In one of the first attempts to model the speed-accuracy relation as a "law of movement", Paul Fitts (1954) presented a mathematical formula ($MT = a + b \operatorname{Log}_2 (2A/W)$) where the width of the target (W) to be moved to and the amplitude of the distance between them (A), result in different amounts of movement time (MT).

The SAT paradigm in cognitive psychology studies the inverse relationship of RT and accuracy by examining the process of information accumulation through time. In this way, the experimenter can observe how different methods of manipulation of speed emphasis (such as instructions, payoffs, response deadlines, and response signals) result in changes in both RT and accuracy of the response. Under speed pressure, more incorrect responses are expected, therefore, SAT curves specify how much time is needed to achieve a particular accuracy level. This procedure was used by a few researchers in the 1970s (e.g., Reed, 1973, 1976) to study cognitive processing.

In 1977, Wickelgren formalized the relation between accuracy (in terms of d') and time (t) using the following equation,

$$d' = \lambda\left[1 - e^{-\gamma(t-\delta)}\right], \qquad (1)$$

where λ is the asymptotic accuracy level, γ stands for information processing rate, and δ is the time intercept in a SAT curve.

In the SAT context, the definition of RT as the minimum amount of time needed to produce a correct response represents an assumption. Indeed, even experienced participants in experimental settings generally make 2-3% errors in most RT tasks (Pachella, 1974). Therefore a "maximum accuracy" would be a better operational term in experimental settings. However, when the experiment is extremely simple and/or plenty of time is available, 100% correct responses are expected.

Finally in 1989, Rabbitt presented a model of understanding subjects' response behaviour on a trial-to-trial basis in which individuals gradually discover the fastest but safest way to respond. He suggested that the participants start to respond faster and faster until they respond too quickly and an error occurs. On the next trial after detecting the error, they slow down at first but speed up again until another error is made. Through practice, they learn an efficient pattern of responding in which speed is at an optimum and error at a minimum.

The Three Components of an SAT Curve

The time-course functions described by Wickelgren's (1977) equation have three parameters: (a) an "intercept" which is the minimum processing time, it is the point in time that response accuracy begins to rise and describes when performance departs from the chance level; (b) a "rate" of rise indicating how quickly accuracy increases from chance to maximum with increases in RT; and (c) an "asymptote" representing the maximum possible accuracy. The asymptote reflects the level of accuracy reached with functionally unlimited processing time. An example of a typical empirical SAT curve from Campbell (1985) is given in Figure 1.

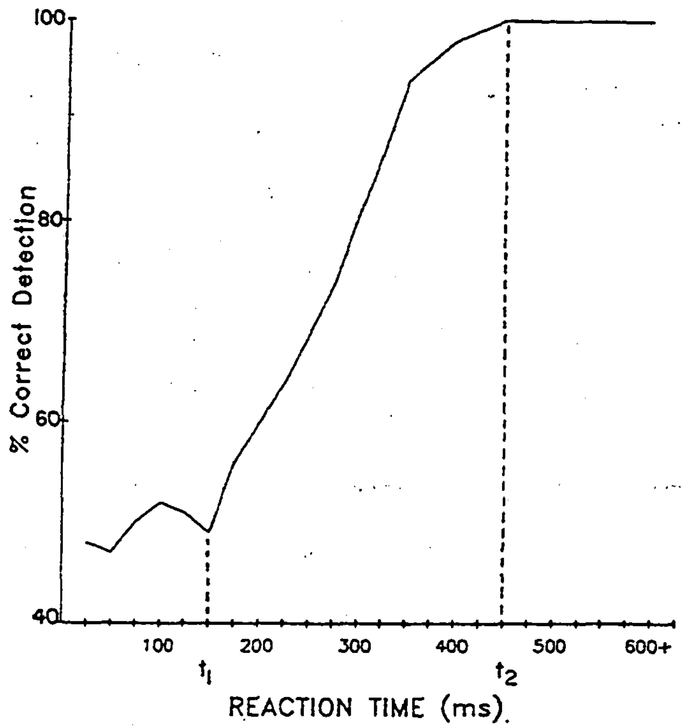


Figure 1: A typical SAT curve (from Campbell, 1985).

In the initial phase of this SAT curve (RT<t1), accuracy is around the chance level. In the second phase of this SAT curve (t1<RT<t2), because relation between increasing accuracy and RT is nearly linear, a linear equation can be used to approximate this relationship (Campbell, 1985),

$$A = M\,(RT - C), \qquad (2)$$

where A (accuracy) is the function of multiplying M (the amount of change in A for each unit of RT, slope) by the difference between RT and C (the point, t_1, where the rise begins). In the third phase of this SAT curve (RT>t2), accuracy is at maximum. As the extremes occur not very often in practice (when very few errors or very many errors occur), the relationship between speed and accuracy in most situations is approximately a linear relationship characterized by RT versus percent correct.

One of the key concepts in studying SAT is the macro/micro-tradeoff functions which can be viewed as being independent of each other (Pachella, 1974; Sanders, 1998). In macro-tradeoff functions, the time-accuracy relation is studied across experimentally controlled conditions (involving manipulations such as setting deadlines, instructions, payoffs, or signals to respond) for which a differential emphasis on speed or accuracy of performance is placed. In micro-tradeoff functions, the time-accuracy relation within a given macro-tradeoff condition is studied. It takes sets of trials with specific latencies and calculates the accuracy which corresponds to responses at these latencies. For example, the accuracy associated with the 10 fastest responses, the next 10 fastest, and so on is examined.

SAT Methods

Through different methods, experimenters can explicitly manipulate speed versus accuracy emphases in order to study their effects directly.

Wickelgren (1977) reported six basic methods to study SATs: instructions, payoffs, deadlines, time bands, response signals, and partitioning of reaction times. However, a combination of the methods is also possible. For example, Pachella and Pew (1968, cited in Wickelgren, 1977) combined the deadline and the payoff methods using a 2 X 2-payoff matrix of correct-incorrect and faster-slower reaction times.

Instructions

One of the simplest techniques to measure SAT is by using different speed versus accuracy emphasis instructions. If speed only were stressed (e.g., "It is important that you go very fast in these tests, completing them in the shortest possible time), the participants would ignore errors and respond more or less at random in order to maximize speed (see Figure 2). If accuracy only were stressed (e.g., "It is important that you work very accurately in these tests and make no errors"), they would attempt to control their responses by spending more time responding in order to avoid as many errors as possible (see Figure 3). The ambiguous instruction of "complete the tasks as fast as possible while maintaining "high" accuracy" may be ranked as "neutral" because there is no obvious emphasis on either speed or accuracy.

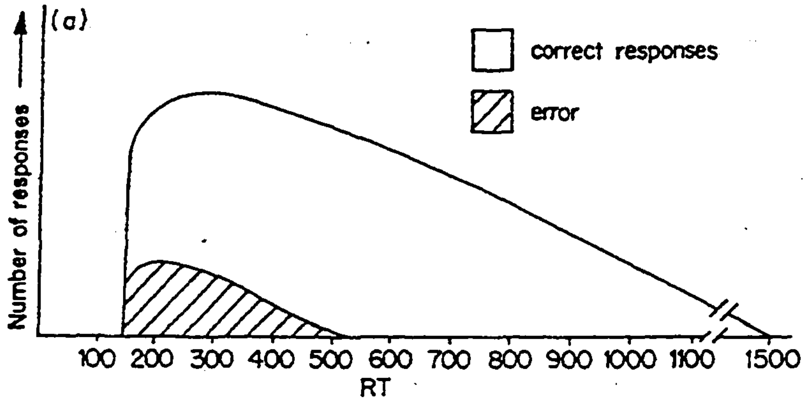


Figure 2: Responding where speed is stressed (from Rabbitt, 1989).

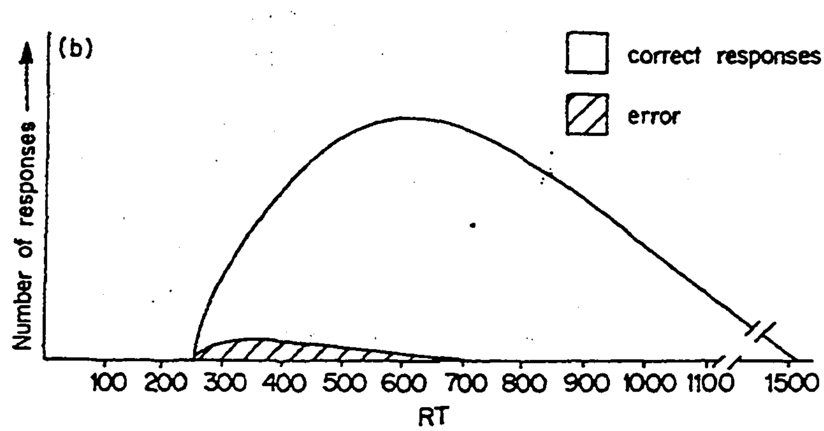


Figure 3: Responding where accuracy is stressed (from Rabbitt, 1989).

Figure 4 represents the idealized inverse relation of speed-accuracy on the basis of speed versus accuracy emphasis instructions. The open circle is the point which Pachella (1974) suggested represents the common definition of reaction time where a maximum accuracy can be obtained in the least amount of time.

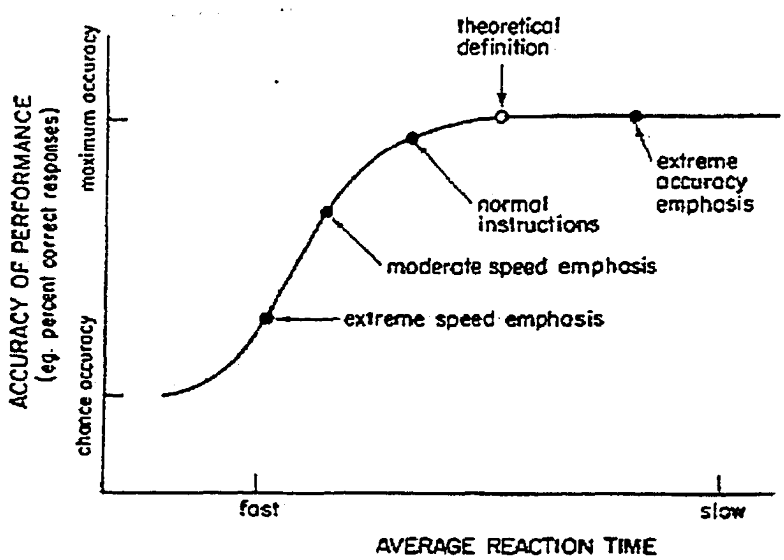


Figure 4: An idealized SAT curve (from Pachella, 1974).

However, as Sanders (1998) believes, participants can often be fairly insensitive to changes in such speed-accuracy instructions. They usually dislike errors and these preferences can influence their responses. On the other hand, the usual experimental instruction is the neutral one (e.g., "go as fast as you can and make as few errors as possible") which it asks participants to react quickly and more accurately. If a participant simply asks which matters more – speed or errors – the answer would result in different responses (in terms of more concentration on time or accuracy) because the requirements of speed and accuracy are in direct opposition. Emphasis on either one will lead to lower performance on the other and ultimately affects the results.

Deadlines and Payoffs

In the deadline method, participants are required to make a response at a specified time after the test stimulus is presented. The method involves instructing participants to meet the deadlines by responding before certain times (e.g., 300 ms, 700 ms, etc.) following the onset of the stimulus in different blocks. By providing feedback, participants learn to produce responses by the required times in subsequent trials. Using this method, Link (1971, cited in Wickelgren, 1977) used three different deadlines in which his participants were instructed at the beginning of each trial about the deadlines they had to respond prior to.

Payoff is another method in which participants are rewarded for quick correct responses and penalized for errors. Payoffs can be given for either speed or accuracy or both. Payoffs method was first demonstrated and used by Fitts in 1966 (cited in Wickelgren, 1977). He showed how the use of a payoff matrix emphasizing either speed or accuracy would result in different performances (Pachella & Pew, 1968). Leth-Steensen (1992) also developed a payoff matrix in order to induce his participants to meet speeded deadlines while also not greatly sacrificing accuracy. In this way, the participants were rewarded by potentially increasing their base salary when they responded both accurately and by the deadlines and penalized if the responses were inaccurate or too slow.

Response Signals

In this method, a response signal (i.e., a tone) is presented at various times after stimulus presentation and prompts participants to stop processing and respond without any delay (i.e., within a few hundred milliseconds of the signal). This method interrupts the participant's stimulus processing at different times after stimulus presentation.
In this way, different intervals (between stimulus presentation and response signal) can be used in order to examine the variation in the amount of processing that can occur before the response signal and ultimately the amount of accuracy associated with that amount of processing time.

One of the problems in using the deadline method, which might affect the results of SAT studies, is the use of different cognitive strategies by participants between blocks of trials in order to cope with the deadlines. Hence, the response signal method measures the SAT without such strategy confounds because the signal presentation time is unknown when response signal times are manipulated within each block. However, this also introduces a degree of time uncertainty with respect to when the response needs to occur which is an important variable in its own right. In addition, very long response signals lead to situations in which responses must be withheld even after processing has long been completed.

Wickelgren (1977) evaluated the methods of generating SAT functions and concluded that all except the response-signal method were unsatisfactory because (even when mixed rather than block procedures were used) participants are informed of time pressure conditions prior to the trials.

SAT Models

Different models have been proposed to explain the mechanisms involved in SATs. Two distinct classes of models (Osman, Lou, Mueller-Gethmann, Rinkenauer, Mattes, & Ulrich, 2000) are a) mixture models (Yellot, 1971) which postulate the presence of guesses and accurate responses – fast-guesses and deadline models are two examples of this class – and b) models which postulate differential decision criteria for accumulating evidence to respond – the random walk model (Link, 1975; Ratcliff, 1978) and the accumulator model (LeBerge, 1962; Vickers, 1970) are two examples of this class.

1. Mixture Models

1.1. Fast-Guess Model

One of the models for the speed-accuracy trade-off was presented by Yellott (1971) and is called the fast-guess model. According to this model, two possible types of responses under speed stress will be produced. One involves "stimulus controlled responses" in which the full amount of time is taken to process, discriminate, and generate responses with a high level of accuracy. Therefore, they are made on the basis of fully analyzed stimuli. The other involves "fast-guesses" which refer to much faster (but with only a chance probability of being correct) responses made without the usual stimulus processing as there is not enough time available to process the stimuli. They are unaffected by the stimuli.

If participants realize that they cannot complete the processing during the supposed period of time, they can decide to make the best guess on the basis of information external to the trial itself (e.g., expectations about differential stimulus probabilities). That is, they trade accuracy for speed by making a quick response on the basis of a pre-determined guess on a proportion of the trials. The decision of whether to make a fast guess (with low accuracy) or to complete the stimulus processing (with high accuracy) is made after his or her estimation and before each trial (Ruthruff, 1996).
The proportion of guesses versus non-guesses can be manipulated through changing deadlines, speed instructions, and response signals.

The mixture of two possible responses is shown in Equation 3.

$$Y_{overall} = [(p_{guesses})(Y_{guesses})] + [(1 - p_{guesses})(Y_{non\text{-}guesses})], \qquad (3)$$

where Y represents either mean RT or percent correct responses.

In a fast-guess model, the traditional SAT curve can be characterized in terms of a linear relation as Figure 5 shows. The ordinate represents the difference between the average duration of correct and error responses (P_cM_c-P_eM_e). The difference between the probability of correct and error responses is presented at the abscissa (P_c-P_e). As it can be seen, perfect responding is obtained at the longest point of consumed time.

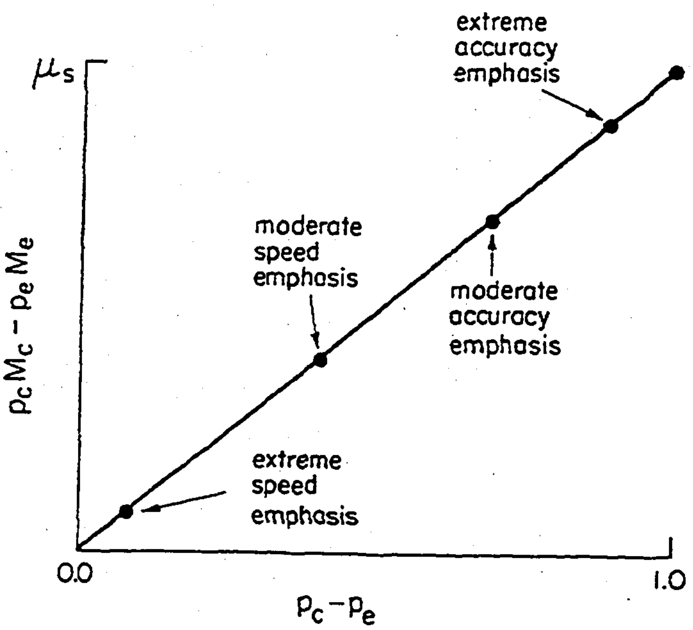


Figure 5: The form of the SAT curve in the fast-guess model (from Pachella, 1974).

There are a number of problems with this model, however, one of which is the fact that because it is a mixture, the RT distribution under speed emphasis should be more variable than under accuracy, which it typically is not (e.g., Smith & Mewhort, 1998). As well, because the decision to fast guess is made prior to perceiving the stimulus, any differences in accuracy between different stimulus conditions must be the same for both accuracy and speed emphasis conditions which clearly is not the case (see discussion of Poltrock, 1989).

1.2. Deadline Model

In the deadline model (Yellot, 1971, Swensson, 1972, Ollman 1977), instead of just deciding to make random guesses right away, time deadlines are set by participants. Faster time deadlines are set when there is more time pressure (which results in more errors). Individuals respond either when the stimulus discrimination time is finished or when the deadline has been reached, whichever comes first (i.e., a "race"). After this period, later (or "residual") processes serve to form the final response.

In this way, participants set deadlines to initiate responses by estimating the interval on every trial needed to accumulate enough information to respond correctly before the deadline. If they are not able to accumulate sufficient information by the deadline, then they guess. Therefore, two possible distinct responses would be either a random guess when enough information has not accumulated before the deadline or a stimulus-controlled response as soon as enough information has accumulated before the deadline. Note, that this idea has been utilized by Meyer et al., (1988) to derive their speed-accuracy decomposition (SAD) technique. In their experimental procedure they used response signals as a substitute for internal deadline but still assume that responding involves a race between stimulus-controlled and guessing responses from that point on.

Equation (4) shows the mixture of two possible responses that can occur as a result of the race,

$$Y_{overall} = [p_{Ti>Td}) (Y_{guesses})] + [(1 - p_{Ti>Td}) (Y_{non\text{-}guesses})], \qquad (4)$$

where Y represents either mean RT or percent correct responses. Td represents the deadline interval set interval by the participant, Ti represents the time to accumulate enough information to make a correct response.

Figure 6 (A) shows the cumulative distribution of guessing completion times in a response-signal paradigm which is located between the cumulative distribution of regular trials and response-signal trials. (Note that these response signals can be regarded as being analogous to deadlines). Figure 6 (B) shows how the effects of the intervals between the imperative and response signals affect the location of the cumulative guessing completion distribution. Since the timing of the guessing process remains unchanged, the slope does not change due to different intervals. Obviously, the placement of the distribution of guessing completion times will affect the outcome of the race with stimulus-controlled times (because the location of that distribution does not change).

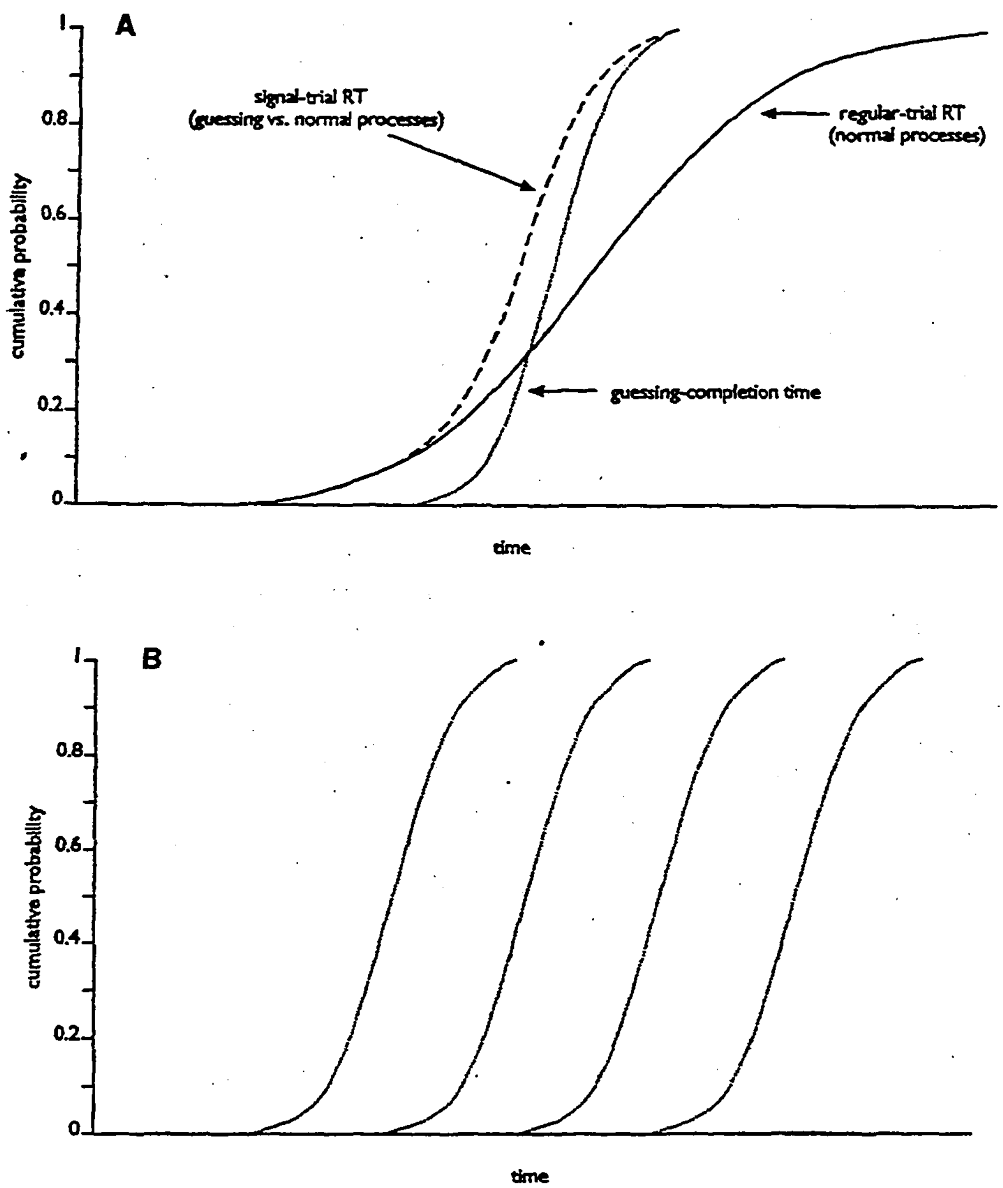


Figure 6a and 6b: Cumulative distributions of completion time in deadline model where different response signals are presented (from Meyer et al., 1988).

In contrast to the fast-guess model, the deadline model assumes that individuals cope with the time pressure by adopting a subjective time deadline. Hence, participants can still distribute their speed and accuracy of performance over the entire range of performance. Any changes to the interval affect the guess and non-guess response rates.

This model is sometimes called "slow-guess" model as opposed to the fast-guess model because in this model, guesses can happen slower than non-guesses.

In the deadline model, if participants have enough information, they respond earlier and it is the responses that are made very close to the set deadline that are usually the guesses. As more time is spent (and therefore more information is accumulated) for the guesses in this model, they seem to be more accurate than guesses in the fast-guess model. The effects of task complexity can also be explained by the deadline model, as more complex tasks are the least likely to finish before the deadline more errors are expected to happen and RTs are longer. Note, however, that the deadline model has been tested explicitly by Ruthruff (1996) and was not supported.

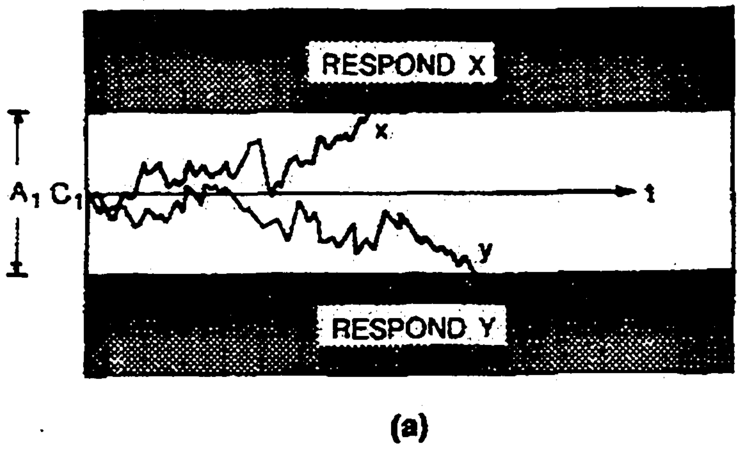
2. Evidence Accumulation Models

There are some models which assume that information is accumulated over time and a response can be produced either when it is required or when enough information has been received. The accumulator model and the random walk model are two examples of this category. Indeed the SAT concept could be regarded as implying the gradual accumulation of information over time. The accumulation of evidence starts from a baseline (starting point) and grows over time towards decision boundaries (criteria).

The direction or speed of the growth depends on the amount of information for each alternative. Once the amount of evidence reaches the criterion, the corresponding response is executed. As an alternative to mixture models, in evidence accumulation model, participants choose a pure speed or accuracy strategy that can be modeled by changing the size of the decision boundaries. Note, that unlike either the fast guess or deadline models, this model assumes that people can exert direct control over the amount of time spent processing the stimulus (Ruthruff, 1996).

2.1. Random Walk Model

The random walk model, which is based on the relative judgment theory presented by Link (1975), helps to provide an understanding of some aspects of mental comparison in human performance. Figures 7a and 7b show how different RTs can occur when different emphases on accuracy (and therefore different positions of the boundaries) are present. The distance between the bounds and the baseline determines the degree of emphasis on RT or accuracy at the cost of the other one. When the boundaries are set far from the starting point, accuracy has been emphasized. In this situation, RT is slower but responding is more accurate. When the boundaries are closer to the starting point that indicates a speed emphasis and shorter RTs and lower accuracy is expected. In this way, the response threshold can be set higher in order to avoid accidental incorrect responses but this setting will increase the RT as well.



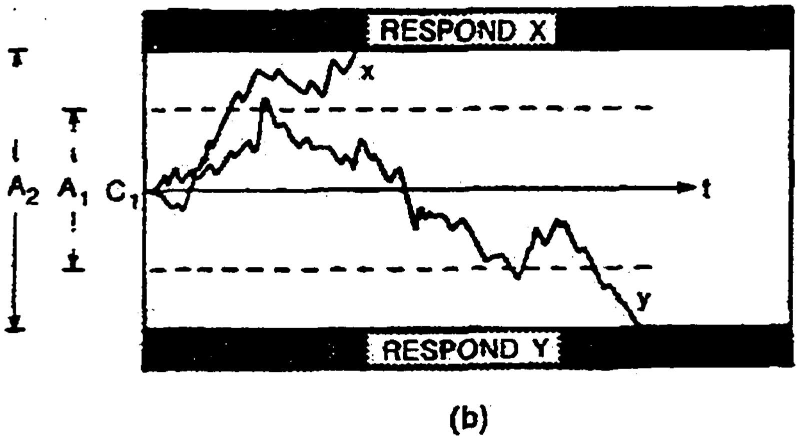


Figure 7a and 7b: The distribution of reaction time with different values of accuracy (from Sperling & Dosher, 1986).

Random walk models can explain the process of information accumulation, which ends when one of alternatives is chosen. It shows how two stimuli are compared and a selection is made after the absolute accumulated value exceeds a boundary although it is also quite important with respect to the response signal paradigm to note that "interrupted" versions of this process can also occur in which responses can be made on the basis of which side of the baseline the walk is on. When the random walk reaches the wrong boundary errors occur. Such errors usually happen when the duration of responses is low and enough information of the correct kind has not been accumulated. This situation is more likely to occur when the boundaries are set closer to the starting point.

The walk usually starts from a null line where the distance to each of the boundaries is the same. However, in case of differing levels of bias, different starting points would be considered. If the individual believes one of the responses to be more likely, he or she can set the starting point closer to the expected boundary and resulting unequal distances between the starting point and boundaries (Nikolic & Gronlund, 2002). A shorter decision time would be the consequence of changing the starting point, although it ends in a biased decision (Figure 8). That fact that participants can strategically adjust the setting of the response criteria forms the basis for the SAT. They change the setting to respond at an acceptable level of speed and accuracy.

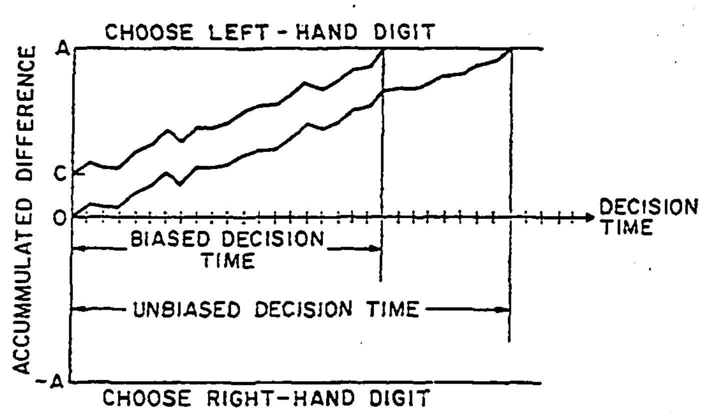


Figure 8: Biased and unbiased decision time in random walk model (from Poltrock, 1989).

It is important to note that the thing is being modeled here is actually only the decisional component of the RTs, that is, the overall RT is actually derived as:

$$RT = DT + R \qquad (5)$$

where DT represents the decisional time and R represents the residual time taken up by such processes as encoding the stimuli and the motor processes required to give the actual response.

Poltrock (1989) examined the variation of RT and accuracy while his participants were instructed to compare digits. He used a random walk model and observed the inverse relationship of response time and error rates. He showed how the results could be fit by the random walk model (Experiments 1 and 2). In Experiment 3, changes in SAT were examined explicitly using three response deadline "target" conditions. He found that (a) error rates increased with faster deadlines, (b) error rates increased as the absolute digit difference decreased and this increase was enhanced with faster deadlines, and (c) when the left-hand digit was greater than right-hand digit, error rates were greater (Figure 9).

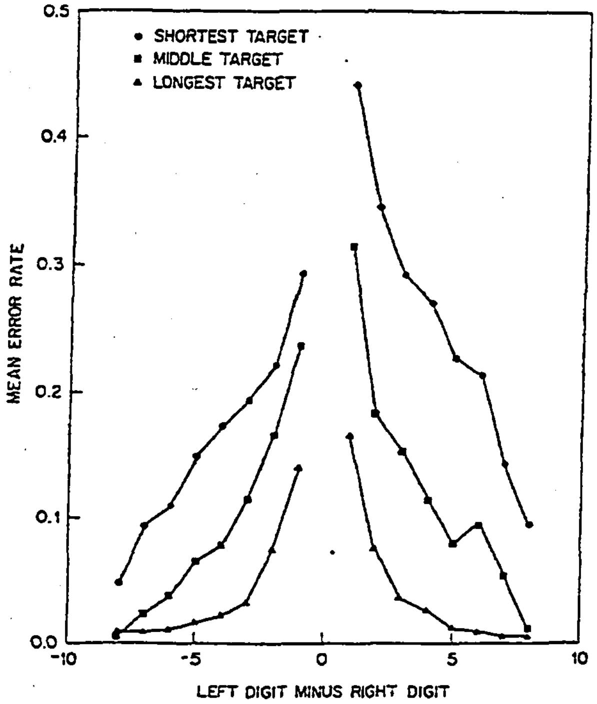


Figure 9: Error rates in calculations of left and right-hand digit in Poltrock's (1989) Experiment 3.

The mean RT as the function of the difference between the left-hand and right-hand digits for each RT target was also investigated. He found that: (a) RTs decreased with faster deadlines, (b) RT decreased with digit differences but less so at faster deadlines, and (c) when the left-hand digit was greater than the right-hand digit, mean RTs were longer (Figure 10).

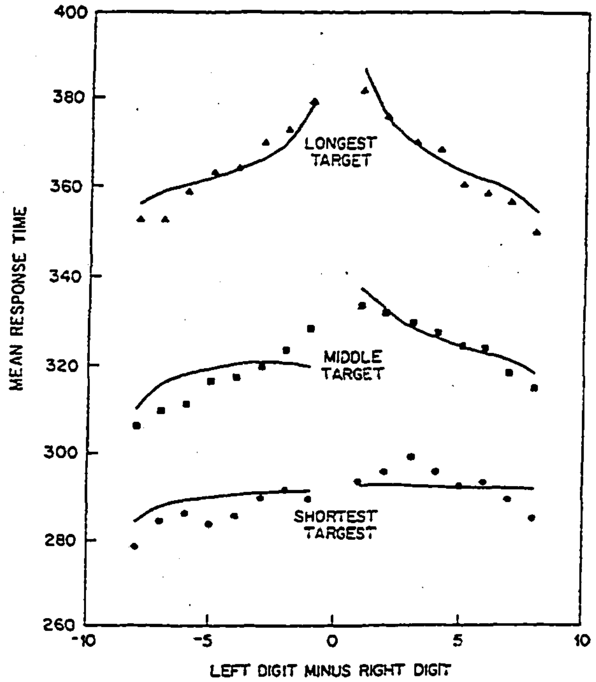


Figure 10: RTs in calculations of left and right-hand digit in Poltrock's (1989) Experiment 3.

All of these effects on errors and RTs could be modeled by assuming (a) that evidence accumulation rate increases with digit differences, (b) that decision thresholds are smaller for shorter deadlines, and (c) that the starting point was biased towards responding that the left digit was smaller.

In addition, the modeling results also indicated that the residual component, R, decreased with shorter deadlines. This result suggested that speed emphasis can induce a general speed up in non-decisional processing components as well.

2.2. Accumulator Model

In the accumulator model, evidence is assumed to be added in or totaled with other available evidence about that stimulus received up to that moment. When some critical values are met, a response is made. A higher probability of being correct and longer RT would be expected as the critical values are raised or the evidence is weak.

The accumulator model also follows a similar logic to the random walk model, however in the accumulator model, evidence is aggregated for each alternative separately. The accumulator model has separate counters (Ruthruff, 1996) which keep track of the amount of evidence for each alternative. Once any of these counters has reached its criterion, the response is executed. In random walk model, instead, a single counter keeps track of the evidences in favor of one response over another. Once the counter has reached to its either positive or negative criterion, the response is executed.

Response Signal Paradigm

The presentation of a response signal is a method which has been used extensively to study the SAT function at different delay interval conditions. Some of the earliest work employing the response signal paradigm was performed by Schouten and Bekker (1967). These researchers referred to their paradigm as the "method of forced reaction time" in order to contrast it with the standard "free reaction time" method. These researchers reasoned that forcing participants to respond very shortly after appearance of a stimulus in a choice reaction time task would allow them to explicitly determine the nature of the dependence between the proportion of errors and reaction time. Although this issue could be examined by measuring the degree of error responding associated with very fast response times in free reactions, typically the number of such responses is quite small. Schouten and Bekker (1967) were interested in demonstrating whether such a dependency existed because it would essentially serve to rule out any theory of choice reaction performance that assumes that participants can only react when they have reached a certain degree of certainty.

Their task involved a manual choice response to two visual stimuli which were always kept in view for 1 s. The response signal employed was a series of three acoustic pips separated by 75 ms, for which their participants were instructed to respond concurrently with the third pip. Response signals used ranged from 100 ms to 800 ms and were presented in a blocked fashion with 100 choice trials per block.

Schouten and Bekker (1967) found that their participants could indeed respond at the very short response signals although, like waiting for long response signals to occur before responding, it often seemed rather un-natural to do so. Their results showed that error proportions were sharply enhanced for very short response times and decreased in a gradual fashion as response time increased (both across and within distributions of responses to the different response signal times). To account for their results, these researchers proposed a theory of perceptual focusing in which the perceptual representations of each of the presented stimuli become more defined as a function of time. Importantly, they also proposed that any one participant's free reaction time performance was likely determined by a compromise between both the level of speed and the level of accuracy that was acceptable to them.

In a now classic recognition memory experiment, Reed (1973) used the offset of the test recognition stimulus as the response signal and required his participants to respond after different intervals from the stimulus onset in a mixed manner in which the different delay duration conditions occurred within the blocks of trials. After spending 15 s vocally counting back from a number by threes, participants were required to remember and respond if the displayed test consonants and digits were among the three consonants and three-digit number shown on an electroluminescent display panel at the beginning of trial. By setting different response signal latencies (after the 15 seconds) of 0.5, 1, 2, 4, and 8 s, Reed (1973) was able to measure the retrieval accuracy (in terms of d_t) at different time lags. He found that accuracy increased with total recognition time (signal plus latency) in a negatively accelerated fashion (i.e., less increase at higher signal times). Importantly, Reed (1973) argued that these data were incompatible with "fast-guessing" because, unlike the deadline method, participants were not told how much retrieval time they would have on each trial.

Next, Corbett and Wickelgren (1978) studied SAT in a semantic memory retrieval context in which instances that are rated as most typical of a category are retrieved faster than others. In other words, some category-example associations (e.g., a robin as a bird) are verified faster than some others (e.g., chicken as a bird). They used the category-example production norms as a measure of instance "dominance" which refers to the strength of association from a category to an instance in category-example associations.

In reviewing different models for semantic memory retrieval, Corbett and Wickelgren (1978) pointed to the models in which typicality plays a critical role. In the "serial search model" (Rosch, 1973, cited in Corbett & Wickelgren, 1978), a string of features from the most to the least typical is assumed to exist. A search starts and continues (from "the best" to "the worst" typical feature) in that category until a good match is found. In their example, categorizing a robin as a bird, the features of the bird category rate from most typical (such as wings and distinctive shape) to least typical (such as perch in trees). In the "two-stage model" (Smith, Shoben & Rips, 1974, cited in Corbett & Wickelgren, 1978), the defining as well as the characteristic features of both categories and instances are identified. In the first stage, the features are retrieved and matched with equal weighting. The second stage, features weighted by degree of definingness (i.e., essential features) are retrieved and matched. If the degree of match at the first stage meets the high (most typical) or low criteria, a fast positive or negative answer is produced. For the degrees between the two extremes, at the second stage, the defining features are distinguished. Therefore, since the degrees matched with the high or low criteria are answered and do not need to go to the second stage, they take less time than the degrees between the two extremes. In their similar two-stage model, Juola, Fischler, Wood, &

Atkinson (1971, cited in Corbett & Wickelgren, 1978) assumed a direct-access process which produces a "yes-no" decision at the first stage when the associative strength is above a high or below a low criterion. Otherwise moving to the second step is required to do a serial search in order to come up with a decision. Indeed, it occurs for intermediate degrees of similarity when a distinctive "yes" or "no" answer can not be executed. Hence, the overall verification time should be less on the first stage where typical examples are verified than on the second stage.

As the third model, Corbett and Wickelgren (1978) examined the simplest direct-access model for verifying category-example associations (Anderson, 1976; Collins and Loftus, 1975; Wickelgren, 1975; all cited in Corbett & Wickelgren, 1978). This model, assumes a directly activated association without any (serial) search, and no two-stage processing and indeed no difference is predicted in the retrieval process of high and low typical examples in that category. However, direct-access retrieval is not instantaneous and to make more accurate recognition decisions, participants need more time. Improving accuracy (by giving more time) continues to some asymptote level which this level reflects the strength of an association in storage.

An SAT curve, in the context of memory retrieval, provides a direct measure of the entire time course of memory retrieval dynamics associated with given error rates. Corbett and Wickelgren (1978) argued how giving more time to make a recognition decision enhances the strength of the relevant associations in memory and consequently, improves accuracy rate to some asymptotic level. Indeed, it helps to distinctively determine whether associative dominance has its effect on either or both retrieval dynamics and asymptotic strength. Corbett and Wickelgren (1978) assume that the time course starts with an initial period associated with chance accuracy and following that, an exponential approach which is associated with the proportion of remaining and unretrieved trace strength and finally a maximum level which represents the asymptotic accuracy associated with the asymptotic strength of association. Therefore, to obtain the SAT, the response signal method was used in their study in which the signal was presented at some point in time after the stimulus onset on each trial. Their participants were supposed to respond within a short interval thereafter. Since it is assumed that the information continues to accumulate until the response signal occurs, the decision is then based on the level of accumulation.

Four participants were involved in the study. Each trial started with a "Ready" message on a screen for 1 s followed by presenting 1 of 52 category names for 2 s. Then, a test example which may (one of 30 category members) or may not belong to that category was presented. The test example remained on the screen and the participants had variable (and randomly assigned) time lags of 0, 100, 200, 300, 400, 600, 800, 1000, 2000, and 3000 ms from onset of the example when a brief tone (the signal) prompted them to make a yes-no response of whether or not the example belonged to that category. The participants were instructed to respond within 200 ms after the tone and the example (stimulus) remained on the screen till a response was made. Hence, two time intervals could be measured (a) the lag, which was the delay between presenting the example and the beep sound (response signal) and (b) the latency, the delay between the beep sound and the participant's response. Total retrieval time was calculated by adding the two time intervals for each trial.

Participants received a total of 3000 experimental trials over 20 sessions with a pause of 2 - 3 s between each trial. After responding to each trial, they were also requested to rate their confidence in their yes-no decision on a scale from one to six. Following that, they were provided feedback on their latencies (from the onset of the tone). One of the differences between Schouten and Bekker (1967) SAT study and this study is that instead of having two different stimuli which are mapped on to one of two response buttons, there were 1500 possible correct and incorrect category-example pairs.

After excluding a small number of responses with latencies greater than 1 s, the mean for latencies at the 10 different lags of the four participants revealed that latencies were longest at the shortest lag and on average decreased by 60 ms from the shortest to the longest lags (180 ms - 240 ms). The accuracy rate for each lag was measured by d_t, which is a d′–type measure based on two probabilities of a successful "yes" response condition and its comparable error condition after adjusting for the effects of non-unit slope based on the confidence judgment data. Plotting the SAT graph showed a typical SAT curve for each participant where the mean for the intercept (δ), rate (γ), and asymptote (λ) parameters were as follows: 438 ms, 0.0045, and 3.8. Some accuracy measures for data collected at the two shortest lags (because of high response bias) and at the five longest lags (because of perfect performance) were also not available for some participants and were excluded before the analysis.

After dividing the category-example pairs into three different levels of dominance associations, the SAT functions obtained for each level were fit with four different models for parameters. The models were different on the basis of the dominance influence on each of asymptotic strength (λ) and retrieval dynamics (γ and/or δ). Among four best-fitting models, which were nearly equivalent, the simplest one which assumed that the dominant and the less dominant category-example associations differ only in asymptotic associative strength, with no difference in intercept and retrieval dynamics (3λ, 1γ, 1δ) was selected as the best model. Hence, asymptotic strength, in that model, decreased from high to medium to low dominance associations while retrieval dynamics did not change across different dominance level.

Considering the fact that the first two semantic memory retrieval models (the serial search model and two-stage model) both apply a similar progressive search procedure, they were expected to predict either intercept or rate differences with typicality/dominance differences. However, this was not found as the best SAT model differentiated between instance dominance levels only with respect to the asymptote. Instead, the results were deemed consistent with the third semantic memory retrieval model, the simplest direct-access model as it predicted no difference in the retrieval process in terms of dominance level associations.

Also, to study the practice effect, the 20 sessions of the experiment was split in half and pooled for each participant as the first and last halves. Then, they were then fit with the four different models to obtain a best-fitting model. However, no significant change or improvement was seen in the parameters in each of the models suggesting any change in asymptotic strength (λ) or retrieval dynamics (γ and/or δ). Therefore, long-term practice was considered invariant with respect to each of the SAT curve components.

Next, Dosher (1981) studied the effect of associative interference on the speed of memory retrieval as well as strength of the memory trace. In other words, (1) length of delay after study and (2) amount of associative interference were investigated in terms of memory retrieval speed and accuracy. Presenting several relevant retrieval models, Dosher (1981) indicated how in some models of studying memory and forgetting, such as Wickelgren's (1974, cited in Dosher, 1981) model of memory storage dynamics, memory trace strength is affected by initial degree of learning, time since learning, interference with other materials, and trace fragility. However, retrieval speed has been often ignored and recognition accuracy under relatively unspeeded retrieval conditions was being measured following a limited training period.

Another group of studies reviewed by Dosher (1981) were those that investigated interference manipulations in the sentence memory domain (such as Anderson, 1974, cited in Dosher, 1981) in which the effects of repeated use of a word in different sentences of a multi-sentence stimulus set has been examined. After presenting several sentences in the learning phase, reaction times were measured to recognize a test sentence as true or false. The results showed large and stable increases of reaction time when using shared sentences, which presumably act as interference.

Applying the SAT methodology, Dosher (1981) used the response signal method to examine memory processes for verbal associations. Since recognition involves different degrees of accuracy, a SAT relation which is called the "retrieval function" could be drawn by having several interruption times showing the relation between recognition accuracy and response time. This issue was examined by presenting the test items and then interrupting the retrieval process at various times to produce a SAT curve in which intercept refers to the minimum retrieval time, rate indicates the retrieval process where accuracy is improving as processing time increases, and asymptote indicates the overall strength of the memory (maximum accuracy). In this way, the second phase of the SAT, where accuracy is improving with increased processing time, reflects the speed of the retrieval process and the asymptote represents the strength of the memory trace in memory.

The (six) participants in the experiment were required to learn a series of word pairs which contained either an interference relation (AB, DE, AC, including a shared member, A) or did not (AB, DE, FC, with no members in common). After three study trials, participants had a test trial which began with a 3 second backward counting followed by the presentation of recognition probe, an old/new pair of stimuli. After the response signals, the participants were interrupted with a tone and the yes-no recognition performance was measured.

Short-delay recognition trials tested the group of three paired associates immediately preceding it, while for the long-delay tests, the participants were tested on the five preceding study sets together in the same order of presentation. The other aspects and the format of both short- and long-delay test trials (such as random order of interruption times and types of recognition probes) were identical and the response signal interruptions occurred at 0.3, 0.7, 1, 1.5, 2, and 3 s after test stimuli onset.

Whether associative interference or the length of delay between study and test affected retrieval speed as well as asymptotic strength was examined in the study. Therefore, four basic SAT curves were examined: short-delay interference, long-delay interference, short-delay independent, and long-delay independent. The d_t average of each condition across participants for accuracy was the lowest (1.317) for interference, long delay with a small change (to 1.364) for independent, long delay. Instead, in short delay a large increase (in d_t) was observed for both interference (1.771) and independent (1.924) conditions. Results of ANOVA then showed a significant effect of delay.

For the RT, as it is expected, participants spent less time to respond in short-delay memory delay (vs. long-delay) conditions and slightly less time in independent (vs. interference) conditions. To justify the difference, Dosher (1981) referred to the awareness of the participants about the delay condition operating prior to recognition onset. Moreover, analysis of variance revealed a highly significant effect of lag in which response times after the response signal were slightly longer for shorter interruption times. Since the differences between conditions were actually quite small, a total processing time (defined as the lag plus mean response latency) was used to derive the SAT functions in each of the four conditions. Interestingly, first of all, the same intercept was found for all conditions. Second, the retrieval speed for the long-delay conditions was slower than the short ones which, indeed, was indicated by a significantly smaller rate parameter for the long-delay conditions. The retrieval speed for interference conditions (as expected) was also slower than for corresponding independent conditions. Third, the differences between both short versus long delays and independent versus interfering associations on asymptotic accuracy were clearly evident in these functions. In an attempt to find a best model to fit the data, Dosher (1981) tested several models and presented the (4A, 4R, 1I) model as the one which had the highest r^2.

McElree and Dosher (1989, 1993) used SAT methods to explore the issue of serial versus parallel retrieval processing in memory. In one of the first attempts to study the processes in item recognition (Sternberg, 1969, cited in McElree & Dosher, 1993), a linear function was found for the number of items studied and correct RTs. However, since only RT was measured, the finding could not discriminate between serial and parallel processing mechanisms because both may lead to equivalent RT predictions. One solution to this problem is to consider some properties of RT such as RT variance, the shape, or higher order moments of the RT distribution. Another alternative (and indeed a better way) to contrast the serial and parallel processes is to examining the full time course of processing using SAT procedures in which the retrieval process is interrupted with a cue to respond and accuracy can be measured at various points across the retrieval process. As McElree and Dosher (1993) argued, RT data may represent an unknown mixture of dynamic and asymptotic information processing effects where in some cases RT can covary with dynamic SAT differences (i.e., intercept and rate) and in other cases it can covary with asymptotic SAT differences in the absence of dynamic differences (c.f., Corbett & Wickelgren, 1978). Hence, it is only by using SAT that the impact of experimental factors on dynamic and asymptotic performance in both serial and parallel processing can be clearly distinguished. For example, in a study by McElree and Dosher (1989), no difference was found in SAT retrieval dynamics when participants received different study set sizes (a list of three to six words) or serial positions within the lists, and therefore a parallel (instead of serial) direct access item retrieval process was concluded.

In their next study (McElree & Dosher, 1993), they used SAT techniques to investigate the possible serial or parallel mechanisms of retrieval processes in the recovery of temporal order information from short-term memory. More specifically, they examined performance in the relative judgement of recency task (JOR; i.e., which of two test items was presented more recently in a previous study list).

Temporal tags (Yntema & Trask, 1963, cited in McElree & Dosher, 1993), trace strength (Peterson, 1967, cited in McElree & Dosher, 1993), trace fragility (Wickelgren, 1972, cited in McElree & Dosher, 1993), and attribute counts (Bower, 1972, cited in McElree & Dosher, 1993) been assumed to be used in JOR decisions. However, both Muter (1979, 1980, cited in McElree & Dosher, 1993) and Hacker (1980, cited in McElree & Dosher, 1993) independently examined RT and accuracy in the relative JOR task as a function of item position and found an inverse relationship between mean correct RT and position of the more recent (or later) test probe. As the most recent probe was drawn from earlier study positions, mean RT was increased; which however, was unaffected by the position of the less recent test probe. Accuracy also decreased when the more recent probe was drawn from earlier study positions. When the study position of the more recent probe was held constant, a slight change in accuracy was found for more remote study positions of the other probe.

To model the retrieval pattern of RT and accuracy, Hacker (1980, cited in McElree & Dosher, 1993) proposed a model in which a backward (or recency-based), serial search does the comparison of the test probes with the elements in the memory. Similar to Sternberg's model, in Hacker's model, items are ordered by their positions in the list. Less recent items are less available and probes are compared with elements in memory in a serial fashion with a search that starts with the most recent item in memory and moves backward. This scan is self-terminating in that the first probe that matches an item found in the memory is chosen as the more recent (where either or both items can sometimes become unavailable). The three processing parameters in this model are as follows: (a) a base time, b, which is the average time to encode probes and respond, (b) a search time, s, which is the average time to compare the test probes with an individual item in memory, and (c) a guessing time, g, which is the average time to guess in case of unavailability of both probes.

Although, the mean RT data patterns for JOR judgments are consistent with a serial-search scan model, they can not deny the existence of a parallel model. However, with respect to the SAT curve, McElree and Dosher (1993) argue that the serial backward scan process makes the strong prediction that the intercept of the SAT curve should increase as the most recent item moves away from the end of the study list because no information about the recency of either item is available until the scan reaches the position of the most recent item.

McElree and Dosher (1993) had a total of 20 sessions (14 SAT sessions and 6 standard RT sessions) for their first Experiment (1a and 1b). Each session was consisted of two blocks of 210 trials and following every 3rd SAT session, 1 standard RT session was performed. After presenting six study stimuli sequentially for 300-500 ms each, a test probe consisting of two consonants was presented. For the standard RT sessions, probe items stayed on the screen until a response was made through pressing one of the two keys indicating the (judged) more recent one. In the SAT sessions, depending on the designated lag, the probe stayed on the screen for 0.15, 0.35, 0.55, 0.75, 1.0, 1.5, or 3.0 s and a short tone prompted the participants to respond by pressing one of the two keys (like in the RT sessions). In both tasks, latency feedback was given after each response. In SAT tasks, participants were trained to respond between 130 ms and 270 ms after hearing the tone.

Both the main RT and accuracy (d') results were compatible with Hacker's (1980) serial, self-terminating backward scan model. With respect to how the three components of the SAT curve varied with the conditions, a 5 asymptote, 15 rate, and 3 intercept (5λ-15γ-3δ) model appeared to provide the best description of the data. The 5 asymptote parameters decreased as the position of the most recent test stimulus decreased, there was a different rate parameter for each test pair, and the 3 intercepts were associated with test pairs containing study stimulus 6, 5 - 4, and 3 - 2 respectively. Therefore, in a large extent, the study position of most recent probe affected both the asymptotic and intercept components.

McElree and Dosher (1993) then argued that both RT and SAT tasks reflected common encoding and retrieval processes by showing that standard RT and accuracy points were very close to the observed SAT functions (i.e., by superimposing those points onto the

SAT curve plots). However, as it was also expected, SAT asymptotes were higher than corresponding standard RT task accuracies. The clear and profound differences in SAT intercept associated with the study position of the more recent or later probe showed that the SAT data was completely incompatible with parallel models and its mechanisms and, indeed, provided clear evidence for the serial self-terminating retrieval of order information in the JOR task.

In their Experiment 2, in which the design, stimuli, and procedure were the same as Experiment 1, the test probes were consisted of two consonants: one from the list of the study positions and one new consonant at random from the 14 consonants not presented in the study set. In that way, the experiment focused on the issue of the retrieval of item versus information within the exact same two-alternative forced-chance paradigm used in Experiment 1.

Like the first experiment, recognition accuracy significantly varied with study position of the old probes indicating a typical serial position function. Departing from the pattern reported in other studies, there was an apparent rate advantage for the next-to-most recent position (i.e., Serial Position 5) when compared with other less recent positions. Regarding the best-fitting SAT functions, there were six separate asymptotes (one for each study position), three rate parameters (for study positions 1- 4, 5, and 6), and only one intercept (i.e., a 6λ-3γ-1δ fit).

Experiment 1

A review of the task switching literature reveals that endogenous control is responsible, at least to a part, for switching costs. Even the TSI account (Allport et al., 1994) does not deny the involvement of executive control processes in task switching because to do switching and complete the tasks, awareness and intentions are needed. Moreover, Allport et al. (1994; Experiment 5) also found a "small reduction" in switch costs when the tasks were predictable.

Indeed, it is generally accepted that reconfiguration processes are intentional and therefore, can be manipulated. To examine this issue further and to examine the extent to which control processes involving in task switching are affected by intentions, Experiment 1 was conducted. To study the extent of participants' control on the control process of task switching, speed-accuracy manipulations will be used. By applying SAT instructions, the role of (top-down) executive control on switching costs (for example, by shortening it when they are under speed emphasis instruction) could be investigated.

On the other hand, in order to complete the processing (consciously), participants require some time between the tasks (in each trial) to do reconfiguration for the second task. As it has been already investigated and discussed, having short or long intervals between the tasks (RSIs) can significantly affect the responses in terms of switch costs. However, in the best task switch conditions in the sense that the tasks are cued properly and RSI is long enough to do a complete reconfiguration, there are still some switch costs (i.e., residual switch costs) which have been attributed to the exogenous components of switching costs. The FTE account by De Jong (2000) is one of the theories developed to justify the residual switch costs when RSI is long. De Jong (2000) argued that although having long RSIs makes the participants less alert, even though they get the benefit of long RSI to prepare to do the switching, the failures should be common. However, under speed emphasis instruction, participants are motivated to be more prepared and therefore, RT residual switch costs should be smaller because participants would be less likely to fail to engage. Indeed, De Jong's (2000) suggestion formed the initial motivation for this experiment, namely to examine whether speed-accuracy manipulations could affect the residual switch costs.

In general, with respect to the effect of speed emphasis instruction on the size of the latency switch cost at short RSIs, three results are possible a priori. First, if switch costs are reduced, this would have indicated that the endogenous control of task-set reconfiguration can, indeed, be purposefully accelerated just as other non-decisional components of RT can (such a motor processes). If switch costs remain the same, this would indicate that controlled reconfiguration processes are immune to such speed-ups. Finally, an increase in switch costs with speed emphasis would indicate that the strategic requirement to speed responding (which could also be regarded as involving controlled processes) directly interferes with the endogenously controlled process of task set reconfiguration (either structurally or by taking up shared resources).

With respect to the effect of speed emphasis on the size of the switch cost at long RSIs, the same three results are possible with similar accounts for them made on the basis of how speed might affect exogenously controlled reconfiguration processes. However, there are some interesting predictions that arise out of the various different accounts for the source of the residual switch cost. For example, if such costs are due to purely automatic processes (e.g., task repetition priming as proposed by Sohn & Anderson, 2001), no change in the residual switch cost might be expected under different speed versus accuracy emphasis. However, note that if task repetition priming serves to modulate the rate of evidence accrual in the decision process, then attenuating that process under speed emphasis could serve to reduce the residual switch cost as in Poltrock, 1989). Alternatively, if such costs are due to faulty preparatory processes (De Jong, 2000), it might be expected that an arousal-enhancing speed emphasis would enhance preparation and, hence, reduce the residual switch cost.

This experiment was performed in order to isolate and measure the durations of the two identified components of switch costs: endogenous and exogenous. Presenting different speed-accuracy instructions at the beginning of each block also allowed for an examination of the affect of speed-accuracy emphasis on each of these two switch-cost components.

Method

Participants

Thirty-one introductory Psychology students at Carleton University were recruited to participate in the experiment and received two experimental credits toward their final mark for their participation. The participants were made aware that their involvement was voluntary and had the option to withdraw at anytime if they so wished.

Apparatus

Using an IBM compatible PC, MEL software (Micro Experimental Lab System 2.0, Psychology Software Tools, Pittsburgh, PA) regulated event sequencing, generated the stimuli, recorded the responses, and measured their times.

Materials

As a replication of Sohn and Anderson's (2001) method, each stimulus always consisted of two components: A letter which was either one of four vowels (A, E, I, and U) or four constants (G, K, M, and R) and a digit which was either one of four odd numbers (3, 5, 7, and 9) or one of four even numbers (2, 4, 6, and 8). The stimuli were presented in MEL font in the center of the screen, ordered vertically with one located directly above the other.

In total, there are 64 possible different stimuli (i.e., 8 letters X 8 digits). Also like Sohn and Anderson (2001), each trial in this experiment consisted of responding to two of these stimuli in sequence. Hence, each of these 64 letter-digit stimuli was paired with one of the other letter-digit stimuli with the constraints that neither the exact letter nor the exact digit from the first stimulus be repeated in the second stimulus. Two different sets of 64 stimulus pairings were generated by computer. In addition to all of the constraints to be mentioned, one set had all letters in the top location of the first stimulus and the other set had all digits in the top location of the first stimulus. Half of the time in each set the position of the letter and digit was randomly switched from the first to the second stimulus.

Compatibility, as one of the independent variables in this study refers to a situation in which responding to each of the two stimuli on the screen results in a correct response, no matter if it is a letter or a digit task. For example, pressing a left button is a correct response for the letter "A" when completing a letter task. However, if it comes with an odd number (e.g., 3), responding to the digit also results in a correct response for the letter task. Each set of 64 stimulus pairings was then randomly divided into four subsets of 16 pairings with the constraint that every subset contained four compatible/compatible, four compatible/incompatible, four incompatible/compatible, and in four incompatible/incompatible pairs. Compatibility was included as a factor because previous work (Rogers & Monsell, 1995; Meiran, 1996) has shown that it can affect the size of the switch, hence, it is important to determine whether it can also moderate the effect of speed versus accuracy emphasis. As well, 8 of the pairings in each subset of 16 were randomly assigned to be task-repeat trials and 8 to be task-switch trials. Of the eight task-repeat trials, four were assigned to be letter-letter trials and four to be digit-digit trials, and of the eight task-switch trials, four were assigned to be letter-digit trials and four to be digit-letter trials. The latter assignments were also constrained to have each of the four possible left-right manual response pairings to each of the stimuli in a trial occur four times each within each subset of 16 pairings.

Four blocks of 32 trials were then derived by joining two subsets of 16 pairings from each set of 64 pairings (note that in addition to the number of task repeat and switch trials, all possible combinations of letter-digit locations within and across the first and second stimuli, letter-digit response compatibility across the first and second stimuli, letter-digit task assignments across the first and second stimuli, and left-right responses across the first and second stimuli were equalized within each block of 32 trials). As well, four more blocks of trials were derived by reversing the task repeat and task switch assignments from the first four blocks. For each of trials in these four other blocks, new letter and digit task assignments were derived according to the same constraints mentioned above.

Procedure and Design

The experiment took place in Rooms A530 and A530A of the Loeb Building at Carleton University. Each participant was tested individually in a quiet environment. The experimental session was approximately 1 hour and 30 minutes in length. Participants were seated approximately 70 cm away from the computer monitor with their left and right index fingers ready to press two different labeled keys ("s" and ";") in response to the different stimuli. To enhance concentration and perception of the stimuli, the experimental room was kept dark except for a dim light from a lamp positioned behind the participant.

Speed-accuracy emphases in Experiment 1 were presented at the start of each block through two different short and explicit instructions prior to trial presentations. Speed emphasis: "It is important that you go very fast for these tasks, completing them in the shortest possible time, while still trying not to completely ignore the accuracy of your responding". Accuracy emphasis: "It is important that you try to be very accurate for these tasks, avoiding errors as much as possible, while still trying not to take too much time".

Each trial started with either a "REPEAT" or a "SWITCH" message at the top center of the screen, which forewarned the participants that there would be either two similar tasks (repeat) or two different tasks (switch) on that trial. In Experiment 1, this message remained on the screen throughout the whole trial. Whenever he or she was ready to start the trial, the participant pressed the space bar. Following a pause of 1000 ms, the first stimulus was displayed. The participants were already instructed at the beginning of the experiment that a green-coloured stimulus signaled the letter task and that a red-coloured stimulus signaled the digit task. Participants were instructed to press the left "s" key for vowels or odd numbers and the right ";" key for consonants or even numbers.

Either a short or long interval (200 ms for short RSIs and 2000 ms for long RSIs) separated the response to the first stimulus and the onset of the second stimulus (see Figures 11 and 12). If it was a task repetition trial, the task for the first stimulus was identical to the task for the second stimulus (i.e., if the first task was a letter task, they received another letter task and if the first task was a digit task, another digit task occurred). The second stimulus was presented after the RSI and stayed on the screen until the participant responded by pressing one of the designated keys to indicate the required response. Between each trial there was a blank screen for 500 ms and then the "REPEAT" or "SWITCH" message appeared again for the next trial.

Each participant performed eight blocks of 32 trials two times in succession. Speed-accuracy instructions were provided at the start of each block and were manipulated over each eight blocks of trials in either an ASSAASSA or SAASSAAS fashion across participants. In each of the eight blocks, half of participants were given four blocks of short RSIs first and the other half were given four blocks of long RSIs first. Note that each of the eight blocks involved two replications of blocks in each of the speed-accuracy emphasis and short-long RSI treatment combinations. Within each block, trials were presented in a completely random fashion that was different for each participant.

Participants were also given two blocks of 8 practice trials at the very start of the experiment, the first to familiarize them with the trials and the second to practice speeded responding. When the first block for a participant was an accuracy-emphasis block, the second practice block occurred just before the second block of 32 trials. Finally, before performing the second round of eight blocks, the participants took a short break. During this break, the experimenter performed a simple analysis that provided that participant's mean correct response time to the second stimulus in each trial during the first four speed-emphasis blocks. The program for the next eight blocks was then adjusted such that if a participant's response time to the second stimulus on a trial during any of the speed-emphasis blocks was greater than 70% of that previous mean time, a "TOO SLOW" message was displayed for 1000 ms after that response had been made.

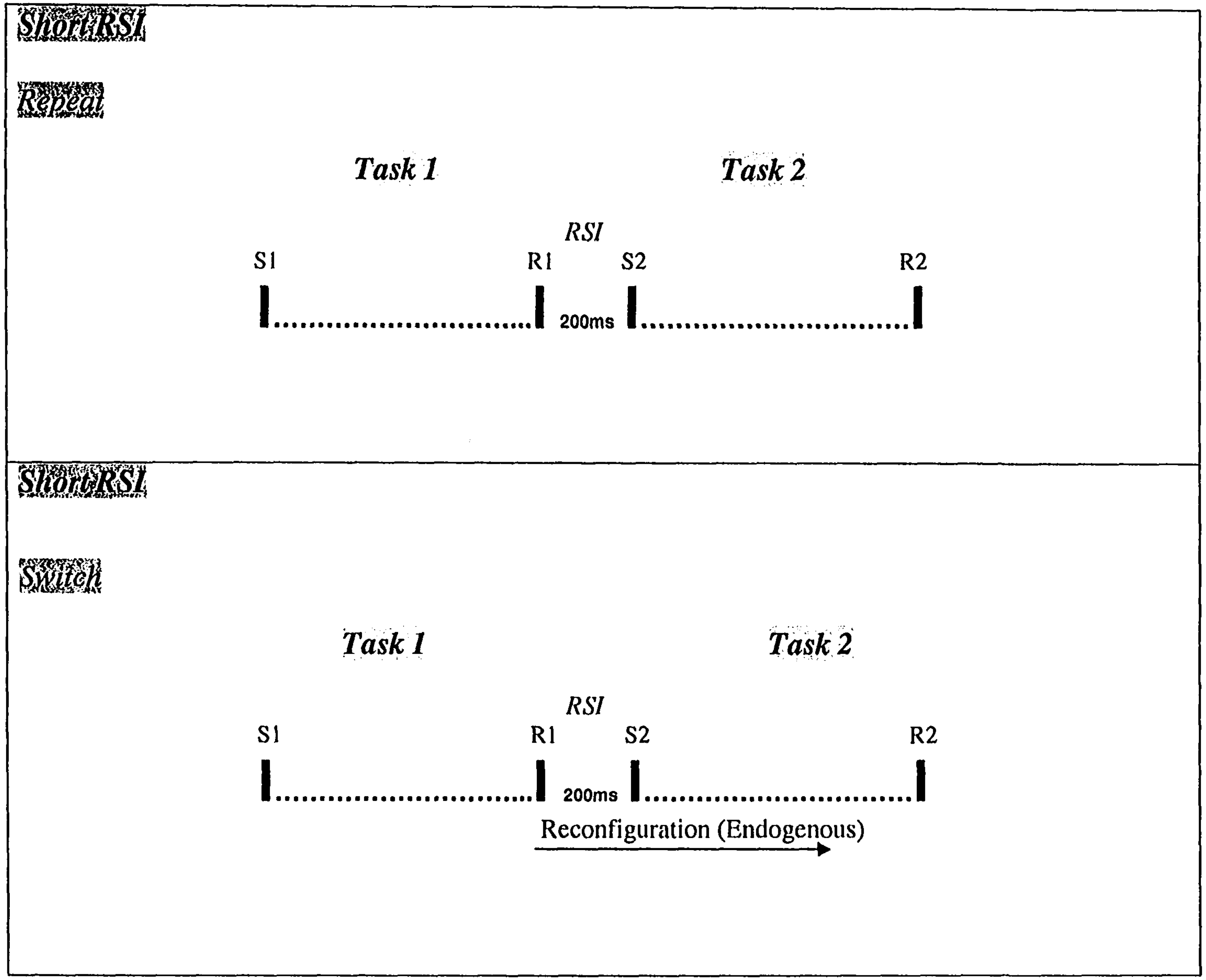


Figure 11: Schematic of Repeat and Switch Trials in Experiment 1 with Short RSI

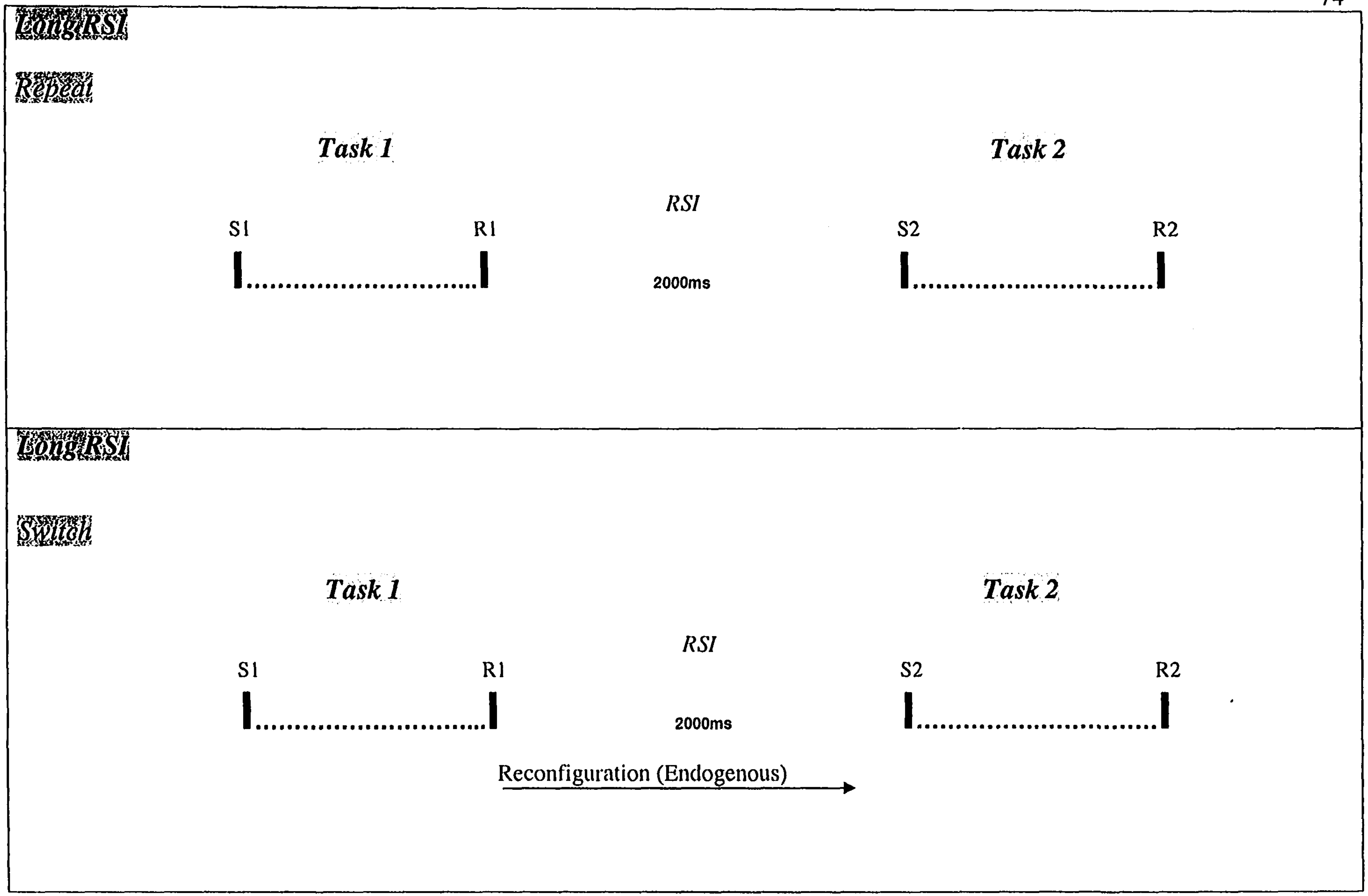


Figure 12: Schematic of Repeat and Switch Trials in Experiment 1 with Long RSI

Results

The first eight blocks of trials for each participant was regarded as practice. The mean correct response times and accuracy for responses to the second stimulus (i.e., Task 2) in each trial during the second eight blocks of trials was analyzed using a 2 (instructional emphasis: speed, accuracy) X 2 (RSI: short, long) X 2 (task transition type: repeat, switch) X 2 (second stimulus task type: letter, digit) X 2 (second stimulus compatibility type: compatible, incompatible) X 2 (block replication: first, second) fully repeated measures design.

Using the MEL "Analyze" program to filter the data, a trial was counted as correct whenever Task 1 and Task 2 responses both were correct. At the beginning, the data of two participants who had overall accuracy at the chance level and one participant who had 16 missing cell values were discarded from the analysis. RT data lower than 200 ms and greater than 5000 ms were not used in the analysis. Some of the remaining data also seemed to represent extreme values. Considering the fact that the tasks were very simple and that the participants had a full practice session (i.e., the first eight blocks were regarded as practice) prior to the actual experimental session, the RT data were explored for any possible outliers by computing standardized (z) scores for each condition in the data set. After marking the observations with standardized scores in excess of 3.0 (21 out of 1792 cases, 1.1%), they were labeled as outliers. To reduce their impact, they were replaced with scores obtained through the following "additive model" procedure:

Grand Mean + (Participant Mean – Grand Mean) + (Condition Mean – Grand Mean), in which the second term represents the participant effect and the third term represents the condition cell effect. This equation can also be simplified as:

$$\text{Participant Mean} + \text{Condition Mean} - \text{Grand Mean}.$$

This same procedure was used for replacing 52 (2.9%) other missing observations.

Task 1 analysis

Latency

Before examining the method and results of Task 2 analysis, it should be mentioned that an identical analysis was also done for Task 1 latencies. The results showed that except for a speed-accuracy instruction emphasis main effect [$F(1, 27) = 14.160, p < .001, MSE = 3280841$], no any other main effect was significant. As well, among 56 possible interactions involving the six variables under study, only 3 interactions of Task Transition X Task Type [$F(1, 27) = 6.644, p < .016, MSE = 757867$], Task Type X Compatibility [$F(1, 27) = 4.837, p < .037, MSE = 210781$], and RSI X Task Transition X Task Type X Block [$F(1, 27) = 4.257, p < .049, MSE = 170627$] were found to be significant effects for Task 1 latency.

Task 2 analysis

The overall mean latency regardless of the condition was 942 ms with an overall accuracy rate of .888. Table 1 shows the mean latency and accuracy rate for Task 2 as a function of RSI, block replication, task type, task transition, instruction emphasis, and compatibility.

Table 1: Mean of Latencies and Accuracy Rates for the Levels of Each of the Six Independent Variables in Experiment 1.

Source	*Mean (ms)*	*Accuracy Rate*
RSI		
Short	930	.878
Long	954	.899
BLOCK		
First	966	.888
Second	918	.888
TASK TYPE		
Letter	973	.886
Digit	910	.891
TASK TRANSITION		
Repeat	871	.911
Switch	1013	.865
INSTRUCTION EMPHASIS		
Accuracy	1098	.941
Speed	785	.836
STIMULUS COMPATIBILITY		
Compatible	934	.904
Incompatible	949	.872

The mean correct RTs and accuracy rates in the experimental session for each participant at each of the 64 treatment combinations (a full listing of which is presented in Appendix A) were used as dependent variables in two separate, fully repeated measures 2 X 2 X 2 X 2 X 2 X 2 analysis of variance (ANOVA) design. These designs included the independent variables of instruction emphasis (accuracy-speed), RSI (200 ms and 2000 ms), block replication (first-second), task type (letter-digit), compatibility (compatible-incompatible), and task transition (repeat-switch). Because all factors had only two levels, there was no need to use the Greenhouse-Geisser epsilon adjusted degrees of freedom.

Latency

All significant main effects and interactions of latencies found in these analyses are reported in Table 2. The complete list of the ANOVA latency results is presented in Appendix B.

Table 2: Significant ANOVA Results for Latencies in Experiment 1.

Task Transition
Instruction Emphasis
Task Type
Block
RSI x Task Transition
Task Transition x Task Type
Instruction Emphasis x Task Type
Instruction Emphasis x Block
RSI x Block x Task Transition
RSI x Task Transition x Compatibility x Task Type
RSI x Block x Compatibility x Task Type

As expected, the main effect between repeat and switch trials was highly significant [$F(1, 27) = 68.714, p < .0001, MSE = 131192$]. Therefore, it significantly took longer for the participants to perform Task 2 when the task type was switched from Task 1 than when it was repeated (see Table 1). The analysis also yielded significant main effects of instruction emphasis [$F(1, 27) = 63.064, p < .0001, MSE = 693340$]. Participants were faster under speed instructions than accuracy instructions (see Table 1). This criterion showed the extent of differentiation between the two instructions by the participants and indeed reflected the effectiveness of those instructions. A significant main effect was also found between letter and digit tasks [$F(1, 27) = 9.992, p < .004, MSE = 176302$]; that is, on average, the participants responded faster to the digit task than to the letter task (see Table 1). The main effect of block replication was also significant [$F(1, 27) = 8.189, p < .008, MSE = 126310$]. The participants spent more time to complete the tasks the first time they performed a specific speed-accuracy, short-long RSI block than the second time (see Table 1). Finally, no significant main effects of RSI [$F(1, 27) = 1.275, p < .269, MSE = 206439$] or compatibility [$F(1, 27) = 1.780, p < .193, MSE = 61224$] were found.

It is important, as well, to note that the mean Task 2 error latencies were 977 ms and 659 ms in the speed and accuracy emphasis conditions, respectively.

Table 2 also reports seven significant interactions for which in four of them RSI is involved, although its main effect was not significant. Compatibility was involved in two of the higher-order interactions. Except for Figure 17, the following figures represent the significant latency interactions with the corresponding accuracy data. Along with the means in the figures, whenever interaction effects were significant, 95% Loftus and Masson (1994) confidence intervals were also presented to indicate the range of potential values above and below the means, showing the magnitude of sampling variability.

First, RSI significantly interacted with task transition [$F(1, 27) = 19.734, p < .0001, MSE = 65455$]. While repeat and switch trials took 832 ms and 1027 ms, respectively, with short RSIs (195 ms switch cost), it took 910 ms to perform repeat trials and 998 ms to perform switch trials with long RSIs (88 ms switch cost). Figure 13 (upper panel) shows mean RT as a function of task transition and RSI.

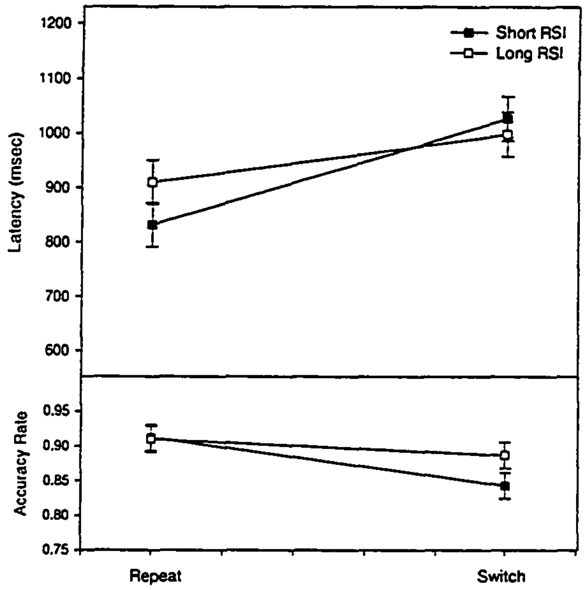


Figure 13: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition and RSI in Experiment 1.

As well, task transition significantly interacted with task type [$F(1, 27) = 5.939, p < .021$, $MSE = 69644$]. Although letter tasks needed more time to be completed in repeat as well as switch trials and both tasks showed slower responses to switch trials, the switch cost for the digit tasks was larger. As it is shown in Figure 14 (upper panel), for the letter tasks, the latency is greater for switch trials (1029 ms) compared to repeat trials (917 ms; a switch cost of 112 ms). For digit tasks, the participants also spent more time to complete the switch trials (996 ms) than the repeat trials (824 ms), but the switch cost was greater (172 ms).

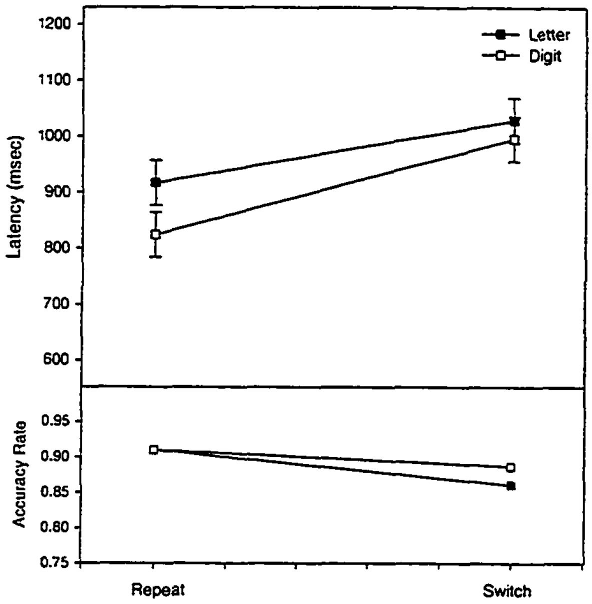


Figure 14: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition and Task Type in Experiment 1.

Furthermore, the main effect of instruction emphasis also interacted significantly with task type [$F(1,27) = 7.498, p < .011, MSE = 56172$]. As it can be clearly seen in Figure 15 (upper panel), while letter and digit tasks took 1145 ms and 1051, respectively, to be completed under accuracy instructions, these latencies were 801 ms (letter) and 769 ms (digit) under speed instructions.

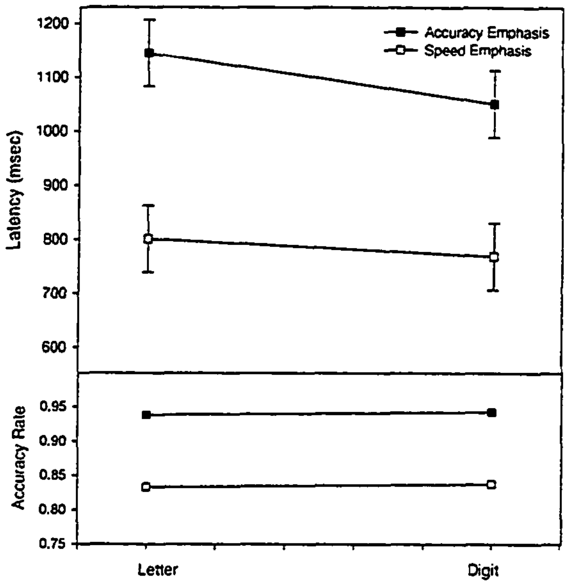


Figure 15: Mean Task 2 Latencies and Accuracy Rates as a Function of Instruction Emphasis and Task Type in Experiment 1.

The last significant two-way interaction was between instruction emphasis and block replication [$F(1, 27) = 4.977, p < .034, MSE = 75545$]. As Figure 16 (upper panel) shows, the participants were faster responding to the trials when they were under speed instructions (i.e., the main effect of instruction emphasis). However, their responses were also affected by the block replication. On average, participants were faster when performing the second block replication than the first block replication under accuracy-emphasis instructions (1136 ms than 1059 ms, respectively). Although the same pattern can be seen for the speed-emphasis instructions, the difference was smaller (795 ms for the first block replication than 776 ms for the second block replication).

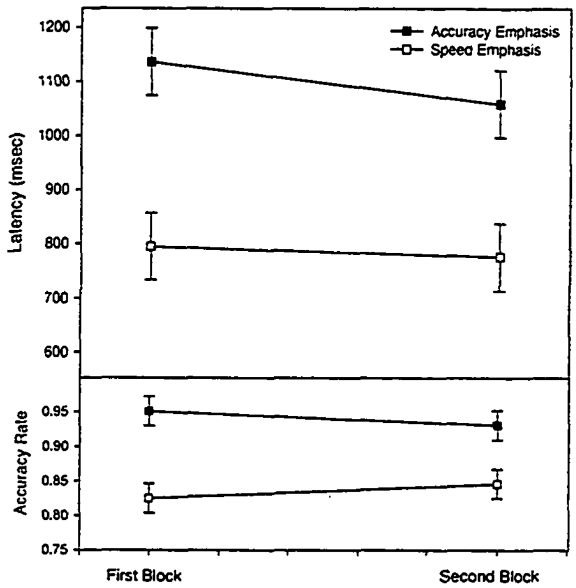


Figure 16: Mean Task 2 Latencies and Accuracy Rates as a Function of Instruction Emphasis and Block in Experiment 1.

Although the interaction between task transition and instruction emphasis was non-significant [$F(1, 27) = 2.247, p < .145, MSE = 88333$], Figure 17 (upper panel) has been given in order to reveal how these two factors functioned in the present experimental setting. This figure shows that the main effects of both instruction emphasis and task transition were additive for RT reflecting the fact that both factors essentially contributed to adding constant effects to the total variance of the RT data. The mean RTs were 1021 ms (repeat) and 1174 ms (switch) under accuracy emphasis instructions (for a switch cost of 153 ms) and 720 ms (repeat) and 851 ms (switch) under speed emphasis instructions (for a switch cost of 131 ms).

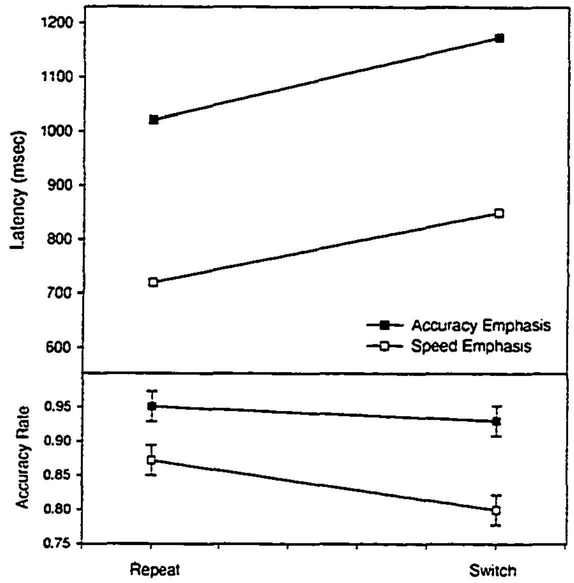


Figure 17: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition and Instruction Emphasis.

The only significant three-way interaction in this study in terms of latency involved RSI, task transition, and block replication [$F(1, 27) = 5.184, p < .031, MSE = 54177$]. Figure 18 (upper panel) illustrates the relations among these factors. While in short and long RSI trials of the second block replication, participants showed a more similar pattern across task transition with a small difference in switch costs (175 ms for short RSIs and 117 ms for long RSIs), in the first block, the switch costs were 217 ms and 59 ms for short and long RSIs respectively.

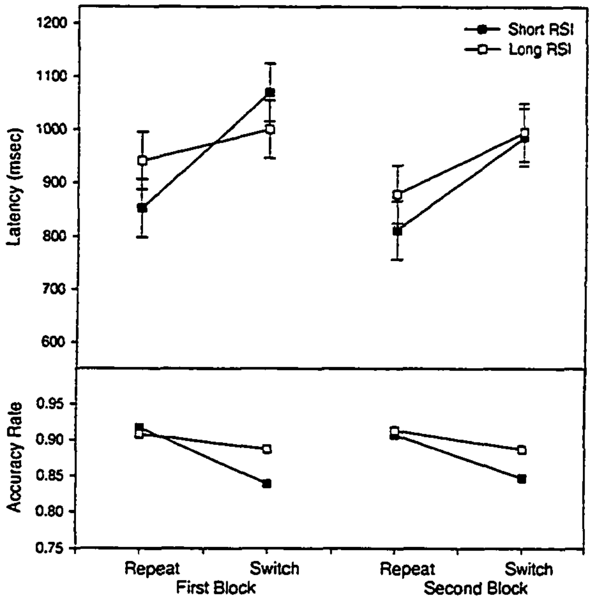


Figure 18: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition, Block, and RSI in Experiment 1.

The four-way interaction involving RSI, task transition, compatibility, and task type is rather interesting. While the three-way interaction of RSI, task transition, and compatibility is not at all significant [$F(1, 27) = .849, p < .364, MSE = 95298$] adding task type changes the picture somewhat [$F(1, 27) = 4.185, p < .05, MSE = 51479$].

As Figure 19 (upper panel) clearly shows, although in both letter and digit tasks, a similar pattern of task transition can be seen in the four conditions of compatibility X RSI, digit tasks showed more variability in task transition, especially in repeat trials. While a relatively large difference in repeat trials can be seen between short (729 ms) and long (878 ms) RSIs of digit tasks in compatible trials, the difference was very small for corresponding incompatible trials (842 ms for short and 862 ms for long RSI). Moreover, although in all conditions, participants completed the switch trials faster when RSI was longer, the difference was much larger in compatible trials of digit tasks (51 ms) than the other three conditions (with a mean difference of 22 ms).

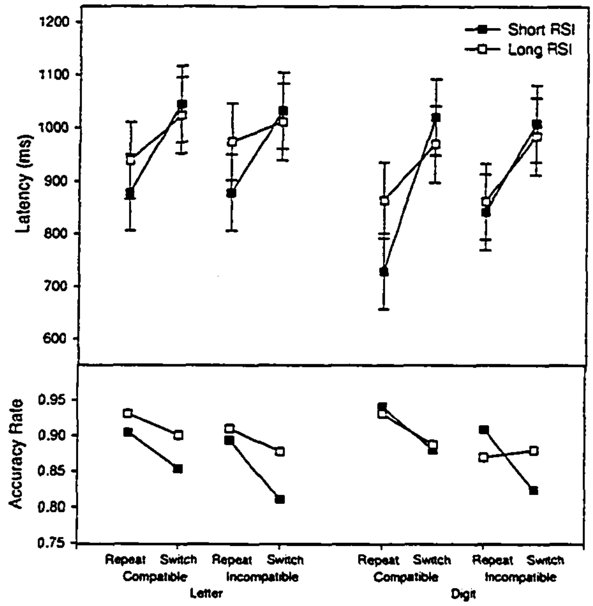


Figure 19: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition, Compatibility, Task Type, and RSI in Experiment 1.

A second significant four-way interaction involves compatibility, RSI, task type, and block replication [$F(1, 27) = 6.206, p < .019, MSE = 39383$]. Figure 20 (upper panel) illustrates this interaction.

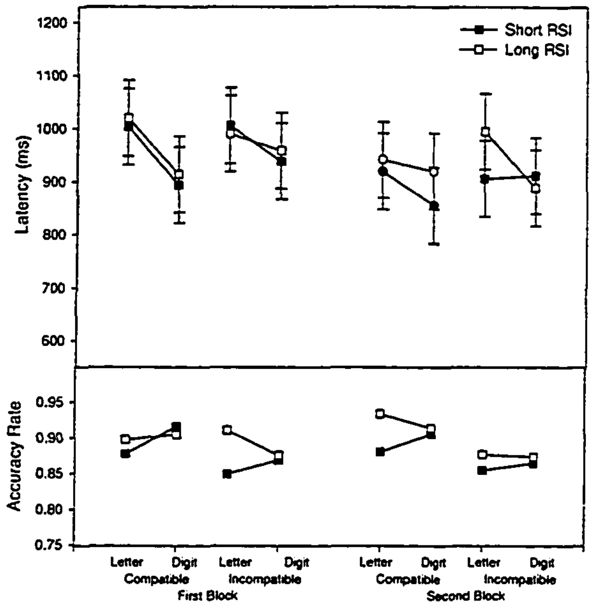


Figure 20: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Type, Compatibility, Block, and RSI in Experiment 1.

No other higher-order interactions reached statistical significance.

Accuracy Rate

All significant main effects and interactions in terms of arcsine transformed accuracy rates are reported in Table 3. (The complete list of the ANOVA results for accuracy rates is presented in Appendix C). The accuracy rate main effects of four independent variables including RSI, Task Transition, Instruction Emphasis, and Compatibility were significant. Along with mean latencies of the six factors, the corresponding mean accuracy rates are also given in Table 1. Mean accuracy rate for the long RSI trials was significantly higher than for the short RSIs [$F(1, 27) = 5.553, p < .025, MSE = .11050$]. Mean accuracy rate for repeat trials was significantly higher than for switch trials [$F(1, 27) = 30.737, p < .0001, MSE = .08683$]. Furthermore, the main effect of compatibility was also significant [$F(1, 27) = 16.311, p < .0001, MSE = .07758$]. The mean accuracy rate for compatible trials was higher than for incompatible trials. Despite this highly significant main effect, as Table 3 shows, the compatibility factor did not form any significant two- or three-way interactions with other factors. Finally, a significant main effect was also found for instruction emphasis [$F(1, 27) = 61.535, p < .0001, MSE =$ .23591]. The mean accuracy rate for the speed emphasis was much lower than for the corresponding accuracy emphasis.

Table 3: Significant ANOVA Results for Accuracy Rates in Experiment 1.

RSI
Task Transition
Compatibility
Instruction Emphasis
RSI * Task Transition
Instruction Emphasis * Task Transition
RSI * Instruction Emphasis
RSI * Task Type
Instruction Emphasis * Block
Instruction Emphasis * Task Transition * RSI
Instruction Emphasis * Task Transition * Compatibility * Task Type
RSI * Task Transition * Compatibility * Task Type * Block

The previous Figure 13 (lower panel) also clearly shows the significant interaction between RSI and task transition in terms of accuracy [$F(1, 27) = 8.071, p < .008, MSE =$ .08069]. The accuracy rates of repeat and switch trials were .912 and .843, respectively (switch cost of 6.9%), when RSI was short. When the interval was long, the participants responded to the repeat trials with a mean accuracy of .910 and to the switch trials with a mean accuracy of .887(switch cost of 2.3%). Putting it another way, receiving different RSIs did not affect the accuracy rate in the repeat trials but did in the switch trials.

Unlike in the RT analysis, the interaction between instruction emphasis and task transition was significant in terms of accuracy [$F(1, 27) = 12.908, p < .001, MSE =$ .05660]. The previous Figure 17 (lower panel) shows this interaction. While under accuracy emphasis instructions, proportion correct was .951 for repeat trials and .930 for switch trials (switch cost of 2.1%). These accuracy rates changed to .872 (repeat trials) and .800 (switch trials) when speed emphasis instructions were given (switch cost of 7.2%).

As well, there was a highly significant interaction of RSI and instruction emphasis [$F(1, 27) = 19.551, p < .0001, MSE = .04977$], reflecting the fact that the accuracy rate of the speed and accuracy instruction emphases is also significantly affected by RSI. When completing the trials under accuracy emphasis, a slightly higher accuracy was seen for the short RSI trials (.944) than the long RSI trials (.937), while under speed emphasis, participants showed much lower accuracy rates for short RSI trials (.811) than for long RSI trials (.860). Figure 21 (lower panel) illustrates this significant accuracy interaction.

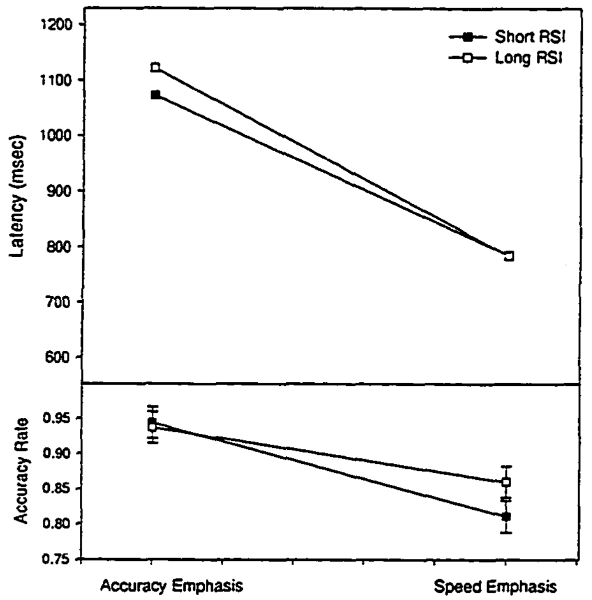


Figure 21: Mean Task 2 Latencies and Accuracy Rates as a Function of Instruction Emphasis and RSI in Experiment 1.

RSI also interacted significantly with task type [$F(1, 27) = 5.943, p < .021, MSE =$ .06032]. In short RSI trials, the mean accuracy rate for letter tasks was .866 and for digit tasks .889. In long RSI trials, the mean accuracy rate for letter and digit tasks were .905 and .892, respectively. Figure 22 (lower panel) illustrates the interaction in which among the four possible conditions, letter tasks with long RSIs had the highest accuracy rate but letter tasks with short RSIs had the lowest accuracy rate. Since the overall mean accuracy for letter tasks was less (.886) than digit tasks (.891), the obtained means reveal the effect of short RSI on task type where it affects responding to letter tasks more than to digit task.

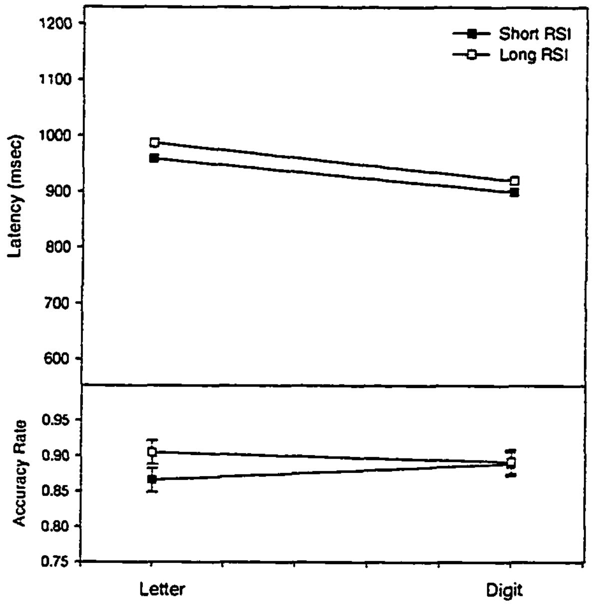


Figure 22: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Type and RSI in Experiment 1.

In addition, as in the RT analysis, instruction emphasis interacted significantly with block replication [$F(1, 27) = 10.722, p < .002, MSE = .07042$]. The participants had differential accuracy rates for the first and second block replication under different instruction emphases. Under accuracy emphasis, they showed higher accuracy rate (.951) in the first block than in the second block (.931). Interestingly, under speed emphasis instruction, the accuracy rate was lower (.825) for the first block than the second block (.846). The significant interaction can be seen in the previous Figure 16 (lower panel).

Although RSI and Compatibility were both significant as main effects, they did not significantly interact with each other [$F(1, 27) = .010, p < .919, MSE = .06517$]. As Figure 23 (lower panel) presents, an additive factor effect exists involving these two factors. For compatible trials, the accuracy means were .895 ms for short and .913 ms for long RSIs. The accuracy means for incompatible trials were .860 ms and .884 ms for short and long RSIs, respectively.

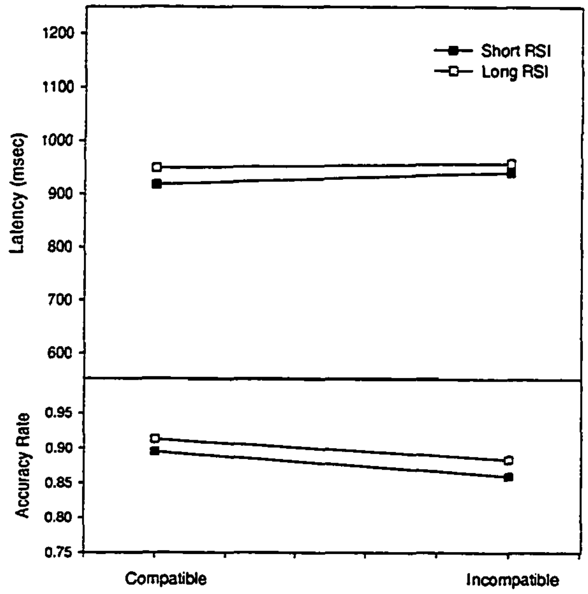


Figure 23: Mean Task 2 Latencies and Accuracy Rates as a Function of Compatibility and RSI in Experiment 1.

Another additive factor effect was also found between task transition and compatibility [$F(1, 27) = .0001, p < .996, MSE = .06713$]. The accuracy means of compatible repeat and switch trials were .927 and .881, respectively. For incompatible trials, participants had the means of .896 for repeat and .848 for switch trials. Figure 24 (lower panel) shows these means.

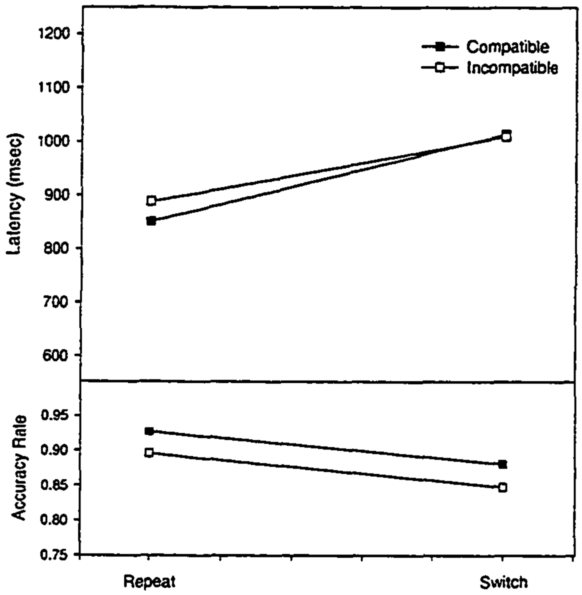


Figure 24: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition and Compatibility in Experiment 1.

There was also a reliable three-way interaction involving RSI, task transition, and instruction emphasis in terms of accuracy [$F(1, 27) = 6.898, p < .014, MSE = .07081$]. The significant interaction is shown in Figure 25 (lower panel). Interestingly, the accuracy rates while under accuracy emphasis were slightly higher when RSIs were short (.954 and .934 for repeat and switch trials, respectively). For long RSIs, the accuracy rates were .948 (repeat) and .926 (switch). However, under speed emphasis instructions, although there is a significant overall decrease from accuracy emphasis, accuracy rates with short RSIs behaved quite differently and were lower in both repeat (.871) and switch (.752) trials. The corresponding long RSI trials showed accuracy rates of .873 (repeat) and .847 (switch).

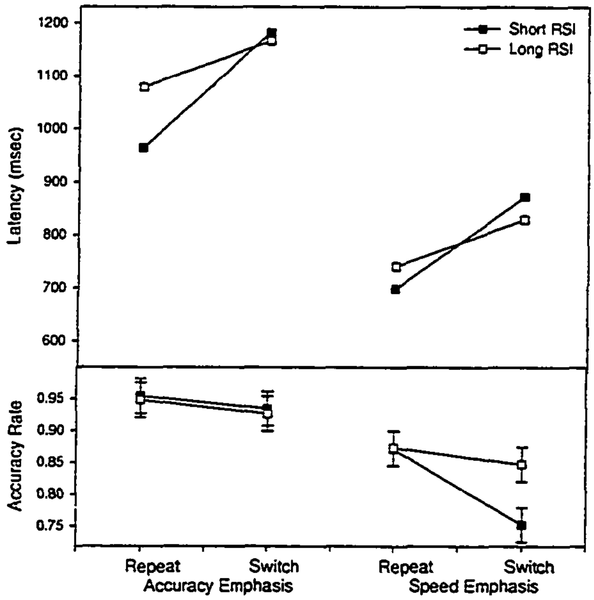


Figure 25: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition, Instruction Emphasis, and RSI in Experiment 1.

A four-way interaction involving task transition, task type, instruction emphasis, and compatibility was also significant [$F(1, 27) = 5.484, p < .049, MSE = .04979$]. Figure 26 (lower panel) shows the means of each of these conditions.

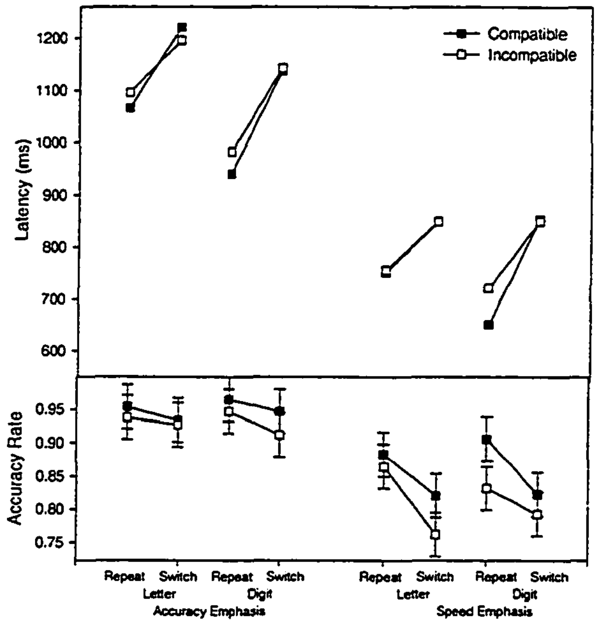


Figure 26: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition, Task Type, Instruction Emphasis, and Compatibility in Experiment 1.

Finally, a five-way interaction involving RSI, block, task type, compatibility, and task transition [$F(1, 27) = 4.380, p < .045, MSE = .06359$] was also found to be significant. No other significant interactions were found in accuracy analysis.

Discussion

As discussed previously, one of the components of switch cost is assumed to involve endogenous control and is responsible for preparing the cognitive system for an upcoming switch. Such preparation involves the top-down activation of relevant or inhibition of irrelevant task set in order to switch to the next task. This process occurs consciously under the control of SAS. The top-down control mechanism reflects task-set reconfiguration which is the process of configuring different connections between cognitive modules (Rogers & Monsell, 1995). This part can be completed prior to the presentation of the second stimulus given enough time. The second component of switch cost, which is assumed to be under exogenous control, refers to the uncontrolled, bottom-up activation that requires the presentation of the stimulus in order to be completed. That is what it is called the residual switch cost (Rogers & Monsell, 1995; Meiran, 1996). By increasing the time for endogenously controlled reconfiguration through providing a longer RSI, the switch cost is decreased and what remains is the residual switch cost, the exogenous component of the switch cost.

Previous research has shown that the switch costs reach an asymptotic level after a period of time (600 ms or so in Rogers & Monsell's, 1995, study) after which there are very small changes (in terms of reductions in RT and number of errors) with more preparation time. Hence, when the RSI is short (i.e., 200 ms), participants will not have enough time to reconfigure and prepare for the upcoming task (see Figure 11). This situation is assumed to have large switch costs (containing both the endogenous and exogenous components). In contrast, the effects of the endogenous (controlled/ preparatory) component of the switch costs should be decreased profoundly when the RSI is long (i.e., 2000 ms) because plenty of time between the two tasks allows the participants to prepare sufficiently for the next task (see Figure 12). Hence, at long RSIs only the exogenous component should remain (Allport et al., 1994; Rogers & Monsell, 1995).

In general, it can be assumed that speed-emphasis instructions should result in faster responses (shorter RTs) and higher number of errors (lower accuracy) for both switch and repeat trials in comparison to accuracy emphasis (longer RTs and higher accuracy). More important, though, is the effect of speed versus accuracy emphasis on the switch cost itself. At short RSIs, it is the effect of such emphases on mainly the endogenous component. At long RSIs, it is the effect of such emphases on only the exogenous component.

With respect to the effect of speed emphasis on the size of the latency switch cost at short RSIs, three results were possible a priori. First, if switch costs were reduced, this would have indicated that the endogenous control of task-set reconfiguration can, indeed, be purposefully accelerated just as other non-decisional components of RT can (such a motor processes). If switch costs remained the same, this would indicate that controlled reconfiguration processes are immune to such speed-ups. Finally, an increase in switch costs with speed emphasis would have indicated that the strategic requirement to speed responding (which could also be regarded as involving controlled processes) directly interferes with the endogenously controlled process of task set reconfiguration (either structurally or by taking up shared resources).

With respect to the effect of speed emphasis on the size of the switch cost at long RSIs, the same three results are possible with similar accounts for them made on the basis of how speed might affect exogenously controlled reconfiguration processes. However, there are some interesting predictions that arise out of the various different accounts for the source of the residual switch cost. For example, if such costs are due to purely automatic processes (e.g., task repetition priming as proposed by Sohn & Anderson, 2001), no change in the residual switch cost might be expected under different speed versus accuracy emphasis. However, note that if task repetition priming serves to modulate the rate of evidence accrual in the decision process, then attenuating that process under speed emphasis could serve to reduce the residual switch cost as in Poltrock, 1989). Alternatively, if such costs are due to faulty preparatory processes (De Jong, 2000), it might be expected that an arousal-enhancing speed emphasis would enhance preparation and, hence, reduce the residual switch cost.

With respect to the actual results of Experiment 1, they are fairly clear in showing that the requirement to speed responding, did not meaningfully reduce the size of the switch cost for either short or long RSIs. As a clue to what potentially might have been happening, the accuracy mean of switch trials for short RSIs under speed emphasis seems to stands out from the rest in Figure 25 (which essentially leads to the three-way interaction in that figure). This can be considered as an evidence that people seem to be having a hard adjusting to the control-related demands of both speeding their responding and switching their mental task set (when they are not given the time to prepare the switch as for long RSIs). Note that this result is not due to the fact that they are speeding up or "rushing" the switching (i.e., reconfiguration) process because the upper plot shows that they are not). Indeed, it seems like in the face of speed demands at short RSIs, people are often still taking the time to reconfigure properly, because they will have a hard time responding correctly otherwise. With respect to the long RSI findings, no change in the switch cost under speed emphasis would seem to support the presence of a stimulus-cued exogenous control process (Rogers & Monsell, 1995) that is used to complete the reconfiguration of task set and whose duration is not under the control of the participants.

There are some other findings of interest in Experiment 1 as well. First, the significant interaction between RSI and task transition (illustrated in Figure 13) represent the "classic" preparation effect (Monsell, 2003) in which more time available for preparation (i.e., longer RSI) results in lower switch cost. Indeed, manipulating RSI has been used as a procedure to measure the endogenous control role in response executions. By increasing the time between tasks, it is assumed that individuals increase their (endogenous) control voluntarily and sequentially, make faster and more accurate responses. However, although participants improved their performance (both in RT and accuracy rate) by having long RSIs in switch trials, there was no gain and indeed a worse performance for long RSIs in repeat trials. It seems that having more time helps to do reconfiguration for a new task (in switch trials) but since no reconfiguration is needed for repeat trials, having more time degrades performance. Because long RSIs had their largest effect in repeat trials, the results in Figure 13 could be regarded as supporting a task repetition benefit effect (Sohn & Anderson, 2001; i.e., which dissipates over time). However, they could also be interpreted in terms of a generalized slowing of both repeat and switch trials at long RSIs. For example, long RSIs in repeat trials could be considered as a pause which deactivates the present task set and more time is needed to load and reactivate the task set (rendering repeat trials more similar to switch trials).

Second, RT switch costs were larger for the easier digit task (see Figure 14). In other words, as in Allport et al. (1994), it was harder to switch from the harder to the easier task than the other way around.

Third, as shown in Figure 15, letter-digit RT differences that exist under accuracy emphasis are not present under speed emphasis. This result is consistent with the fact that in general, speed emphasis typically serves to attenuate RT differences between other conditions (as in Poltrock, 1989). A similar finding with respect to block differences is evident in Figure 16.

Finally, considering Figure 18, It looks like participants could be less "alert" to endogenous preparation at long RSIs when they go through the long RSI blocks a second time (which could reflect a "time-on-task" effect on the "failure to engage" hypothesis introduced by De Jong, 2000).

Experiment 2

The purpose of this experiment was to examine more response time data for a set of well-practiced individuals and also the shapes of the distributions of response times obtained under each of the conditions of Experiment 1.

Method

Participants and Apparatus

Ten students at Carleton University took part in this experiment. To remove any effect of interference, no participants from Experiment 1 were allowed to participate in Experiment 2. Participants were recruited through announcements and received $12 per hour for their participation.

Materials

The materials of Experiment 2 were the same as that in Experiment 1, except for the fact that only the 128 trials from the first four blocks of the Experiment 1 sessions were used along with a new stimulus set of 128 trials that were generated for use in this experiment in the same manner as described for Experiment 1.

Procedure and Design

The procedure and design of Experiment 2 was essentially identical to Experiment 1. However, in this experiment, each participant performed multiple sessions in order to obtain a larger number of observations in each condition from each individual. On the first two days, participants ran through eight blocks of trials each day that were essentially identical to the first and second eight blocks of trials in Experiment 1. On each of the next Days 3 to 6, the participants ran through one set of eight blocks of trials per day (four blocks for each stimulus set). On each day, only one of the RSIs was used (i.e., RSI was blocked across sessions). Half the participants had RSIs of 200 ms on Day 3 that was then alternated with the 2000 ms RSI on subsequent days. The other half started with the 2000 ms RSI on Day 3. Each of the ASSAASSA or SAASSAAS speed-accuracy instruction orders was used twice, once with each RSI. One aspect of Experiment 2 that differed from Experiment 1 was that although as before the REPEAT and SWITCH prompts appeared at the start of each trial, they were erased when the first stimulus was responded to (Experiment 2 and 3 were actually run before Experiment 1 where this aspect was changed).

Before each session, the experimenter obtained the participant's mean correct response time to the second stimulus in each trial during the last four speed-emphasis blocks of the previous day. For Days 2 and 3, 80% of that previous mean time was then used to set the "TOO SLOW" message for that day, and for Days 4–6, the previous mean time itself was simply used to set the "TOO SLOW" message for that day.

Results

Applying similar procedures as those used to filter and analyze the data of Experiment 1, the data of Experiment 2 were reviewed to detect any possible outliers or participants who had very low accuracy and/or had very long overall RTs. No outliers or missing data were found in this data set. Moreover, all of the ten participants had overall accuracy rates above .80. In this experiment also, a trial was counted correct when Task 1 and Task 2 responses both were correct.

Task 1 analysis

Latency

As in Experiment 1, Task 1 latency was also analyzed. The results again showed only the significant main effect of speed-accuracy instruction emphasis [$F(1, 9) = 14.433, p < .004$, $MSE = 826502$]. Among the interactions involving the six variables, 3 interactions of RSI X Task Type X Block [$F(1, 9) = 9.027, p < .015$, $MSE = 12555$], RSI X Task Type X Compatibility X Block [$F(1, 9) = 6.495, p < .031$, $MSE = 39069$], and RSI X Task Transition X Compatibility X Task Type X Block [$F(1, 9) = 5.532, p < .043$, $MSE = 12306$] were significant.

Task 2 analysis

Similar to Experiment 1, a fully repeated measures 2 X 2 X 2 X 2 X 2 X 2 ANOVA design including the independent variables of instruction emphasis (accuracy, speed), RSI (200 ms, 2000 ms), block replication (first, second), task type (letter, digit), stimulus compatibility (compatible, incompatible), and task transition (repeat, switch), was performed to analyze the mean correct RTs and accuracy rates, which were considered as dependent variables, for each participant at each of the 64 treatment combinations. However, instead of having single sessions, the performance of each participant was examined across multiple sessions. Therefore, the participants in Experiment 2 were more experienced and well practiced across 6 days of sessions for which data from the last four days were used in the following analyses. In general, the results could be regarded as being more stable and reliable since more data was collected for each condition from each participant. Again, because all factors had only two levels, no Greenhouse-Geisser adjustments to the degrees of freedom needed to be made.

The overall Task 2 mean latency regardless of the condition was 770 ms with an overall mean accuracy rate of .898. Table 4 shows the mean latency and accuracy rate for Task 2 as a function of RSI, block replication, task type, task transition, instruction emphasis, and compatibility.

Table 4: Mean of Latencies and Accuracy Rates of the Levels of Each of the Six Independent Variables in Experiment 2.

Source	*Mean (ms)*	*Accuracy Rate*
RSI		
Short	722	.885
Long	818	.911
BLOCK		
First	759	.896
Second	781	.900
TASK TYPE		
Letter	748	.903
Digit	791	.893
TASK TRANSITION		
Repeat	717	.922
Switch	822	.874
INSTRUCTION EMPHASIS		
Accuracy	879	.943
Speed	660	.853
COMPATIBILITY		
Compatible	746	.928
Incompatible	794	.868

Latency

Table 5 presents all of the significant main effects and interactions involving latencies found in these analyses. A complete list of the ANOVA results for RT can be found in Appendix D.

Table 5: Significant ANOVA Results for Latencies in Experiment 2.

Task Transition
Instruction Emphasis
RSI
Compatibility
Block
Task Transition X Instruction Emphasis
Task Transition X RSI
Task Type X Block
Task Transition X Compatibility X Task Type
Task Transition X RSI X Compatibility X Task Type

The analysis yielded a high significance of task transition [$F(1, 9) = 33.886, p < .0002$, $MSE = 51916$]. The participants were much faster while completing repeat trials than switch trials. Another significant main effect was of instruction emphasis [$F(1, 9) = 24.595, p < .001$, $MSE = 311846$] which indicate the efficiency of speed-accuracy instructions. As it was expected, when accuracy was emphasized, it took longer to respond than when speed was emphasized. The main effect between short and long RSIs was also significant [$F(1, 9) = 6.235, p < .034, MSE = 240241$]. As Table 5 shows, on average, participants responded faster in short RSI trials than long RSI trials. A main effect between compatible and incompatible trials was also found significant [$F(1, 9) = 7.151, p < .025, MSE = 51096$]. When presenting compatible trials, less time was needed than for incompatible trials. The main effect of block replication was also significant

[$F(1, 9) = 10.463, p < .010, MSE = 7290$]. Indeed, to perform the tasks, more time was needed to complete the second block than the first block.

It is important, as well, to note that the mean Task 2 error latencies were 760 ms and 584 ms in the speed and accuracy emphasis conditions, respectively.

The analysis also yielded five significant interactions (listed in Table 5) for which in four of them, task transition was involved. The significant latency interactions along with corresponding accuracy data are plotted in Figures 27 through 31. In some cases, two figures have been plotted to demonstrate the source of an interaction. For cases involving significant interaction effects, standard error bars derived, using the Loftus and Masson (1993; 2003) method, are given. Among the significant interactions, Task Transition X Instruction Emphasis was the only interaction in which both latency and accuracy rate were significant.

Importantly, the main effect of task transition now significantly interacted with instruction emphasis [$F(1, 9) = 14.588, p < .004, MSE = 6579$]. As Figure 27a and 27b (upper panels) show, the mean RT difference between speed and accuracy emphasis instructions was significantly greater for switch than for repeat trials. The mean RTs for repeat trials under accuracy and speed emphasis instructions were 815 and 620 ms, respectively, whereas these means for the corresponding switch trials were 944 ms for accuracy emphasis and 701 ms for speed emphasis. The corresponding switch costs under accuracy and speed were 129 and 81 ms, respectively.

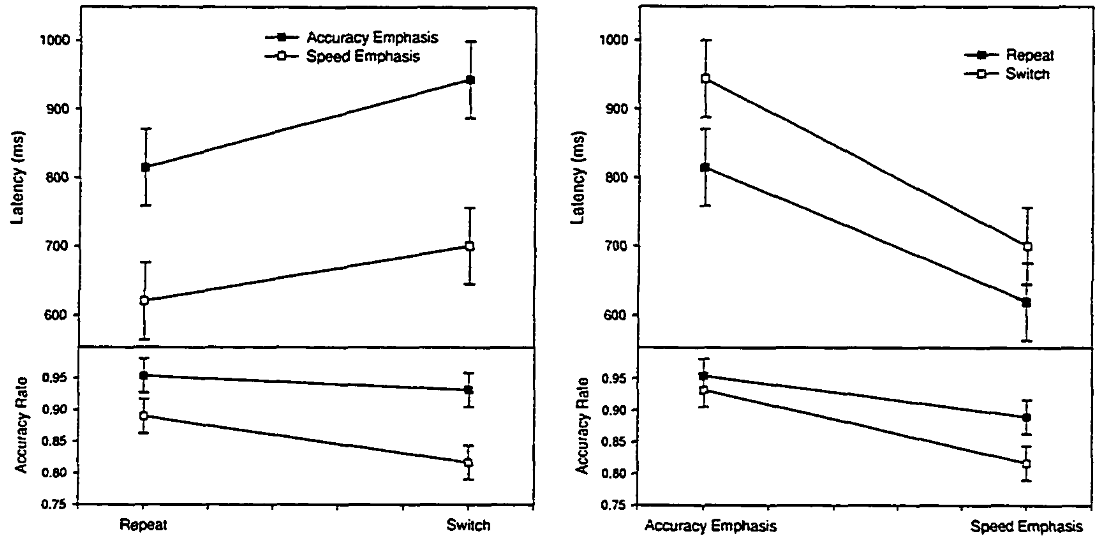


Figure 27a (right) and 27b (left): Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition and Instruction Emphasis in Experiment 2.

Mean RT as a function of RSI and task transition is shown in Figure 28 (upper panel). The interaction between these two components was significant [$F(1, 9) = 9.279, p < .014$, $MSE = 13659$]. On average, the difference between repeat and switch trials was much larger when RSI was short (655 ms for repeat and 788 ms for switch trials for a switch cost of 133 ms) than when it was long (780 ms and 857 ms for repeat and switch trials, respectively, for a switch cost of 77 ms).

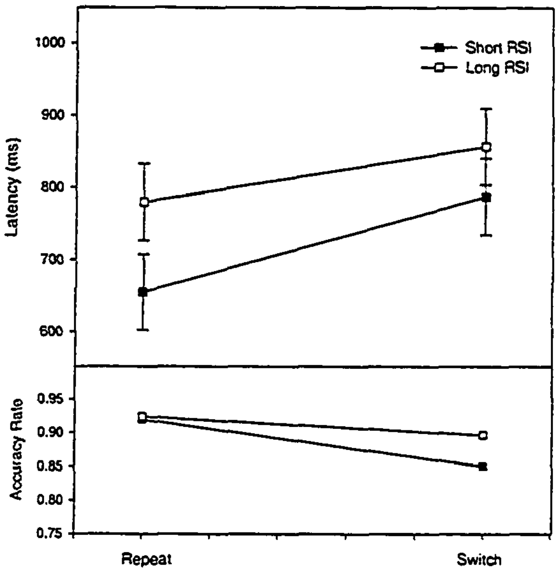


Figure 28: Mean Task 2 Latencies and Accuracy Rates as a Function of RSI and Task Transition in Experiment 2.

Although the main effect of task type appeared to be only marginally significant [$F(1, 9) = 4.983$, $p < .052$, $MSE = 58972$], it formed a significant interaction with block replication [$F(1, 9) = 8.596$, $p < .017$, $MSE = 4894$]. As it is shown in Figure 29 (upper panel), although the mean RT for the first block is only slightly smaller (746 ms) than for the second block (751 ms) for letter tasks, the difference becomes larger for the digit tasks (772 ms and 810 ms for first and second blocks, respectively).

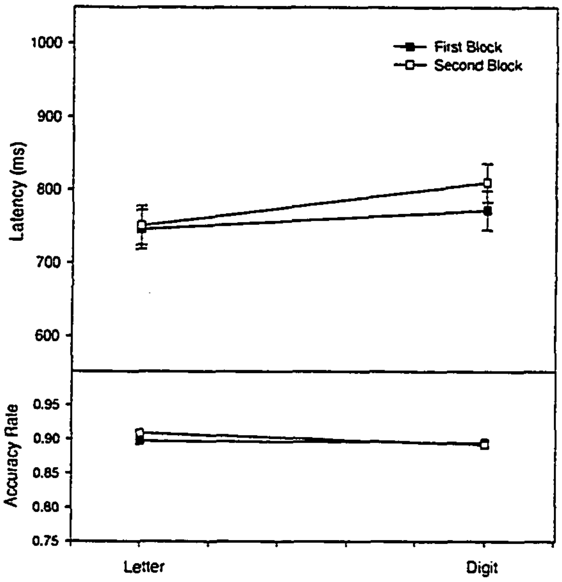


Figure 29: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Type and Block in Experiment 2.

A three-way interaction involving task transition, task type, and compatibility was highly significant [$F(1, 9) = 20.795, p < .001, MSE = 3846$]. As Figure 30b (upper panel) clearly displays, no interaction can be seen between task transition and task type for incompatible trials. Indeed, the source of the interaction can be found in compatible trials where letter and digit tasks show almost same latencies in repeat trials but significantly different latencies in switch trials.

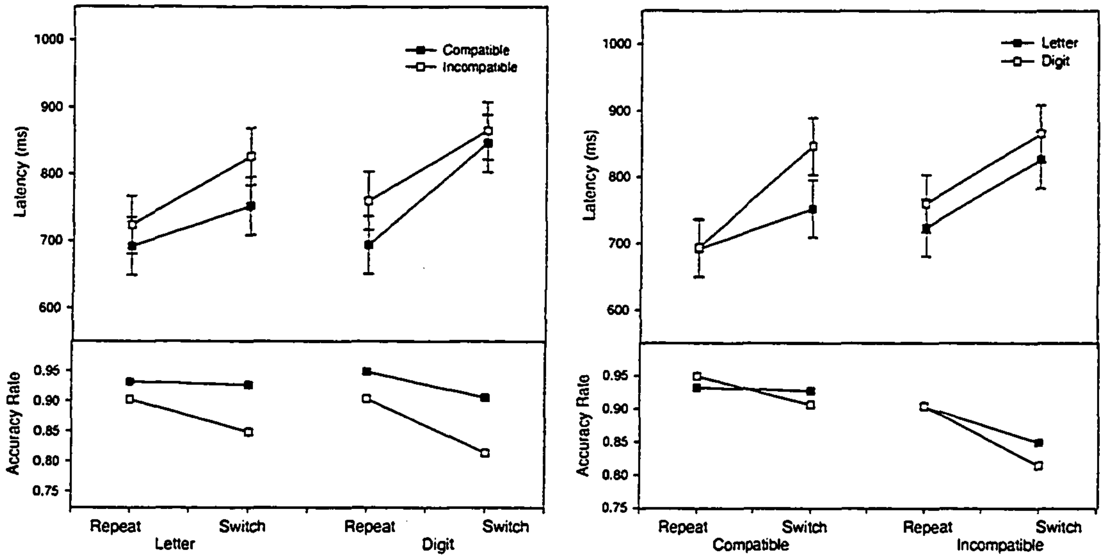


Figure 30a (left) and 30b (right): Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition, Task Type, and Compatibility in Experiment 2.

This three-way interaction is qualified further by a significant four-way interaction involving RSI, task type, compatibility, task transition [$F(1, 9) = 9.310, p < .014, MSE = 6722$]. Figure 31 (upper panel) presents the mean latencies for this interaction which is most evident in the long RSIs, indeed. The figure reveals that for compatible trials in the long RSI blocks, letter tasks show no difference in repeat and switch trials unlike every other repeat-switch difference in this figure.

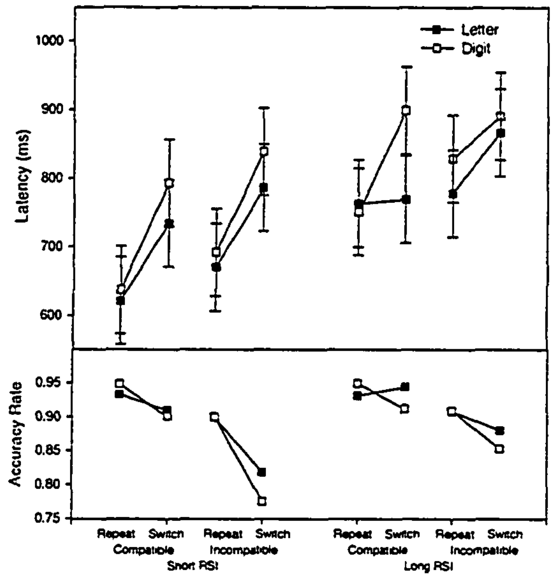


Figure 31: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition, Compatibility, RSI, and Task Type in Experiment 2.

No other significant interactions were found in latency analysis.

It is important to note that the three-way interaction involving task transition, instruction emphasis, and RSI was not significant [$F(1, 9) = .818, p < .389, MSE = 11753$]. Nonetheless the mean latencies of repeat and switch trials in accuracy emphasis blocks were 737 and 903 ms (for a switch cost of 166 ms), respectively, for short RSIs and 892 and 986 ms, respectively, for long RSIs (for a switch cost of 94 ms). The corresponding latencies in speed emphasis blocks were 573 ms and 674 ms, respectively, for short RSIs (for a switch cost of 101 ms) and 668 ms and 728 ms, respectively, for long RSIs (for a switch cost of 60 ms). Figure 32 (upper panel) presents the means.

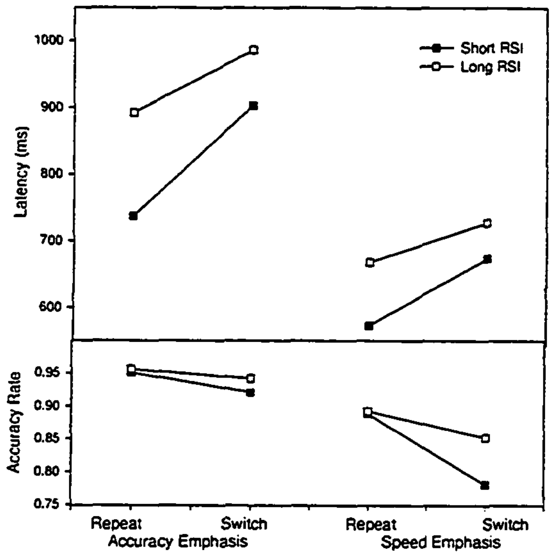


Figure 32: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition, RSI, and Instruction Emphasis in Experiment 2.

Accuracy Rate

The analysis of arcsine-transformed accuracy rates yielded three significant main effects and seven significant interactions which are listed in Table 6. The complete list of the ANOVA results of the accuracy rates is presented in Appendix E. Along with the mean latencies, the mean of accuracy rates for the six independent variables are also listed in Table 4. Task transition was highly significant [$F(1, 9) = 17.816, p < .002, MSE = .04387$]. The overall accuracy rate for the repeat trials was higher than for the switch trials. The main effect of instruction emphasis was also highly significant [$F(1, 9) = 28.552, p < .0004, MSE = .184$]. On average, participants showed lower accuracy for the speed emphasis instructions than for the accuracy-emphasis instructions. The performance for the compatible trials was also significantly more accurate than for the incompatible trials [$F(1, 9) = 15.554, p < .003, MSE = .114$]. RSI appeared to be marginally significant [$F(1, 9) = 4.272, p < .069, MSE = .0623$], however, it was significant in an analysis involving the non-transformed accuracy measures [$F(1, 9) = 8.167, p < .019, MSE = .01255$].

Table 6: Significant ANOVA Results for Accuracy Rates in Experiment 2.

Task Transition
Instruction Emphasis
Compatibility
Task Transition x Instruction Emphasis
Task Transition x Compatibility
Task Transition x Task Type
Task Transition x Block
Task Transition x Block x Task Type
Compatibility x Block x Task Type
Task Transition x Instruction Emphasis x RSI x Compatibility x Task Type

In addition to the significant latency interaction, the previous Figures 27a and 27b (lower panels) also shows the significant interaction between Instruction Emphasis and Task Transition in terms of accuracy rate [$F(1, 9) = 7.237, p < .025, MSE = .02144$]. While for the accuracy-emphasis trials rates of accuracy in repeat and switch trials were .954 and .932, respectively (for a switch cost of 2.2%), they were .890 and .817, respectively (for switch cost of 7.3%) for the speed-emphasis trials.

Another significant two-way interaction involved task transition and compatibility [$F(1, 9) = 18.518, p < .002, MSE = .01957$]. Figure 33a and 33b (lower panels) illustrate how the accuracy rates of compatible (.940) and incompatible (.904) tasks in repeat trials are different than corresponding compatible (.917) and incompatible (.831) tasks in switch trials.

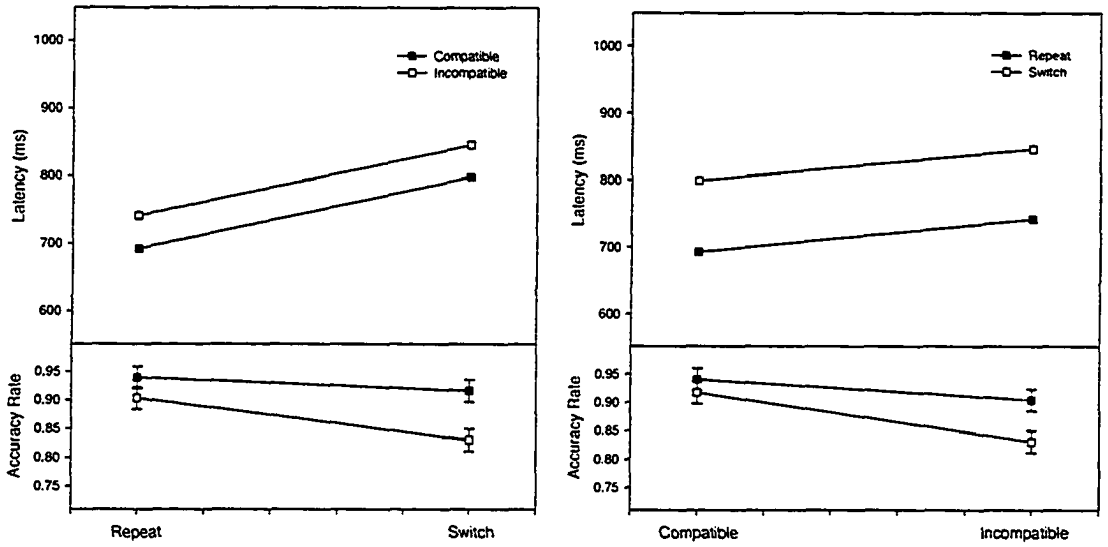


Figure 33a (right) and 33b (left): Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition and Compatibility in Experiment 2.

Another significant interaction was between task transition and task type [$F(1, 9) = 13.304$, $p < .005$, $MSE = .02151$]. The interaction can be seen clearly in Figure 34 (lower panel) in which for the repeat trials, digit tasks have a higher accuracy rate (.927) than letter tasks (.918). In the switch trials, the two task types switch their positions and letter tasks appear to be more accurate (.888) than digit tasks (.860).

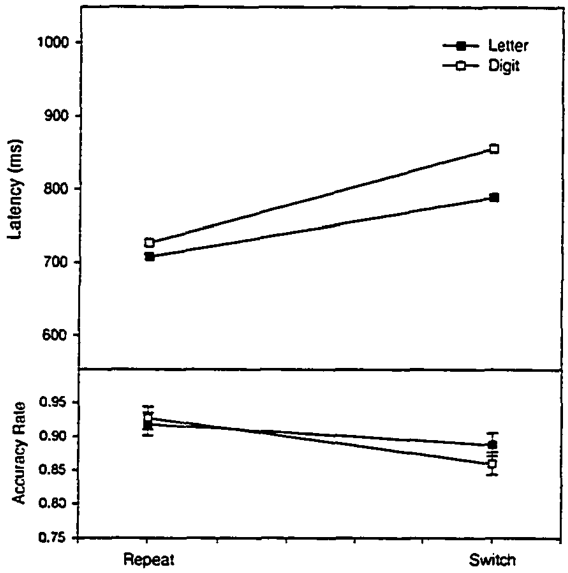


Figure 34: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition and Task Type in Experiment 2.

The lower panel of Figure 35 shows the significant interaction between task transition and block replication in terms of accuracy rate [$F(1, 9) = 8.159, p < .019, MSE = .02635$]. In the repeat trials of the second block, participants responded with an accuracy rate of .930 in comparison to .914 in the first block. Responding to the switch trials, they had a slightly higher accuracy rate in the first block (.877) than second block (.871).

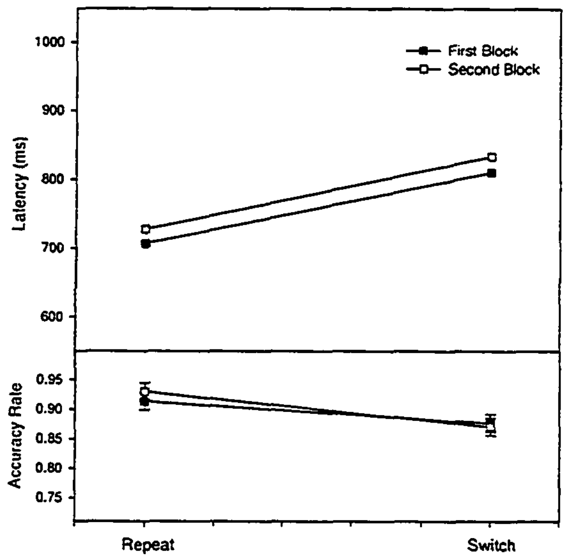


Figure 35: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition and Block in Experiment 2.

The three-way interaction involving compatibility, block replication, and task type was also significant [$F(1, 9) = 7.812, p < .021, MSE = .02462$]. As Figure 36 (lower panel) shows, letter and digit tasks both have a lower rate of accuracy for incompatible than compatible tasks regardless of block. However, only in the compatible trials of the first block, digit tasks are more accurate than letter tasks.

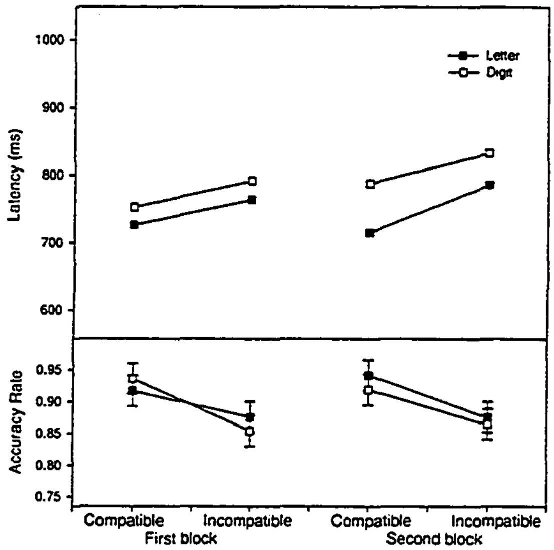


Figure 36: Mean Task 2 Latencies and Accuracy Rates as a Function of Compatibility, Block, and Task Type in Experiment 2.

In addition, there was also a significant three-way interaction involving task transition, block replication, and task type in terms of accuracy [$F(1, 9) = 9.846, p < .012, MSE = .01227$]. Figure 37 (lower panel) clearly shows the interaction for which in the first block, while the accuracy rate of digit tasks decreases from repeat to switch, the change is much less for letter tasks.

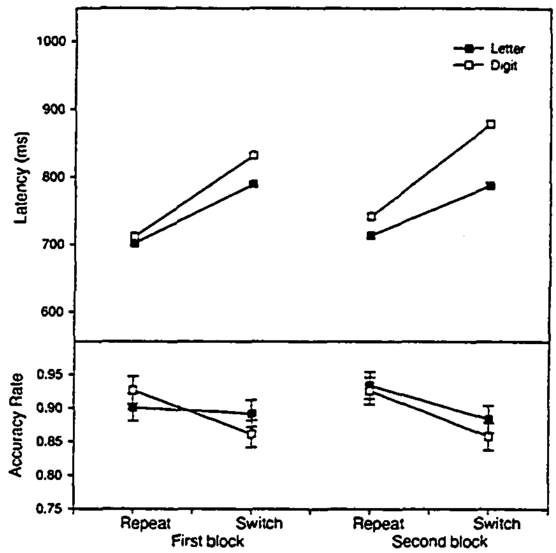


Figure 37: Mean Task 2 Latencies and Accuracy Rates as a Function of Task Transition, Block, and Task Type in Experiment 2.

Finally, a five-way interaction involving instruction emphasis, RSI, task type, compatibility, and task transition was also found highly significant [$F(1, 9) = 14.082$, $p < .005$, $MSE = .005622$]. No other higher-order interactions reached statistical significance in accuracy analysis.

Note, as well, that Figure 32 (lower panel) also presents the mean accuracy rates associated with the three-way interaction involving task transition, instruction emphasis, and RSI which was not significant [$F(1, 9) = 3.418$, $p < .098$, $MSE = .01358$]. The mean accuracy rates of repeat and switch trials in accuracy emphasis blocks were .951 and .921, respectively, for short RSIs (for a switch cost of 3%) and .956 and .942, respectively, for long RSIs (for a switch cost of 1.4%). The corresponding accuracy rates in speed emphasis blocks were .888 and .781 (for a switch cost of 10.7%), respectively, for short RSIs and .892 and .852, respectively, for long RSIs (for a switch cost of 4%).

Discussion

Since Experiment 2 was a replication of Experiment 1 and the major difference was testing well-practiced individuals due to having multi-sessions, any difference in the results may be attributed to practice. Similar to previous task-switching studies (e.g., Rogers & Monsell, 1995; Sohn & Anderson, 2001), the present study also showed that performance (both RT and accuracy) improved with practice. Comparing the results of Experiment 2 with Experiment 1, the overall mean latency had a drop of 172 ms (942 ms to 770 ms) and there was a small increase in overall accuracy rate mean of .010 (.888 to .898). Although, main effect results are good indications of differences in general (and were often significant in this study), interaction analyses reveal (often significant) differences which might be hidden due to being offset by decreases and increases in a measure. Indeed, it was the case in some situations in the present study. Therefore, (significant) interaction results are more reliable and more informative with respect to investigating the relation between the effects of the different independent variables.

The RT results for RSI showed a significant main effect, as well as, along with similar studies (such as Rogers & Monsell, 1995, Experiment 3; Meiran, 1996), a significant interaction with task transition. The main effect of RSI here is interesting because RTs are longer on overall to both repeat and switch trials at long RSIs than for short RSIs (which is not a typical finding in the task switching literature). Since the tasks were predictable (receiving "Repeat" or "Switch" pre-warnings) and having a long RSI of 2000 ms, the failure-to-engage (FTE) hypothesis (De Jong, 2000) may explain the situation in which the participants do not engage in advance task preparation (longer switch times) at long RSIs. However, it cannot explain the longer overall RTs at long

RSIs observed in Experiment 2 for both repeat and switch trials because participants cannot "fail-to-engage" in repeat trials. Hence, the overall long RSI cost must be due to some kind of general preparation degradation (Altman et al., 2004) for which decay of task set activation could be a good explanation (note that the fact that the REPEAT-SWITCH cue was not available during the RSI in Experiment 2 could likely have contributed to this phenomenon). An interesting point is that unpracticed participants in Experiment 1 were not affected overall by such activation decay in their long RSIs. At this point, it seems that the well-practiced participants in Experiment 2 relied more on automatic-type control processing than the unpracticed participants in Experiment 1 who might have been relying heavily on their SAS endogenous mechanisms in all conditions. If the unpracticed participants in Experiment 1 were really concentrating on both actively trying to maintain task sets in long RSI repeat trials and actively reconfigure in long RSI switch trials, this could serve to negate any general effect of task set activation decay. Note that these ideas would suggest that switch cost at long RSIs were reduced in Experiment 1 because long RSI switch trials were more like long RSI repeat trials due to enhanced preparation but that in Experiment 2, long RSI repeat trials were more like long RSI switch trials due to a slacking off of preparation.

With respect to speed versus accuracy instruction emphasis, significant main effects of this factor with both RT and accuracy show that these instructions were also indeed being followed by the participants in Experiment 2. However, in Experiment 2 (unlike Experiment 1), task transition interacted with instruction emphasis for both latencies and accuracy rates (i.e., RT switch costs were lower and accuracy switch costs larger under speed than accuracy emphasis; (see Figure 27). One explanation is that because responding in speeded conditions is more effortful, the requirement to speed responses made these participants put a bit more effort into active preparation in the speed emphasis condition resulting in smaller switch costs and a significant RSI X Instruction Emphasis two-way interaction. This interpretation that was supported by the fact that the overall RSI effect was smaller under speed emphasis (see Figure 32; although the Instruction Emphasis X RSI interaction itself was not significant).

However, the fact that the Task Transition X Instruction Emphasis two-way interaction was significant in Experiment 2 but not the RSI X Task Transition X Instruction Emphasis three-way interaction indicates that switch costs were reduced under speed emphasis for both long and short RSIs. What this means is that the FTE hypothesis cannot fully explain the speed-accuracy emphasis effects on the switch cost in this experiment because it can only explain why switch costs would decrease with speed emphasis at long RSIs not short RSIs (because when there is no time to prepare there cannot be a FTE).

Hence, it seems like the well-practiced participants in Experiment 2 were able to speed up both the endogenous and exogenous switch processes by putting more effort into them during the speed-emphasis conditions than in the accuracy-emphasis conditions. The other explanation is simply that because responding in the speed conditions takes place on a lower position on the SAT curve, such differences occur simply because only differences in RT due to experimental conditions are smaller further down on the SAT curve than further up (such curves will be presented in Experiment 3). However, with respect to either of these explanations, it is not clear why similar effects of speed emphasis on the switch cost were not found in Experiment 1.

In addition, the results showed that well-practiced participants in Experiment 2 found letter tasks easier than digit tasks (the latency difference was marginally significant). This finding is opposed to the corresponding results in Experiment 1 where the difference was highly significant with a higher time cost for the letter tasks. Again, since the conditions and procedure in both experiments were all kept the same, the difference could be attributed to practice. Indeed, more experimental sessions improved both responding to the letter and digit tasks but the difference was larger for the letter tasks and they appeared to be easier in the Experiment 2.

Regarding compatibility, in both letter and digit tasks, larger latencies (see Figures 30a & 30b) were found for incompatible trials. Regardless of task type, compatibility significantly interacted with task transition but only in terms of accuracy rate (see Figure 33a and 33b). This result is compatible with Azuma's (1999, cited in Yeung & Monsell, 2003) finding that showed either similar or larger switch costs for incompatible trials. However, in neither Experiment 1 nor Experiment 2, was a significant two-way interaction between task transition and compatibility found in terms of latency. This finding is, in fact, different than other findings in similar studies (e.g., Rogers & Monsell, 1995, Meiran, 1996, and Goschke, 2000) which may be attributed to the differences in the task types, stimulus constraints, and the procedures used. However, it is important to note that the three-way interaction involving task type, compatibility, and task transition was significant (see Figures 30a and 30b). It seems that the standard lower switch cost for compatible trials does occur for letter tasks (which, as the associated four-way interaction shows, is mainly due to a complete lack of RT repeat-switch effect for compatible letter tasks at long RSIs) but not for digit tasks for which the standard effect seems reversed (i.e., larger switch costs for compatible trials than incompatible; which, as the associated four-way interaction shows, seems to be due to the fact that the repeat-switch difference is smaller for incompatible digit trials at long RSIs).

Experiment 3

The effect of speed versus accuracy emphasis on the time course of processing in task switch and repeat trials can also be examined by full SAT curves. The intercept of SAT indexes the minimal time needed for processing. It is the point where it departs from chance and information processing starts. The rate of rise indicates the continuous growing rate of information processing over time from chance level to asymptote. In other words, rate is the speed of information processing which reflects the gradual increase in accuracy over time to the maximum point, asymptote. The highest level of accuracy is reached after a certain period of time of information processing and after this point, spending more time cannot change the accuracy level significantly.

The difference in terms of switch costs between short and long RSI reflects the effect of task-set reconfiguration since it is assumed that participants cannot start reconfiguration before viewing the stimuli when RSI is short. However, since they receive the REPEAT/SWITCH warnings at the very beginning of the trials, they may start such processing when RSI are long.

It could be assumed that loading a new task set (in switch trials) can be begun right after Task 1 completion. Therefore, after responding to the first task, task set reconfiguration is started. For short RSIs, the time taken to perform this configuration should be reflected in the SAT curve dynamics themselves. Namely, if such reconfiguration represents an information processing bottleneck, this should be evident in the intercept of the SAT curve for short RSI switch trials (because no processing can occur until it is finished). If such reconfiguration represents an interference effect, this could be assumed to effect the rate of the SAT curve on short RSI switch trials (because processing would be slowed and not halted completely). Analogously, differential intercept or rate switch costs at long RSIs trials, will shed light on the nature of the mechanisms responsible for the residual switch cost.

For rate, in general though, as the condition gets more difficult (from the easiest, e.g., repeat-long RSI-compatible trials to the hardest, e.g., switch-short RSI-incompatible trials), more time would be needed to do reconfigurations to reach certain levels of accuracy (and therefore lower rate value at certain time points) because of higher workload. In this way, easier conditions require less time to meet the asymptote. After completing the reconfiguration and reaching the asymptote, however no significant difference would be expected among different conditions because even for the most difficult condition (e.g., switch-short RSI-incompatible trials), spending more time should be result in (almost) the same accuracy level as other conditions given the simple nature of these tasks.

The purpose of the following experiment was to explicitly investigate SATs in task switching through a different method. In Experiment 3, SAT curves obtained using the response signal method were examined directly.

Method

Participants and Apparatus

Nine students at Carleton University took part in this experiment. To remove any effect of interference, no participants from Experiment 1 or 2 were allowed to participate in

Experiment 3. Participants were recruited through announcements and received $12 per hour for their participation.

Materials

The materials of Experiment 2 were also used in Experiment 3.

Procedure and Design

The procedure and design of Experiment 3 was similar to the previous experiments. However, in this experiment there were no speed-accuracy instructions. Instead, response signals at various lags of 100, 200, 300, 400, 500, 600, 800, 1000, and 1200 ms from the onset of the second stimulus on each trial were used. These response signals involved both the disappearance of that stimulus and the presence of a tone (at 900 Hz for 10 ms). These signals prompted the participants to stop processing and respond without delay (see Figures 38 and 39).

Similar to Experiment 2, two sets of eight blocks of trials (i.e., the full 256-trial stimulus set from Experiment 1 and the full 256-trial extra stimulus set derived for Experiment 2) were used. For each of these sets, four different assignments of response signal times to the trials within each block were derived (although care was taken to try and counterbalance the stimuli that were assigned to each response signal as much as possible, note that they were not completely identical across response signals). For each of these assignments, the stimuli used in the first and last four blocks of each set of eight blocks of trials were reversed. Each of these eight sets of eight blocks of trials was then performed twice, once with the short RSI in the first four blocks of trials and once with the long RSI in the first four blocks of trials. This design ensured that for each of the task-repeat and task-switch conditions at each response signal, the same stimuli were being responded to for each RSI.

As in Experiment 2, each participant performed multiple sessions. On the first day, participants ran through eight blocks of trials that were essentially identical to the first eight blocks of trials in Experiment 1 but without any speed or accuracy emphasis conditions. On each of the following Days 2-13, the participants ran through two sets of eight blocks of trials per day (one set of eight blocks for each stimulus set). Participants always performed the same two sets of eight blocks of trials over two consecutive days with the order of presentation of the short and long RSIs reversed (and alternated over pairs of days). The exact same blocks of trials used on Days 2-5, were repeated on Days 10-13 with the following change. On Day 10-13 all response signals of length 1000 ms and 1200 ms were replaced by response signals of length 100 which, it is important to note, had not actually been used up until this point.

In Experiment 3, participants were often given a number of feedback messages (presented for 2000 ms after the end of the trial). For example, if they responded to the second stimulus on a trial before the response signal occurred they were warned not to do that (these trials were also marked for later deletion). They were also warned not to take too much time to respond both after the response signal occurred and also to the first stimulus on a trial. For these latter two warning messages, deadlines were set within the experimental programs to elicit these prompts. These deadlines were 600 ms and 1000 ms, respectively, for Day 2 but were gradually reduced to 250 ms and 550 ms, respectively, by Day 8. Finally, note that like Experiment 2, the REPEAT-SWITCH cues disappeared after the response to the first stimulus, and hence, like Experiment 2, were not present during the RSI.

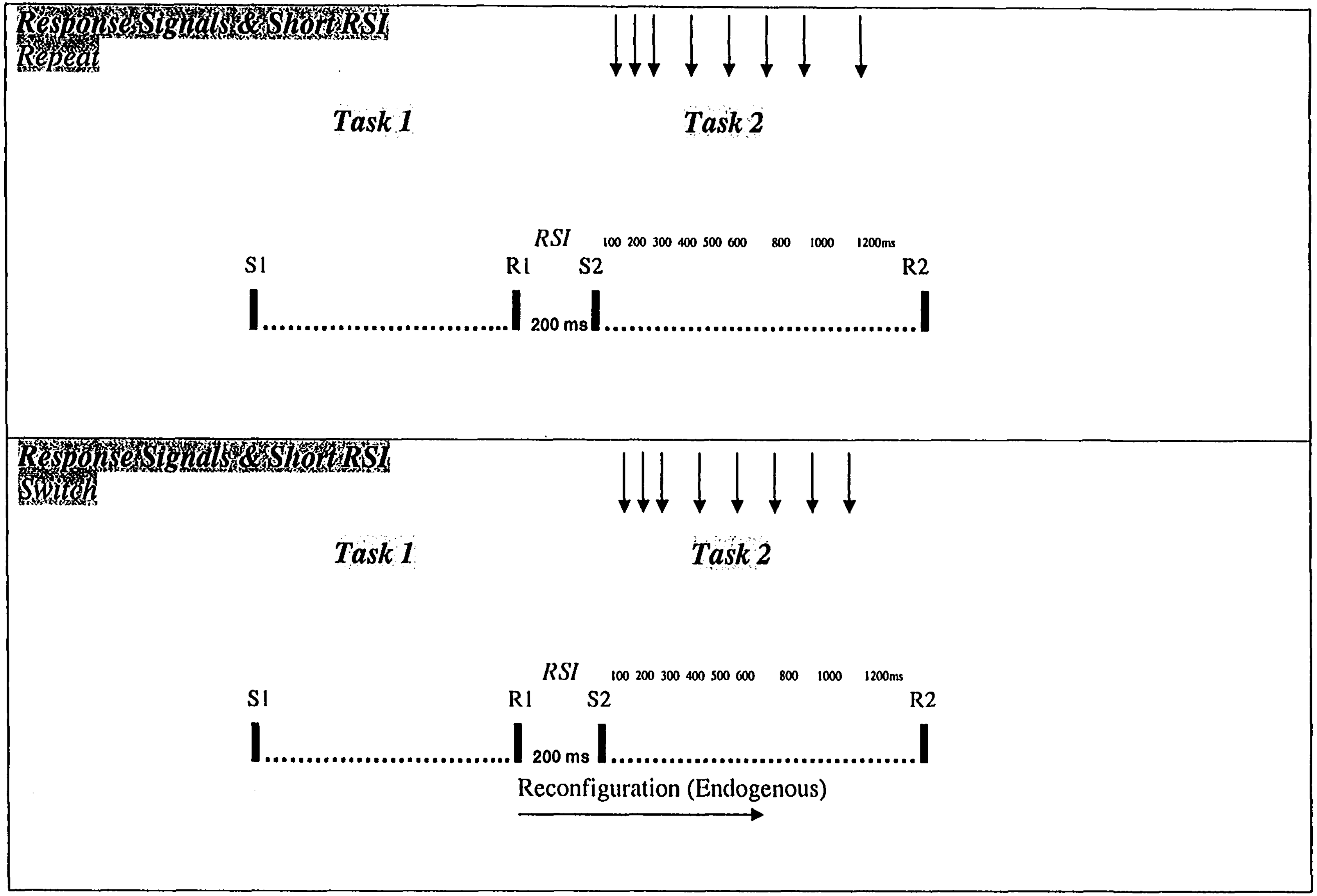


Figure 38: Schematic of Repeat and Switch Trials in Experiment 2 with Short RSI and Response Signals.

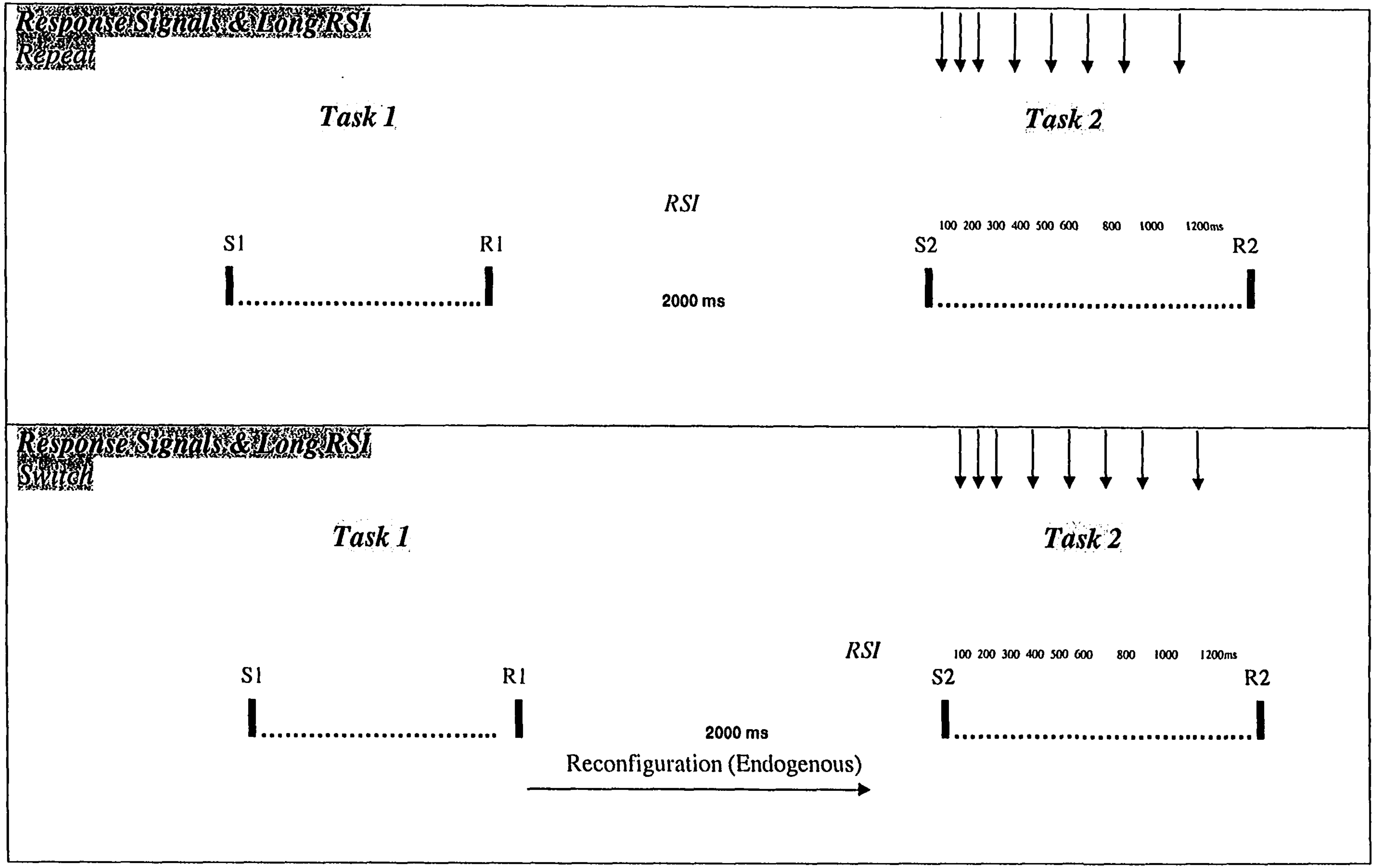


Figure 39: Schematic of Repeat and Switch Trials in Experiment 2 with Long RSI and Response Signals.

Results

Days 1 - 5 were regarded as practice. Each set of eight blocks of trials provided (about) 4 response observations per response signal to the second stimulus in each trial at each of the following 8 conditions: 2 (RSI: short, long) X 2 (task transition: repeat, switch) X 2 (second stimulus compatibility type: compatible, incompatible). Over Days 6 -13, 16 sets of eight blocks of trials were performed by each participant, providing (about) 64 observations per response signal per condition per individual (the about refers to the fact that there was no explicit attempt to equalize the task transition and compatibility types at each response signal).

For each individual, SAT curves were generated for each of the eight experimental conditions mentioned above. From these curves, the three SAT model parameters (intercept, rate, and asymptote) were estimated using Equation 1 (and proportion correct in place of d') and separate 2 X 2 X 2 fully repeated measures ANOVAs were performed on them. Estimation involved a “brute force” computer search routine which iterated through a large number of possible parameter sets keeping track of the best-fitting set in terms of the smallest root mean square deviation between the observed response proportions and those predicted by the SAT curve.

In generating these SAT curves, the RTs used were always the signal time plus the mean response latency to that signal. Before deriving the SAT curves, the data were reviewed to detect and exclude any possible outliers. In this way, any trials with mean response latencies of more than 2000 ms were removed from the analysis (0.43%). The following section presents the results for each of the three SAT parameters separately.

Intercept

The main effect between repeat and switch trials was significant [$F(1, 8) = 10.4, p < .012$, $MSE = 9202$] which indicates the fact that the point at which the SAT curve began to rise was higher for switch trials than repeat trials (see Table 7). Moreover, the main effect of compatibility was highly significant [$F(1, 8) = 79003.125, p < .002, MSE = 3603$]. The intercept was higher for incompatible trials than compatible trials (see Table 7).

Table 7: Mean Values of the Intercept at the Levels of Each of the Three Independent Variables in Experiment 3.

Source		*Mean (ms)*
RSI		
	Short	374
	Long	362
TASK TRANSITION		
	Repeat	332
	Switch	405
COMPATIBILITY		
	Compatible	335
	Incompatible	401

As Table 10 displays, the two-way interaction of RSI and task transition was also significant [$F(1, 8) = 5.396, p < .049, MSE = 2919.531$]. While it took spent 323 ms, on average, for the SAT curve to begin its rise for short RSI repeat trials, it took 425 ms for short RSI switch trials which is a rather dramatic change. There was also a smaller increase in the intercept for switch trials (384 ms) over repeat trials (340) when RSI was long. Although, a similar trend occurred for the RSI X Compatibility interaction (see Table 8), this effect was not significant given the size of the error term. The two-way interaction between task transition and compatibility, however, was highly significant [$F(1, 8) = 13.342, p < .006, MSE = 5387$]. As the means displayed in Table 8 indicate, there is a large increase in the intercept of the SAT curve for incompatible switch trials (469 ms) in comparison with other three means (with an average of 334 ms).

The key results are those associated with the three-way interaction that are given in Table 9. As this table shows, the only differences in the intercept occur for incompatible switch trials for which the size of this parameter is much larger (especially for short RSIs) than for the other six conditions (where the intercept was essentially equivalent for all conditions).

Table 8: Mean Values of the Intercept at the Levels of Each of Three Independent Variables in Experiment 3.

	Repeat	*Switch*	*Compatible*	*Incompatible*
Short RSI	323 ms	425 ms	330 ms	418 ms
Long RSI	340 ms	384 ms	340 ms	384 ms
Repeat	-	-	330 ms	333 ms
Switch	-	-	340 ms	469 ms

Table 9: Mean Values of the Intercept at the Levels of Each of Three Independent Variables in Experiment 3.

	Compatible		*Incompatible*	
	Repeat	*Switch*	*Repeat*	*Switch*
Short RSI	323 ms	336 ms	322 ms	515 ms
Long RSI	337 ms	343 ms	344 ms	424 ms

Table 10: Analysis of Variance Results for the Intercept in Experiment 3.

Source	*F*	*MSE*	*P*	*Sig.*
RSI	.686	3832.031	.432	
REPEAT-SWITCH (RESW)	10.400	9202.344	.012	*
COMPATIBLE-INCOMPATIBLE (COMP)	79003.125	3603.906	.002	**
RSI* RESW	5.396	2919.531	.049	*
RSI* COMP	1.766	5096.441	.221	
RESW * COMP	13.342	5387.587	.006	**
RSI* COMP * RESW	6.754	1875.608	.032	*

* = < .05, ** = < .01, *** = < .001

Rate of Rise

Among the three independent variables for the analysis of the rate of rise of the SAT curve, only the mean effect of compatibility was significant [$F(1, 8) = 7.664$, $p < .024$, $MSE = .00006069$] reflecting a difference between compatible and incompatible trials with respect to the degree to which accuracy increased with signal time (slower for incompatible trials; see Table 11).

Table 11: Mean Values of the Rate at the Levels of Each of Three Independent Variables in Experiment 3.

Source	*Mean*
RSI	
Short	.00946
Long	.00987
TASK TRANSITION	
Repeat	.00951
Switch	.00982
COMPATIBILITY	
Compatible	.01221
Incompatible	.00712

None of the two-way or three-way interactions involving RSI, task transition, and compatibility reached the significant level (see Table 14).

Table 12: Mean Values of the Rate at the Levels of Each of Three Independent Variables in Experiment 3.

	Repeat	*Switch*	*Compatible*	*Incompatible*
Short RSI	.00848	.01043	.01099	.00793
Long RSI	.01054	.00921	.01343	.00632
Repeat	-	-	.01316	.00587
Switch	-	-	.01127	.00837

Table 13: Mean Values of the Rate at the Levels of Each of Three Independent Variables in Experiment 3.

	Compatible		*Incompatible*	
	Repeat	*Switch*	*Repeat*	*Switch*
Short RSI	.01166	.01032	.00532	.01054
Long RSI	.01466	.01221	.00643	.00621

Table 14: Analysis of Variance Results for the Rate in Experiment 3.

Source	*F*	*MSE*	*P*	*Sig.*
RSI	.086	.00003637	.777	
REPEAT-SWITCH (RESW)	.077	.0000217	.788	
COMPATIBLE-INCOMPATIBLE (COMP)	7.664	.00006069	.024	*
RSI* RESW	1.835	.00002635	.213	
RSI* COMP	1.080	.00006851	.329	
RESW * COMP	3.139	.00002762	.114	
RSI* COMP * RESW	.824	.00002563	.390	

* = < .05, ** = < .01, *** = < .001

Asymptote

The results showed that with respect to the asymptote level, none of the three main effects of RSI, task transition, and compatibility was significant. Table 15 displays the means.

Table 15: Mean Values of the Asymptote at the Levels of Each of Three Independent Variables in Experiment 3.

Source		*Mean*
RSI		
	Short	.978
	Long	.984
TASK TRANSITION		
	Repeat	.985
	Switch	.977
COMPATIBILITY		
	Compatible	.980
	Incompatible	.982

As Table 18 indicates, among the two-way and three-way interactions, only the two-way interaction of RSI and task transition was significant [$F(1, 8) = 11.676, p < .009, MSE = .0002303$]. Table 16 shows these means for which the switch trials with short RSI had the lowest mean asymptote accuracy rate of .968 while the other three means involved in the two-way interaction had an overall mean of .985.

Table 16: Mean Values of the Asymptote at the Levels of Each of Three Independent Variables in Experiment 3.

	Repeat	*Switch*	*Compatible*	*Incompatible*
Short RSI	.987	.968	.979	.976
Long RSI	.982	.987	.980	.988
Repeat	-	-	.982	.987
Switch	-	-	.977	.977

Table 17: Mean Values of the Asymptote at the Levels of Each of Three Independent Variables in Experiment 3.

	Compatible		*Incompatible*	
	Repeat	*Switch*	*Repeat*	*Switch*
Short RSI	.987	.972	.988	.964
Long RSI	.977	.986	.983	.991

Table 18: Analysis of Variance Results for the Asymptote in Experiment 3.

Source	*F*	*MSE*	*P*	*Sig.*
RSI	1.553	.0004730	.248	
REPEAT-SWITCH (RESW)	3.295	.0002850	.107	
COMPATIBLE-INCOMPATIBLE (COMP)	.193	.0007209	.672	
RSI* RESW	11.676	.0002303	.009	**
RSI* COMP	1.964	.0002829	.199	
RESW * COMP	.324	.0003477	.585	
RSI* COMP * RESW	.206	.0003298	.662	

* = < .05, ** = < .01, *** = < .001

Figures 40-47 present the modeled group SAT curves for the eight possible conditions involving RSI, task transition, and compatibility along with the calculated SAT parameters (intercept, rate, and asymptote) from the fits to the group data. Figure 48 illustrates all eight SAT curves together.

1- Long RSI, Repeat, and Compatible

Intercept: 335

Rate: .0102

Asymptote: .98

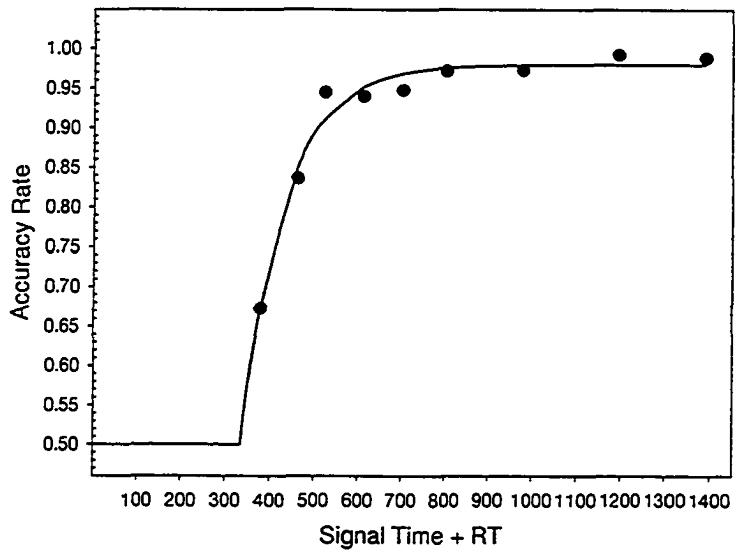


Figure 40: The Modeled Group SAT Curve for Long RSI, Repeat, and Compatible Trials.

2- Short RSI, Repeat, and Compatible

Intercept: 325

Rate: .0095

Asymptote: .98

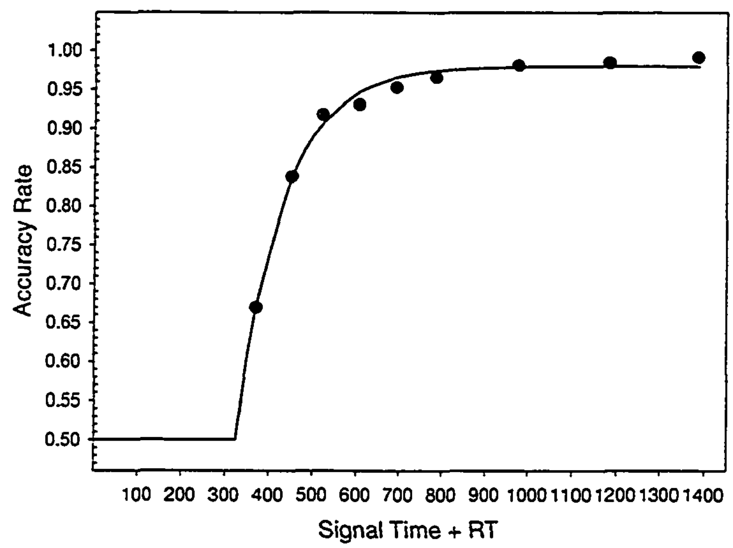


Figure 41: The Modeled Group SAT Curve for Short RSI, Repeat, and Compatible Trials.

3- Long RSI, Switch, and Compatible

Intercept: 330

Rate: .0084

Asymptote: .975

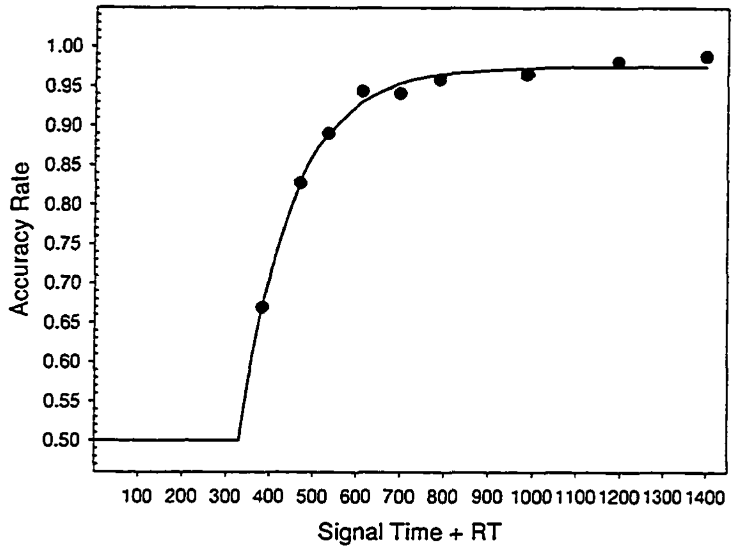


Figure 42: The Modeled Group SAT Curve for Long RSI, Switch, and Incompatible Trials.

4- Short RSI, Switch, and Compatible

Intercept: 320

Rate: .0071

Asymptote: .97

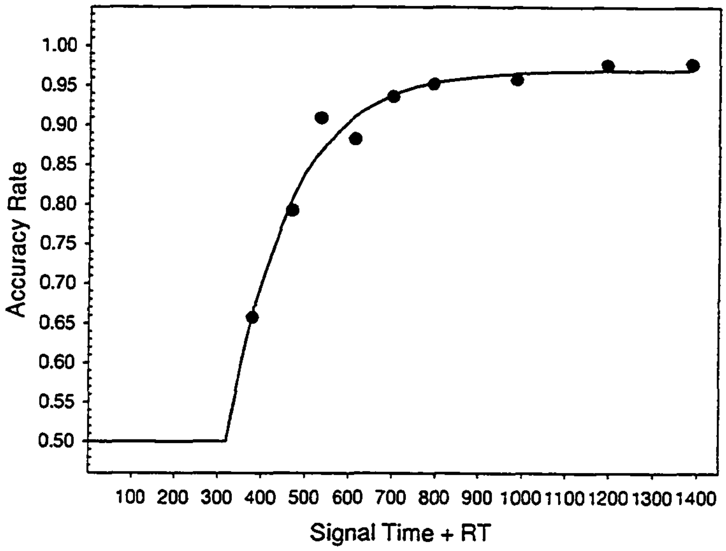


Figure 43: The Modeled Group SAT Curve for Short RSI, Switch, and Compatible Trials.

5- Long RSI, Repeat, and Incompatible

Intercept: 330

Rate: .0050

Asymptote: .985

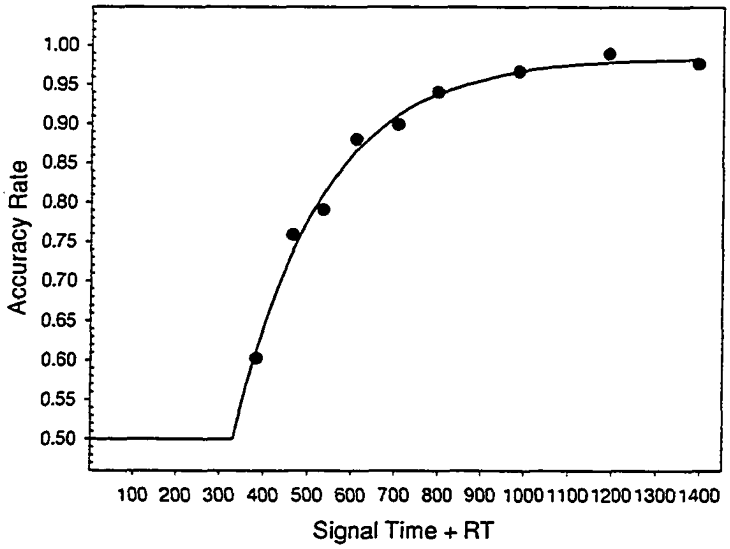


Figure 44: The Modeled Group SAT Curve for Long RSI, Repeat, and Incompatible Trials.

6- Short RSI, Repeat, and Incompatible

Intercept: 315

Rate: .0047

Asymptote: .99

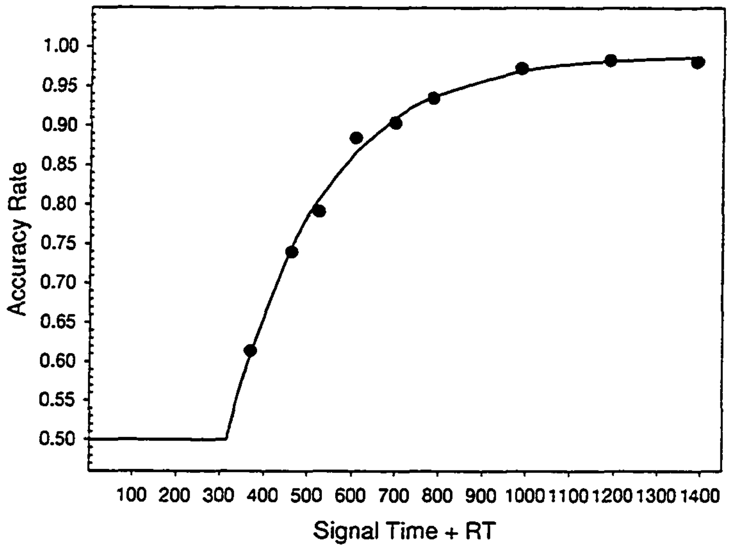


Figure 45: The Modeled Group SAT Curve for Short RSI, Repeat, and Incompatible Trials.

7- Long RSI, Switch, and Incompatible

Intercept: 420

Rate: .0053

Asymptote: .985

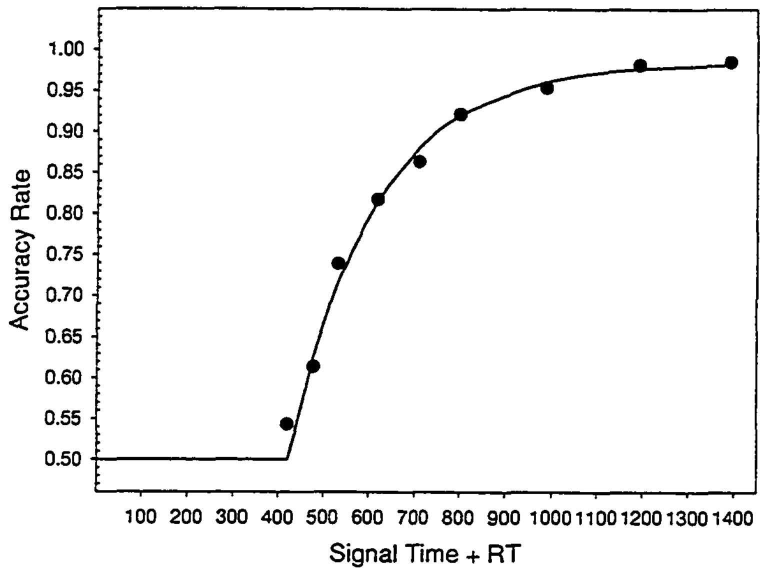


Figure 46: The Modeled Group SAT Curve for Long RSI, Switch, and Incompatible Trials.

8- Short RSI, Switch, and Incompatible

Intercept: 480

Rate: .0060

Asymptote: .975

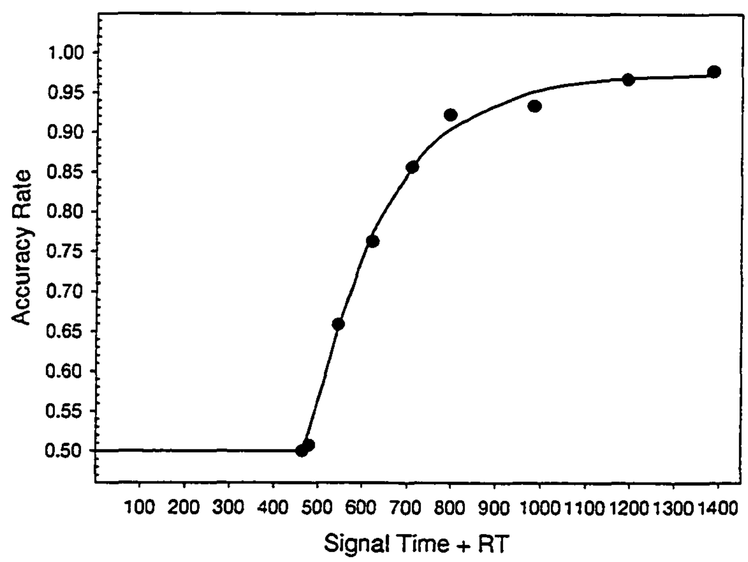


Figure 47: The Modeled Group SAT Curve for Short RSI, Switch, and Incompatible Trials.

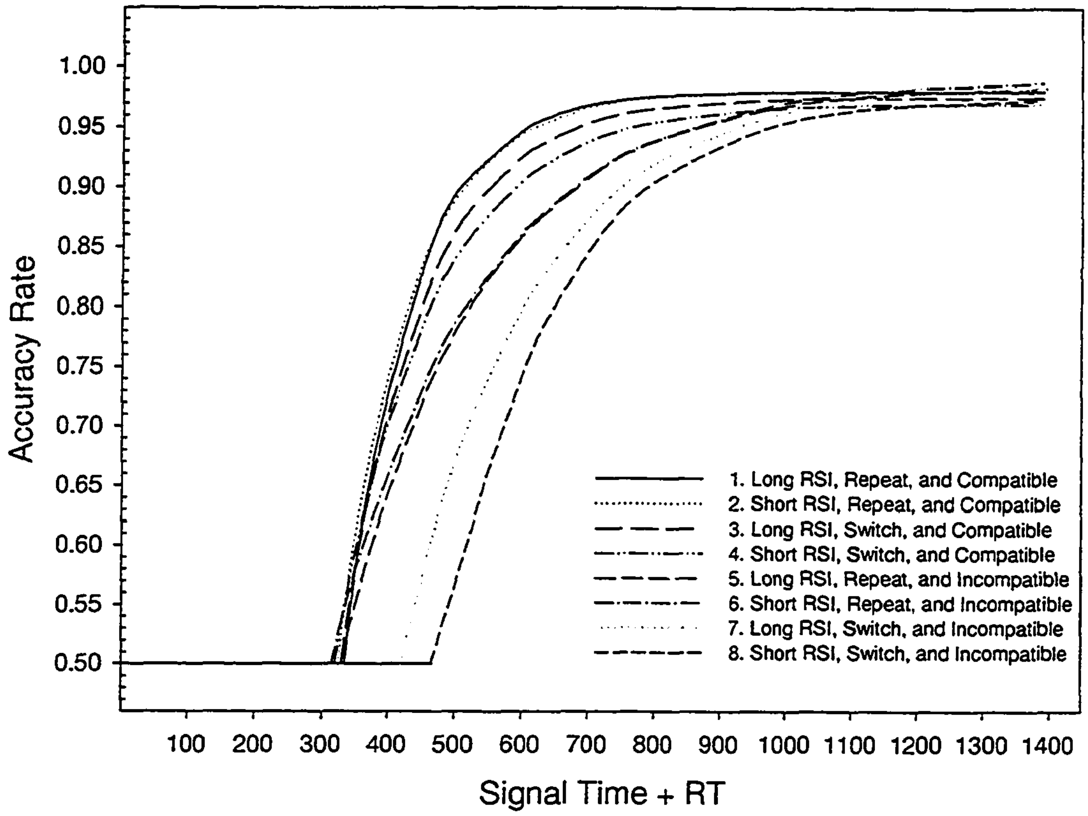


Figure 48: The Modeled Group SAT Curves for the Eight Conditions Involving RSI, Task Transition, and Compatibility.

Table 19: The Overall RTs (Not Including Signal Times) for Each Condition Under Different Signal Time Lags in Experiment 3.

	Time lags								
Conditions	100 ms	200 ms	300 ms	400 ms	500 ms	600 ms	800 ms	1000 ms	1200 ms
1- Long RSI, Repeat, and Compatible	279	263	225	213	203	203	179	195	190
2- Short RSI, Repeat, and Compatible	271	251	222	205	192	184	176	183	184
3- Long RSI, Switch, and Compatible	283	270	234	212	198	190	187	194	199
4- Short RSI, Switch, and Compatible	279	269	235	214	200	193	186	195	187
5- Long RSI, Repeat, and Incompatible	283	265	234	211	206	197	186	191	194
6- Short RSI, Repeat, and Incompatible	269	263	224	207	198	186	187	188	189
7- Long RSI, Switch, and Incompatible	320	277	231	218	209	200	186	191	190
8- Short RSI, Switch, and Incompatible	380	266	246	223	211	197	183	194	186

Discussion

In terms of task switching, as in Experiment 1 and 2, the present experiment is concerned with how manipulating some factors (namely RSI and compatibility) affect switch costs. However, the main issue addressed in the present study was how the SAT functions themselves (i.e., the whole time course of responding to these tasks) is affected when participants are required to switch between different (or repeat similar) tasks.

The results showed that there was no main effect of RSI for any of the three SAT parameters (see Tables 10, 14, and 18). However, since it showed significant interactions with task transition for the intercept and asymptote parameters, it could be assumed that the effects of the short and long RSIs had been moderated by other factors. As the means for the four RSI and task transition combinations show for these two parameters, the largest changes occurred for the switch trials when the RSI was short (i.e., higher intercept terms and lower asymptotic accuracy; see Tables 8 and 16). Hence, for the first time, the effect of not having enough time to prepare for a task switch can clearly be shown to affect measures which reflect the time course of processing. Interestingly, as Figure 48 also clearly illustrates, the RSI X Task Transition results in Tables 8, 12, and 16 show that the effects of short versus long RSI had very little effect on the time course of processing for task-repeat trials (suggesting that any actual RT or accuracy differences between these two conditions in other more standard experiments might be due simply to strategic factors).

With respect to the lowered asymptote for short RSI, task-switch trials, note that unlike all of the previously reviewed memory SAT studies, this cannot represent a lower asymptotic memory strength but could be regarded as representing a true upper performance limit on accuracy for these tasks when they are being switched to with no time to prepare for that switch. When at least 2000 ms of preparation time has been provided, this performance limit approaches that present in task-repeat conditions.

With respect to the higher intercept terms for task-switch conditions at both RSIs (but more so for short RSIs than long RSIs), note that, now like those previous memory studies, the intercept essentially represents minimum time for which no task-relevant processing is possible. Hence, it could be argued that this must represent some form of all-or-none task reconfiguration process on switch trials because proactive interference (i.e., Allport et al.'s TSI) would likely only slow the rate of information processing, not block it out completely.

One problem with this argument though is the fact that, as both Table 9 and Figure 48 clearly indicate, the SAT intercept increased only for task-switch trials involving incompatible stimuli and not for compatible task-switch stimulus trials. However, one key aspect of compatible trials is the fact that, by definition, the response associated with either task is correct. Hence, on these trials, participants would be able to begin to respond correctly upon collecting some evidence about the identity of either the letter or digit stimulus on that trial regardless whether task-set reconfiguration has occurred or not. The fact that the intercepts for task-switch, compatible trials with either RSI are the same as that for all of the task-repeat trials indicates that such information begins to be accrued at the same point as for the task-repeat trials. The fact that the task-switch, compatible SAT curves are smoothly rising with no apparent discontinuities also indicates that when task switch reconfiguration is completed the process of evidence accumulation does not seem to start over from scratch but simply picks up without a hitch (albeit driven by the new task set) and also that the process of reconfiguring itself seems to only slightly affect the rate of the overall evidence accumulation process given that the rise of the task-switch compatible curves are slightly shallower than the task-repeat compatible curves. (Note that it is unlikely that participants will simply not reconfigure on compatible task-switch trials because they never know whether the trial stimuli were compatible or not until after they have finished processing them.)

On the basis of these points, it only really seems appropriate to look for true effects of task-set reconfiguration on the SAT intercept for incompatible stimulus trials because true correct responses to these trials cannot begin to be made until task set reconfiguration has been completed. Given this logic, these SAT data provide clear evidence for both endogenous and exogenous task set reconfiguration processes, respectively, that take about 193 ms for short RSIs (i.e., the intercept switch cost for incompatible, short RSI trials) and about 80 ms for long RSIs (i.e., the intercept switch cost for incompatible, long RSI trials). This interpretation is not confounded by stimulus incompatibility itself because there are no intercept differences between compatible and incompatible repeat trials, only rate differences indicating that incompatibility does indeed seem to have its affect on only the rate of evidence accumulation (most likely by providing evidence for competing responses throughout that process).

In addition, the fact that accuracy remains at chance in the short RSI, incompatible task-switch condition throughout the reconfiguration process means that both tasks should likely be disabled during that process because the continued enablement of the previous task set until the switch occurs would have logically resulted in a below-chance drop in accuracy at time points immediately preceeding the intercept (which did not occur). Hence, during these periods, in task-switch trials, it is likely that responding occurs on the basis of fairly direct (i.e., task-set free) stimulus-to-response mappings that would tend to result in correct responses to (noisy) partially processed compatible stimuli but in essentially chance performance to (noisy) partially processed incompatible stimuli. Finally, the higher rate of rise of the SAT curve for the short RSI, incompatible task-switch condition in comparison to all other incompatible conditions could also be explained by the fact that by the time task-set reconfiguration has occurred in that condition, stimulus processing is already in fairly advanced state.

General Discussion

The participants in Experiment 3 responded to these tasks hundreds of times following the response signals. They learned how to respond correctly while under time pressure which differed throughout the sessions. The responses of these "professional" participants, then, can be compared with the performances of the participants in Experiment 1 and 2 in the sense of showing the effects of varied and unknown time lags on responding rather than adopted speed versus accuracy instructions.

In order to respond to the stimuli in the experiments, participants had to adopt different strategies. The strategy used in Experiment 3 likely involved just doing the reconfigurations and trying to respond correctly as shortly as possible following the response signal. As they have learnt that some of the time lags were extremely short with almost no time to do the reconfigurations, at the very beginning a "fast" guess based on partial stimulus processing could have been generated as a starting point (for those very short signals) while reconfiguration was still taking place. The participants in Experiment 1 and 2, were also under time pressure to respond, but it was limited to a "TOO LONG" message after responding which was set based on the participant's reaction times in earlier sessions. Therefore, the effective speed deadline was much longer (in comparison to Experiment 3) and, more importantly, it was fixed throughout the session. The strategy used in the first experiments, then, could have involved speeding up processing as much as possible in order to respond as correctly as possible and avoid the feedback message.

This issue has been also pointed out by Dosher (1982). She believes that the data collected from standard RT and response signal methods are different for two reasons (even without considering the fact that these data might come from two different groups of participants). First, the time plotted in SAT curves using the response signal method is the maximum time allowed for processing, whereas the mean RT in other standard method is the average time required for processing. Second, as described above, participants could be using different qualitative processing strategies under each method. Moreover, in the response signal method, the participants process both an external stimulus and the response tone before responding whereas this is not true for the other methods. However, in standard RT studies, participants need to do some additional processing to help them to decide when to respond which, in turn, means spending more time. Therefore, Dosher (1982) argued that the SAT curves using standard RT methods lie slightly to the right of the SAT curves obtained using response signals.

Nonetheless, an important issue is to what extent the results of Experiment 3 are comparable with the results of the earlier experiments, particularly Experiment 2 (because the participants were more practiced than in Experiment 1). One way to examine this issue could be to directly compare the Experiment 2 RT-accuracy points for each of the RSI, task transition, and compatibility treatment combinations at both accuracy and speed emphases with the SAT curves derived from Experiment 3.

In order to calculate those points, the curves obtained in Experiment 3 were used to predict the Experiment 2 RT s directly from the Experiment 2 accuracies (for which it was assumed that the three SAT parameters of the eight RSI X Task Transition X Compatibility conditions were the same for both speed- and accuracy-emphasis as they represent two points from the same SAT curve). This can be done by inverting the SAT equation (as shown in Appendix F) and replacing the three parameters for each condition with the ones derived from Experiment 3 (Appendix G). Table 20 and 21 show the actual and predicted values under speed- and accuracy-emphasis for Experiment 2. As it was expected in all conditions, actual values are larger than predicted ones.

Table 20: The Actual and Predicted Values under Speed-Emphasis for Experiment 2.

	Compatible				*Incompatible*			
	Repeat		*Switch*		*Repeat*		*Switch*	
	Actual	*Predicted*	*Actual*	*Predicted*	*Actual*	*Predicted*	*Actual*	*Predicted*
Short RSI	556 ms	483 ms	648 ms	462 ms	589 ms	581 ms	699 ms	575 ms
Long RSI	652 ms	476 ms	700 ms	481 ms	684 ms	568 ms	756 ms	582 ms

Table 21: The Actual and Predicted Values under Accuracy-Emphasis for Experiment 2.

	Compatible				*Incompatible*			
	Repeat		*Switch*		*Repeat*		*Switch*	
	Actual	*Predicted*	*Actual*	*Predicted*	*Actual*	*Predicted*	*Actual*	*Predicted*
Short RSI	702 ms	605 ms	880 ms	776 ms	773 ms	735 ms	925 ms	672 ms
Long RSI	862 ms	588 ms	969 ms	582 ms	922 ms	752 ms	1002 ms	747 ms

To examine this issue even further, though in a more principled fashion, note that because two points on the speed accuracy curve were actually obtained from the participants in Experiment 2 in each of the eight RSI, task transition, and compatibility combinations, it was possible to fit SAT curves to those eight conditions. The results of this analysis are given in Tables 22, 23, and 24.

Table 22: Mean Values of the Intercept at the Levels of Each of Three Independent Variables in Experiment 2.

	Compatible		*Incompatible*	
	Repeat	*Switch*	*Repeat*	*Switch*
Short RSI	480 ms	565 ms	430 ms	625 ms
Long RSI	570 ms	625 ms	575 ms	605 ms

Table 23: Mean Values of the Rate at the Levels of Each of Three Independent Variables in Experiment 2.

	Compatible		*Incompatible*	
	Repeat	*Switch*	*Repeat*	*Switch*
Short RSI	.0275	.0159	.0108	.0111
Long RSI	.0272	.0263	.0157	.0078

Table 24: Mean Values of the Asymptote at the Levels of Each of Three Independent Variables in Experiment 2.

	Compatible		*Incompatible*	
	Repeat	*Switch*	*Repeat*	*Switch*
Short RSI	.970	.970	.945	.890
Long RSI	.965	.960	.950	.945

Although their validity is somewhat tentative given the manner in which they were derived, there are a number of very revealing aspects of these results. First, the intercepts for the four long RSI conditions are clearly inflated in comparison to those for the corresponding short RSI conditions (except for the short RSI incompatible task-switch intercept which, as the Experiment 3 results showed, was likely to be rather high to begin with). This result is highly consistent with the conclusion reached earlier that perhaps the participants in Experiment 2, rather than using the long RSIs to either maintain repeated task sets or prepare new ones, were actually allowing task-set activation to decay to a more neutral task-set orientation during the long RSIs (even in task-repeat conditions). Given this fact, subsequent processing on both repeat and switch long RSIs trials would have been very similar (because even repeated task-sets would have to often be re-invoked at the end of the RSI) and intercept switch costs would be very small even for incompatible trials.

Second, the intercept results for the short RSI trials in Experiment 2 show the same 195 ms intercept switch cost for incompatible trials as was found in Experiment 3. However, they also show an 85 ms intercept switch cost for compatible trials that was not present in Experiment 3. However, although participants in Experiment 2 were asked to perform under speed emphasis, this emphasis was never as rushed (or forced) as it was for very early response signals in Experiment 3. As discussed earlier, perhaps, such an acute emphasis on speed in Experiment 3 made participants focus on processing strategies that allowed them to respond under such conditions, ones that were different from the ones needed to respond adequately to the speed emphasis condition in Experiment 2.

With respect to the rate parameters for the Experiment 2 SAT results they show that, consistent with Experiment 3, incompatibility tend to lower the rate of processing rather than the intercept. In addition, even though the switch costs in the intercepts clearly differed across compatible and incompatible trials, it is differences in the rate parameter that then lead to the finding of results no differential RT switch costs across compatibility in the Experiment 2 RT data. For example, the fact that the rate of processing in the short RSI, task-switch compatible condition is lower in comparison to the short RSI, task-repeat compatible condition would have served to inflate the RT switch cost for compatible trials making it more like that observed for short RSI incompatible trials. As well, the similar rate differences in the long RSI incompatible conditions would have served to inflate those switch costs making them more like those in the short RSI compatible conditions. However, why these rate differences occurred is not clear.

Conclusion

The SAT function intercept results in Experiment 3 are clear in showing that task-switching involves both an endogenous and exogenous task-set reconfiguration process during which time no task-relevant processing can proceed. The extent to which this reconfiguration process shows up in actual RTs and errors in task-switch experiments will depend on (a) the amount of effort devoted to preparation (with respect to both task maintenance and task reconfiguration) when RSIs are long, (b) the approach that participants take to processing trials with compatible stimuli, and (c) where participants are operating on the SAT curves for each condition in the experiment.

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Appendices

Appendix A: The List of 64 Conditions

Conditions	Repeat-Switch	Co-Incompatible	Letter-Digit	First-Second	Short-Long	Accuracy-Speed
1	1	1	1	1	1	1
2	2					
3	1	2				
4	2					
5	1	1	2			
6	2					
7	1	2				
8	2					
9	1	1	1	2		
10	2					
11	1	2				
12	2					
13	1	1	2			
14	2					
15	1	2				
16	2					
17	1	1	1	1	2	
18	2					
19	1	2				
20	2					
21	1	1	2			
22	2					
23	1	2				
24	2					
25	1	1	1	2		
26	2					
27	1	2				
28	2					
29	1	1	2			
30	2					
31	1	2				
32	2					
33	1	1	1	1	1	2
34	2					
35	1	2				
36	2					
37	1	1	2			
38	2					
39	1	2				
40	2					
41	1	1	1	2		
42	2					
43	1	2				
44	2					
45	1	1	2			
46	2					
47	1	2				
48	2					
49	1	1	1	1	2	
50	2					
51	1	2				
52	2					
53	1	1	2			
54	2					
55	1	2				
56	2					
57	1	1	1	2		
58	2					
59	1	2				
60	2					
61	1	1	2			
62	2					
63	1	2				
64	2					

Appendix B: Analysis of Variance Results of Experiment 1: Latency

Source	*F*	*MSE*	*P*	*Sig.*
RSI	1.275	206439	.269	
BLOCK	8.189	126310	.008	**
LETTER-DIGIT (LEDI)	9.992	176302	.004	**
REPEAT-SWITCH (RESW)	68.714	131192	.0001	***
ACCURACY-SPEED (ACSP)	63.064	693340	.0001	***
COMPATIBLE-INCOMPATIBLE (COMP)	1.780	61224	.193	
RSI* BLOCK	.655	128257	.425	
RSI* LEDI	.146	53877	.705	
RSI* RESW	19.734	65455	.0001	***
RSI *ACSP	1.160	236775	.291	
RSI* COMP	.197	96322	.066	
BLOCK * LEDI	2.772	42833	.107	
BLOCK * RESW	.135	56562	.715	
BLOCK * ACSP	4.977	75545	.034	*
BLOCK * COMP	.00001	61675	.997	
LEDI * RESW	5.939	69644	.021	*
LEDI * ACSP	7.498	56172	.011	*
LEDI * COMP	1.070	70152	.309	
RESW * ACSP	1.022	56055	.320	
RESW * COMP	2.247	88333	.145	
ACSP * COMP	.032	101950	.858	
RSI* BLOCK * LEDI	2.385	34554	.134	
RSI* BLOCK * RESW	5.184	54177	.031	*
RSI* BLOCK * ACSP	.294	131411	.592	
RSI* BLOCK * COMP	.014	55762	.906	
RSI* LEDI * RESW	.114	60202	.738	
BLOCK * LEDI * RESW	.075	89058	.785	
BLOCK * LEDI * ACSP	1.069	91696	.310	
BLOCK * LEDI * COMP	2.811	41978	.105	
LEDI * RESW * ACSP	.124	72462	.726	
LEDI * RESW * COMP	.222	87052	.640	
RESW * ACSP * COMP	.012	97028	.910	
RSI* LEDI * ACSP	2.896	66804	.100	
RSI* LEDI * COMP	2.818	37857	.104	
RSI* RESW * ACSP	1.404	40105	.246	
RSI* COMP * RESW	.849	95298	.364	
RSI* COMP * ACSP	.323	44244	.574	
BLOCK * COMP * RESW	.597	83390	.446	
ACSP * BLOCK * RESW	.331	60711	.569	
ACSP * BLOCK * COMP	.720	42462	.403	
ACSP * LEDI * COMP	.025	91112	.873	
RSI* BLOCK * LEDI * RESW	.357	67982	.555	
ACSP * RSI* BLOCK * LEDI	.525	38801	.474	
ACSP * RSI* BLOCK * RESW	.051	46129	.823	
ACSP * RSI* LEDI * RESW	2.318	66049	.139	
RSI* BLOCK * LEDI * COMP	6.206	39383	.019	*
RSI* BLOCK * COMP * RESW	.015	94890	.902	
ACSP * RSI* BLOCK * COMP	.479	84267	.494	
ACSP * BLOCK * LEDI * RESW	.175	65794	.678	
RSI* LEDI * COMP * RESW	4.185	51479	.050	*
ACSP * RSI* COMP * RESW	.018	97552	.892	
ACSP * RSI* LEDI * COMP	.302	59175	.587	
BLOCK * LEDI * COMP * RESW	.1.522	43602	.227	
ACSP * BLOCK * COMP * RESW	2.293	68106	.141	
ACSP * BLOCK * LEDI * COMP	1.071	39723	.309	
ACSP * LEDI * COMP * RESW	.682	82498	.415	
ACSP * RSI* BLOCK * LEDI * RESW	.592	39610	.448	
ACSP * RSI* BLOCK * LEDI * COMP	.000407	69095	.984	
ACSP * RSI* LEDI * COMP * RESW	.148	47034	.703	
ACSP * RSI* BLOCK * COMP * RESW	.310	35770	.581	
ACSP * BLOCK * LEDI * COMP * RESW	.324	39604	.573	
RSI* BLOCK * LEDI * COMP * RESW	.564	63957	.458	

* = <.05, ** = <.01, *** = <.001

Appendix C: Analysis of Variance Results of Experiment 1: Accuracy

Source	*F*	*MSE*	*P*	*Sig.*
RSI	5.553	.11050	.025	*
BLOCK	.013	.06812	.907	
LETTER-DIGIT (LEDI)	.293	.09017	.592	
REPEAT-SWITCH (RESW)	30.737	.08683	.0001	***
ACCURACY-SPEED (ACSP)	61.535	.23591	.0001	***
COMPATIBLE-INCOMPATIBLE (COMP)	16.311	.07758	.0001	***
RSI* BLOCK	.035	.11136	.852	
RSI* LEDI	5.943	.06032	.021	*
RSI* RESW	8.071	.08069	.008	**
RSI *ACSP	19.551	.04977	.0001	***
RSI* COMP	.010	.06517	.919	
BLOCK * LEDI	.014	.06991	.904	
BLOCK * RESW	.004	.03948	.944	
BLOCK * ACSP	10.722	.07042	.002	**
BLOCK * COMP	1.974	.05930	.171	
LEDI * RESW	.045	.07372	.832	
LEDI * ACSP	.0002	.06337	.988	
LEDI * COMP	1.928	.06282	.176	
RESW * ACSP	12.908	.05660	.001	**
RESW * COMP	.00002	.06713	.996	
ACSP * COMP	3.012	.05742	.094	
RSI* BLOCK * LEDI	.276	.05194	.603	
RSI* BLOCK * RESW	.735	.07668	.398	
RSI* BLOCK * ACSP	.692	.13939	.412	
RSI* BLOCK * COMP	1.839	.08937	.186	
RSI* LEDI * RESW	.800	.08489	.378	
BLOCK * LEDI * RESW	1.147	.04151	.293	
BLOCK * LEDI * ACSP	1.393	.09235	.248	
BLOCK * LEDI * COMP	3.512	.08123	.071	
LEDI * RESW * ACSP	.486	.09463	.491	
LEDI * RESW * COMP	1.314	.08011	.261	
RESW * ACSP * COMP	.014	.07461	.903	
RSI* LEDI * ACSP	.184	.05025	.671	
RSI* LEDI * COMP	.0008	.06164	.976	
RSI* RESW * ACSP	6.898	.07081	.014	*
RSI* COMP * RESW	3.435	.05965	.074	
RSI* COMP * ACSP	1.058	.08172	.312	
BLOCK * COMP * RESW	.073	.05434	.788	
ACSP * BLOCK * RESW	.194	.07694	.662	
ACSP * BLOCK * COMP	1.477	.08269	.234	
ACSP * LEDI * COMP	.011	.04449	.914	
RSI* BLOCK * LEDI * RESW	.969	.08809	.333	
ACSP * RSI* BLOCK * LEDI	.190	.09474	.665	
ACSP * RSI* BLOCK * RESW	.120	.06234	.731	
ACSP * RSI* LEDI * RESW	1.242	.06776	.274	
RSI* BLOCK * LEDI * COMP	1.353	.05321	.254	
RSI* BLOCK * COMP * RESW	2.780	.06358	.106	
ACSP * RSI* BLOCK * COMP	.761	.06499	.390	
ACSP * BLOCK * LEDI * RESW	2.103	.04518	.158	
RSI* LEDI * COMP * RESW	.815	.04477	.374	
ACSP * RSI* COMP * RESW	.233	.03974	.632	
ACSP * RSI* LEDI * COMP	2.143	.05248	.154	
BLOCK * LEDI * COMP * RESW	1.107	.10654	.301	
ACSP * BLOCK * COMP * RESW	.00003	.06006	.995	
ACSP * BLOCK * LEDI * COMP	.469	.05226	.498	
ACSP * LEDI * COMP * RESW	5.484	.04979	.049	*
ACSP * RSI* BLOCK * LEDI * RESW	.894	.07027	.352	
ACSP * RSI* BLOCK * LEDI * COMP	.008	.10334	.929	
ACSP * RSI* LEDI * COMP * RESW	.603	.07152	.444	
ACSP * RSI* BLOCK * COMP * RESW	.085	.11469	.771	
ACSP * BLOCK * LEDI * COMP * RESW	.517	.07214	.478	
RSI* BLOCK * LEDI * COMP * RESW	4.380	.06359	.045	*

* = <.05, ** = <.01, *** = <.001

Appendix D: Analysis of Variance Results of Experiment 2: Latency

Source	*F*	*MSE*	*P*	*Sig.*
RSI	6.235	240241.652	.034	*
ORDER	10.463	7290.277	.010	*
LETTER-DIGIT (LEDI)	4.983	58972.522	.052	
REPEAT-SWITCH (RESW)	33.886	51916.857	.0002	***
ACCURACY-SPEED (ACSP)	24.595	311846.097	.001	**
COMPATIBLE-INCOMPATIBLE (COMP)	7.151	51096.623	.025	*
RSI* ORDER	.118	14999.976	.739	
RSI* LEDI	.280	16560.352	.610	
RSI* RESW	9.279	13659.642	.014	*
RSI *ACSP	1.620	48346.007	.235	
RSI* COMP	.058	15144.192	.815	
ORDER * LEDI	8.596	4894.130	.017	*
ORDER * RESW	.009	12738.032	.927	
ORDER * ACSP	.731	18147.345	.415	
ORDER * COMP	4.054	3964.600	.075	
LEDI * RESW	2.446	36592.525	.152	
LEDI * ACSP	3.783	9987.745	.084	
LEDI * COMP	.391	12337.975	.548	
RESW * ACSP	14.588	6579.465	.004	**
RESW * COMP	.027	10051.513	.874	
ACSP * COMP	.664	5442.696	.436	
RSI* ORDER * LEDI	2.551	3912.613	.145	
RSI* ORDER * RESW	.001	10960.755	.977	
RSI* ORDER * ACSP	.002	12416.626	.965	
RSI* ORDER * COMP	.231	9428.821	.642	
RSI* LEDI * RESW	.593	6907.350	.461	
ORDER * LEDI * RESW	2.348	4177.910	.160	
ORDER * LEDI * ACSP	.002	7418.656	.969	
ORDER * LEDI * COMP	1.161	6532.033	.309	
LEDI * RESW * ACSP	.212	20405.807	.656	
LEDI * RESW * COMP	20.795	3846.087	.001	**
RESW * ACSP * COMP	4.934	4495.858	.053	
RSI* LEDI * ACSP	.017	9313.123	.899	
RSI* LEDI * COMP	1.278	3735.188	.287	
RSI* RESW * ACSP	.818	11753.998	.389	
RSI* COMP * RESW	.004	3424.495	.949	
RSI* COMP * ACSP	.457	3567.944	.516	
ORDER * COMP * RESW	.020	8172.701	.890	
ACSP * ORDER * RESW	.002	12984.075	.969	
ACSP * ORDER * COMP	3.594	10549.612	.091	
ACSP * LEDI * COMP	.712	10517.448	.421	
RSI* ORDER * LEDI * RESW	.061	5053.130	.811	
ACSP * RSI* ORDER * LEDI	.999	8238.459	.344	
ACSP * RSI* ORDER * RESW	.081	14902.993	.783	
ACSP * RSI* LEDI * RESW	.007	8954.233	.935	
RSI* ORDER * LEDI * COMP	.027	17532.499	.873	
RSI* ORDER * COMP * RESW	.907	9165.057	.366	
ACSP * RSI* ORDER * COMP	.032	6485.553	.862	
ACSP * ORDER * LEDI * RESW	.001	6397.917	.979	
RSI* LEDI * COMP * RESW	9.310	6722.074	.014	*
ACSP * RSI* COMP * RESW	.031	4113.720	.865	
ACSP * RSI* LEDI * COMP	1.205	12363.600	.301	
ORDER * LEDI * COMP * RESW	1.455	6448.208	.258	
ACSP * ORDER * COMP * RESW	.217	2754.038	.652	
ACSP * ORDER * LEDI * COMP	.005	7723.157	.945	
ACSP * LEDI * COMP * RESW	1.337	12748.419	.277	
ACSP * RSI* ORDER * LEDI * RESW	.740	17750.632	.412	
ACSP * RSI* ORDER * LEDI * COMP	.127	8980.819	.730	
ACSP * RSI* LEDI * COMP * RESW	1.002	8813.753	.343	
ACSP * RSI* ORDER * COMP * RESW	.172	13205.067	.688	
ACSP * ORDER * LEDI * COMP * RESW	.247	16137.401	.631	
RSI* ORDER * LEDI * COMP * RESW	.0005	4137.262	.983	

* = < .05, ** = < .01, *** = < .001

Appendix E: ***Analysis of Variance Results of Experiment 2: Accuracy (transformed data)***

Source	*F*	*MSE*	*P*	*Sig.*
RSI	4.272	.06230	.069	
ORDER	4.098	.02420	.074	
LETTER-DIGIT (LEDI)	.002	.06386	.964	
REPEAT-SWITCH (RESW)	17.816	.04378	.002	**
ACCURACY-SPEED (ACSP)	28.552	.18400	.0004	***
COMPATIBLE-INCOMPATIBLE (COMP)	15.554	.14400	.003	**
RSI* ORDER	.200	.00867	.665	
RSI* LEDI	.150	.03785	.707	
RSI* RESW	4.229	.04053	.070	
RSI *ACSP	2.616	.02895	.140	
RSI* COMP	1.703	.03025	.224	
ORDER * LEDI	2.483	.01817	.150	
ORDER * RESW	8.159	.02635	.019	*
ORDER * ACSP	2.047	.01095	.186	
ORDER * COMP	1.148	.02076	.312	
LEDI * RESW	13.304	.02151	.005	**
LEDI * ACSP	.540	.02593	.481	
LEDI * COMP	.740	.03027	.412	
RESW * ACSP	7.237	.02144	.025	*
RESW * COMP	18.518	.01957	.002	**
ACSP * COMP	2.494	.02010	.149	
RSI* ORDER * LEDI	.349	.01527	.569	
RSI* ORDER * RESW	.089	.02221	.772	
RSI* ORDER * ACSP	.593	.00932	.461	
RSI* ORDER * COMP	.006	.01797	.940	
RSI* LEDI * RESW	.061	.01420	.811	
ORDER * LEDI * RESW	9.846	.01227	.012	*
ORDER * LEDI * ACSP	.370	.01723	.558	
ORDER * LEDI * COMP	7.812	.02462	.021	*
LEDI * RESW * ACSP	.392	.02911	.547	
LEDI * RESW * COMP	.032	.01564	.863	
RESW * ACSP * COMP	.009	.05068	.927	
RSI* LEDI * ACSP	1.908	.01120	.200	
RSI* LEDI * COMP	.444	.02155	.522	
RSI* RESW * ACSP	3.418	.01358	.098	
RSI* COMP * RESW	4.422	.00601	.065	
RSI* COMP * ACSP	1.186	.01857	.304	
ORDER * COMP * RESW	4.155	.01932	.072	
ACSP * ORDER * RESW	1.950	.01059	.196	
ACSP * ORDER * COMP	.974	.01286	.350	
ACSP * LEDI * COMP	2.986	.02462	.118	
RSI* ORDER * LEDI * RESW	.127	.02897	.730	
ACSP * RSI* ORDER * LEDI	1.232	.02191	.296	
ACSP * RSI* ORDER * RESW	.005	.01842	.947	
ACSP * RSI* LEDI * RESW	.169	.01924	.691	
RSI* ORDER * LEDI * COMP	.196	.01857	.668	
RSI* ORDER * COMP * RESW	.535	.01307	.483	
ACSP * RSI* ORDER * COMP	.072	.01650	.794	
ACSP * ORDER * LEDI * RESW	1.286	.02259	.286	
RSI* LEDI * COMP * RESW	3.135	.01421	.110	
ACSP * RSI* COMP * RESW	.013	.02567	.913	
ACSP * RSI* LEDI * COMP	1.070	.01697	.328	
ORDER * LEDI * COMP * RESW	4.700	.01176	.058	
ACSP * ORDER * COMP * RESW	2.012	.01487	.190	
ACSP * ORDER * LEDI * COMP	.002	.02189	.966	
ACSP * LEDI * COMP * RESW	.738	.01557	.413	
ACSP * RSI* ORDER * LEDI * RESW	1.208	.02047	.300	
ACSP * RSI* ORDER * LEDI * COMP	.509	.01286	.494	
ACSP * RSI* LEDI * COMP * RESW	14.082	.00562	.005	**
ACSP * RSI* ORDER * COMP * RESW	.157	.00658	.701	
ACSP * ORDER * LEDI * COMP * RESW	.846	.01991	.382	
RSI* ORDER * LEDI * COMP * RESW	.834	.00683	.385	

* = <.05, ** = <.01, *** = <.001

Appendix F: Inverting SAT equation

The SAT equation (Wickelgren, 1977):

$$d' = \lambda\left[1 - e^{-\gamma(t-\delta)}\right],$$

(where λ is the asymptotic accuracy level, γ stands for information processing rate, and δ is the time intercept in a SAT curve) was adjusted as shown below to obtain fits to the Experiment 3 accuracy data and can be inverted as follows:

$$(Accuracy - 0.5) = (\lambda - 0.5)\,[\,1 - e^{-\gamma(t-\delta)}]$$

$$(Accuracy - 0.5) / (\lambda - 0.5) = 1 - e^{-\gamma(t-\delta)}$$

$$(Accuracy - 0.5) / (\lambda - 0.5) - 1 = -e^{-\gamma(t-\delta)}$$

$$1 - (Accuracy - 0.5) / (\lambda - 0.5) = e^{-\gamma(t-\delta)}$$

$$ln\,[1 - (Accuracy - 0.5) / (\lambda - 0.5)] = -\gamma\,(t-\delta)$$

$$ln\,[1 - (Accuracy - 0.5) / (\lambda - 0.5)]\,/\,-\gamma = t-\delta$$

$$(ln\,[1 - (Accuracy - 0.5) / (\lambda - 0.5)]\,/\,-\gamma) + \delta = t$$

Appendix G: Predicting SAT Points of the Eight Conditions Involving RSI, Task Transition, and Compatibility of Experiment 2

Using the inverted SAT equation (see Appendix F) and the obtained λ, γ, and δ in Experiment 3, the predicted SAT points of the eight conditions involving RSI, Task Transition, and Compatibility of Experiment 2 will be as follows:

1- Short RSI, Repeat, and Compatible

Accuracy:

$$(ln\,[1 - .469/.487]\,/\,-.01166) + 323 = 605$$

Speed:

$$(ln\,[1 - .412/.487]\,/\,-.01166) + 323 = 483$$

2- Short RSI, Repeat, and Incompatible

Accuracy:

$$(ln\,[1 - .434/.488]\,/\,-.00532) + 322 = 735$$

Speed:

$$(ln\,[1 - .365/.488]\,/\,-.00532) + 322 = 581$$

3- Short RSI, Switch, and Compatible

Accuracy:

$$(ln\,[1 - .467/.472]\,/\,-.01032) + 336 = 776$$

Speed:

$$(\mathit{ln}\ [1 - .344/.472] / -.01032) + 336 = 462$$

4- Short RSI, Switch, and Incompatible

Accuracy:

$$(\mathit{ln}\ [1 - .376/.464] / -.01054) + 515 = 672$$

Speed:

$$(\mathit{ln}\ [1 - .218/.464] / -.01054) + 515 = 575$$

5- Long RSI, Repeat, and Compatible

Accuracy:

$$(\mathit{ln}\ [1 - .465/.477] / -.01466) + 337 = 588$$

Speed:

$$(\mathit{ln}\ [1 - .415/.477] / -.01466) + 337 = 476$$

6- Long RSI, Repeat, and Incompatible

Accuracy:

$$(\mathit{ln}\ [1 - .448/.483] / -.006433) + 344 = 752$$

Speed:

$$(\mathit{ln}\ [1 - .369/.483] / -.006433) + 344 = 568$$

7- Long RSI, Switch, and Compatible

Accuracy:

$$(\mathit{ln}\ [1 - .460/.486] / -.01221) + 343 = 582$$

Speed:

$$(\mathit{ln}\ [1 - .396/.486] / -.01221) + 343 = 481$$

8- Long RSI, Switch, and Incompatible

Accuracy:

$$(\mathit{ln}\ [1 - .425/.491] / -.00621) + 424 = 747$$

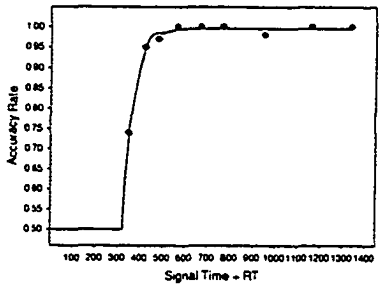
Speed:

$$(\mathit{ln}\ [1 - .308/.491] / -.00621) + 424 = 582$$

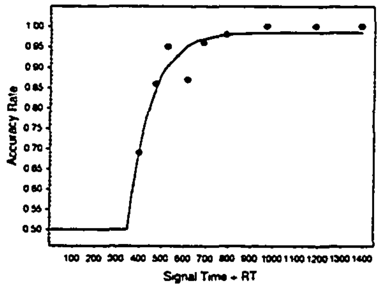
Appendix H: The Modeled Individual SAT Curves for the 8 Conditions

1- Short RSI, Repeat, and Compatible

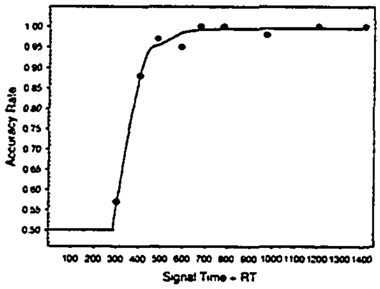
3
Intercept: 325
Rate: .0241
Asymptote: .995



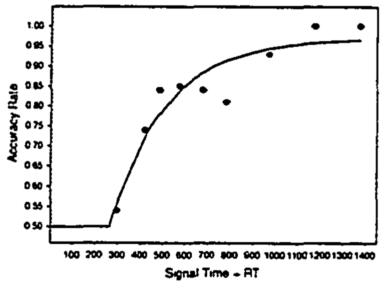
4
Intercept: 350
Rate: .0101
Asymptote: .985



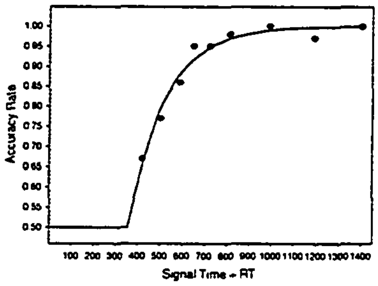
5
Intercept: 295
Rate: .0131
Asymptote: .995



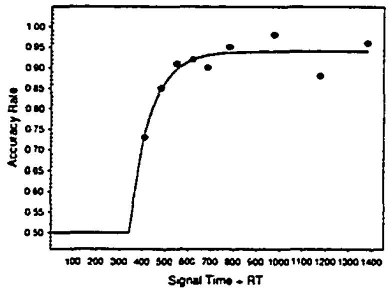
6
Intercept: 265
Rate: .0041
Asymptote: .97



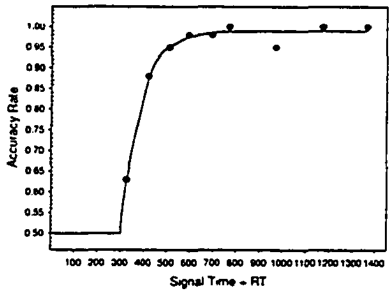
8
Intercept: 355
Rate: .0061
Asymptote: 1.00



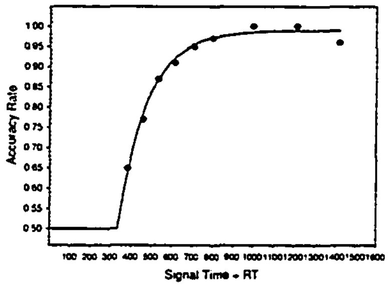
13
Intercept: 340
Rate: .0111
Asymptote: .94



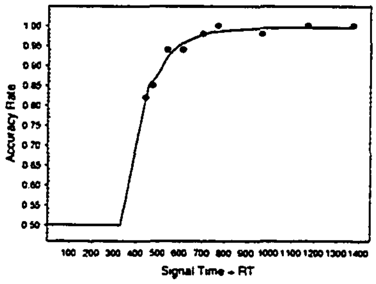
14
Intercept: 300
Rate: .0121
Asymptote: .99



18
Intercept: 335
Rate: .0071
Asymptote: .99

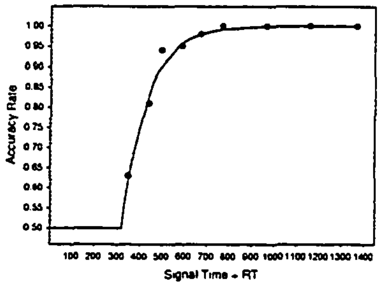


19
Intercept: 330
Rate: .0091
Asymptote: .995

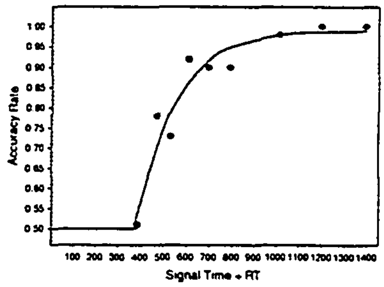


2- Short RSI, Repeat, and Incompatible

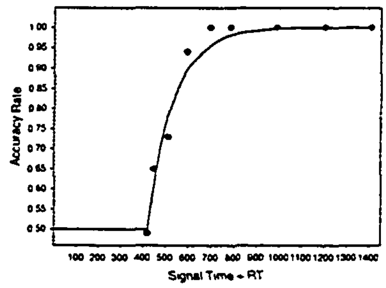
3
Intercept: 320
Rate: .0091
Asymptote: 1.00



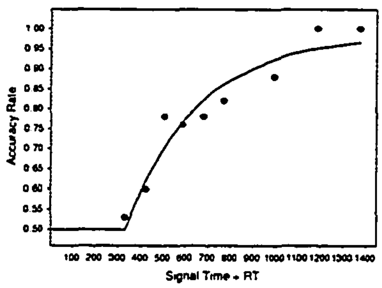
4
Intercept: 385
Rate: .0061
Asymptote: .99



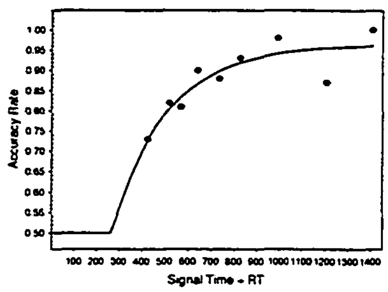
5
Intercept: 420
Rate: .0091
Asymptote: 1.00



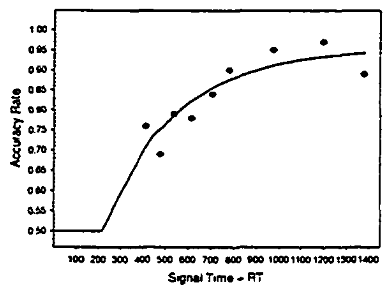
6
Intercept: 330
Rate: .0031
Asymptote: .985



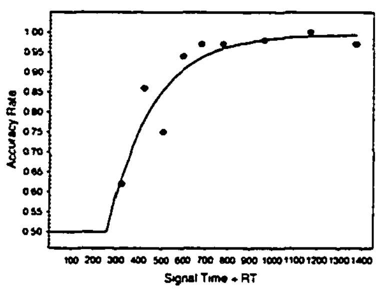
8
Intercept: 260
Rate: .0041
Asymptote: .965



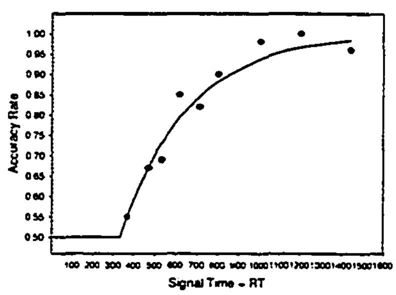
13
Intercept: 215
Rate: .0031
Asymptote: .955



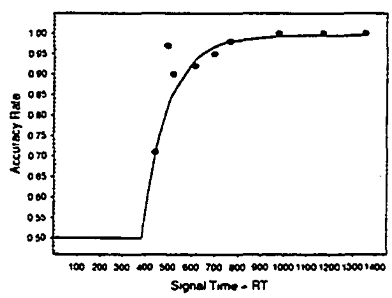
14
Intercept: 260
Rate: .0051
Asymptote: .995



18
Intercept: 335
Rate: .0031
Asymptote: 1.00

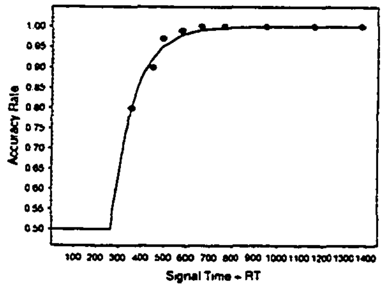


19
Intercept: 385
Rate: .0091
Asymptote: .995

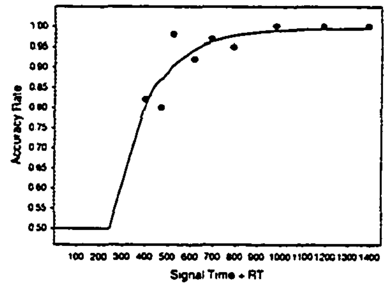


3- Short RSI, Switch, and Compatible

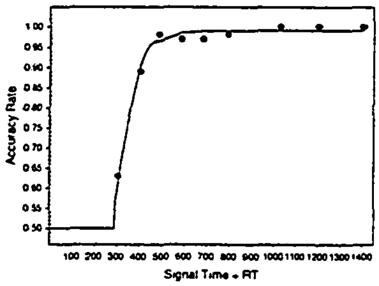
3
Intercept: 265
Rate: .0101
Asymptote: 1.00



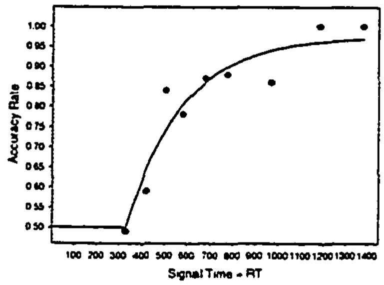
4
Intercept: 245
Rate: .00916
Asymptote: .995



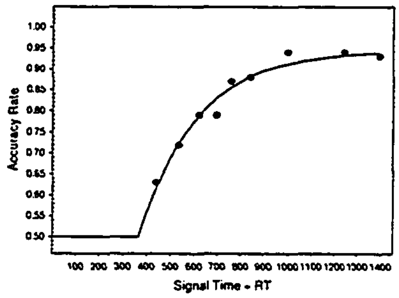
5
Intercept: 290
Rate: .0151
Asymptote: .99



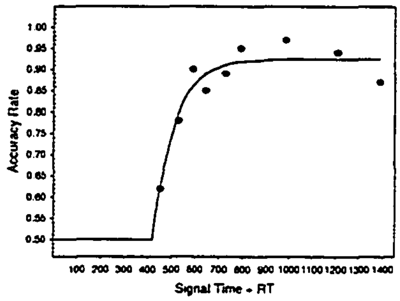
6
Intercept: 330
Rate: .0041
Asymptote: .975



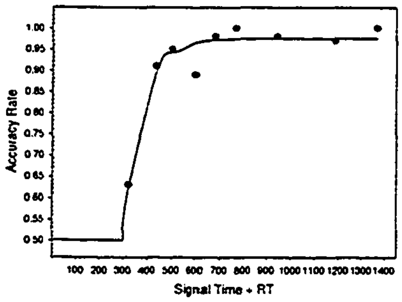
8
Intercept: 365
Rate: .0041
Asymptote: .945



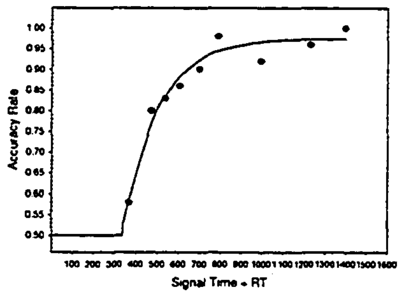
13
Intercept: 420
Rate: .0111
Asymptote: .925



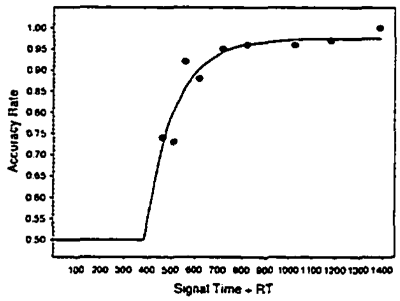
14
Intercept: 300
Rate: .0131
Asymptote: .975



18
Intercept: 335
Rate: .0061
Asymptote: .975

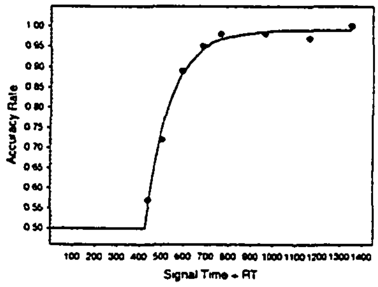


19
Intercept: 385
Rate: .0081
Asymptote: .975

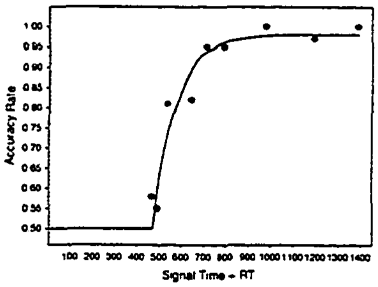


4- Short RSI, Switch, and Incompatible

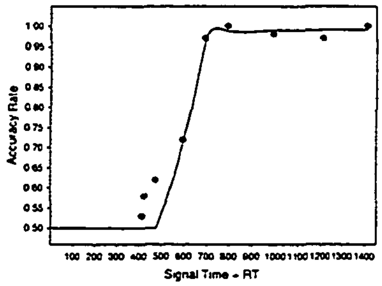
3
Intercept: 425
Rate: .0091
Asymptote: .99



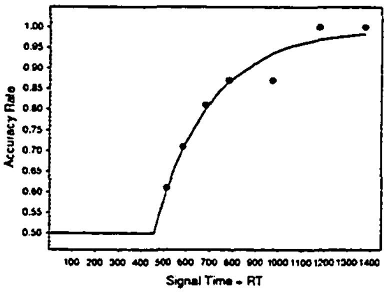
4
Intercept: 470
Rate: .0101
Asymptote: .98



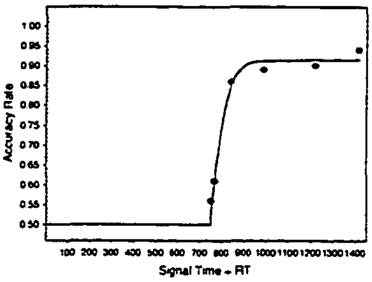
5
Intercept: 475
Rate: .0251
Asymptote: .99



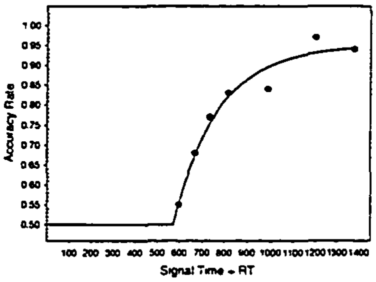
6
Intercept: 455
Rate: .0041
Asymptote: .995



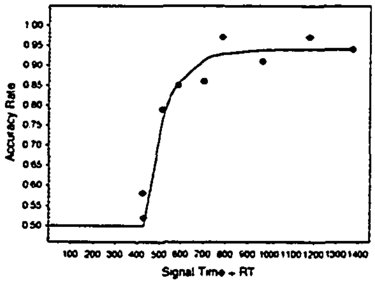
8
Intercept: 750
Rate: .0201
Asymptote: .915



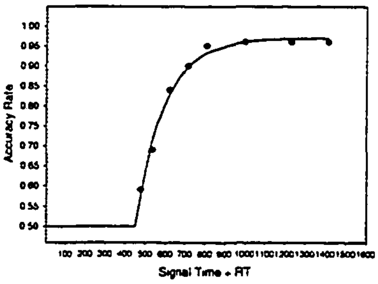
13
Intercept: 570
Rate: .0051
Asymptote: .95



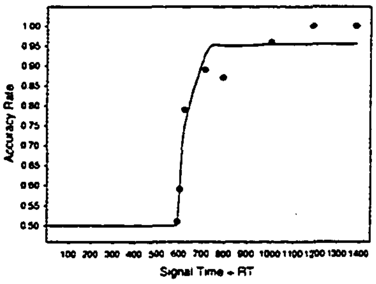
14
Intercept: 425
Rate: .0101
Asymptote: .94



18
Intercept: 450
Rate: .0071
Asymptote: .97

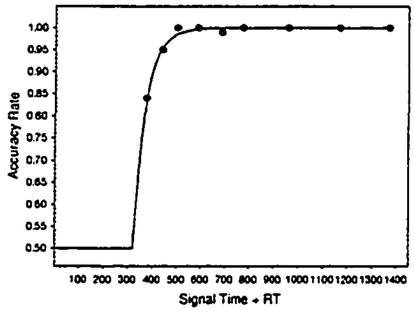


19
Intercept: 590
Rate: .0231
Asymptote: .955

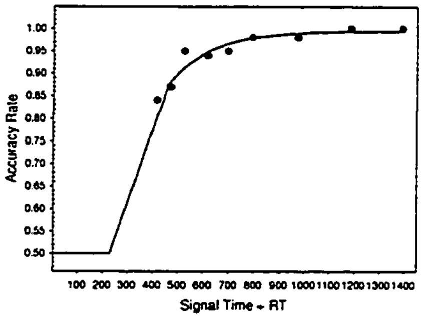


5- Long RSI, Repeat, and Compatible

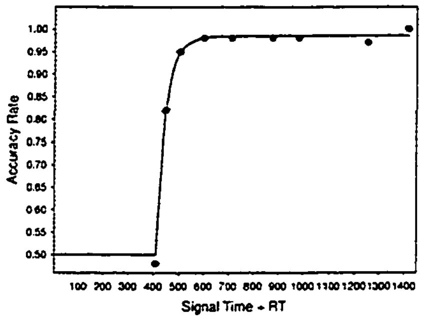
3
Intercept: 320
Rate: .0201
Asymptote: 1.00



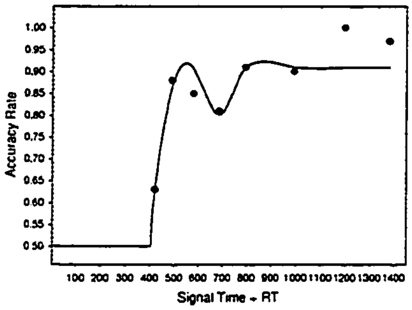
4
Intercept: 230
Rate: .0061
Asymptote: .995



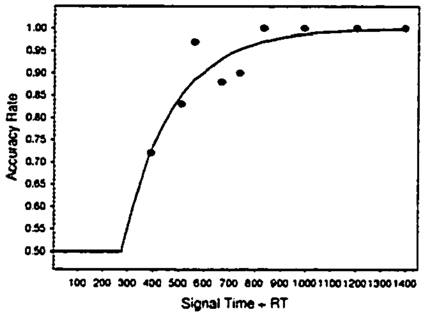
5
Intercept: 410
Rate: .0281
Asymptote: .985



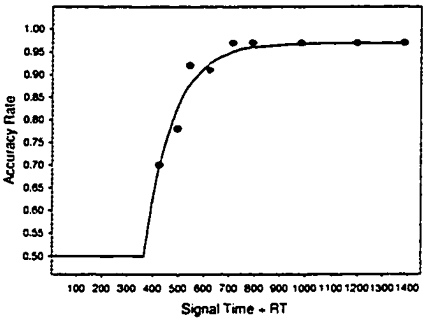
6
Intercept: 405
Rate: .0261
Asymptote: .91



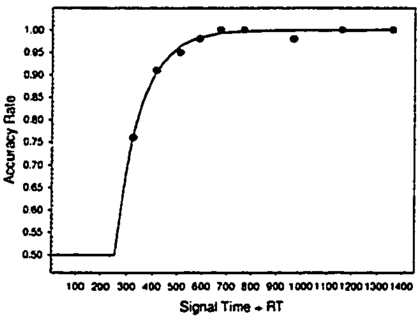
8
Intercept: 275
Rate: .0051
Asymptote: 1.00



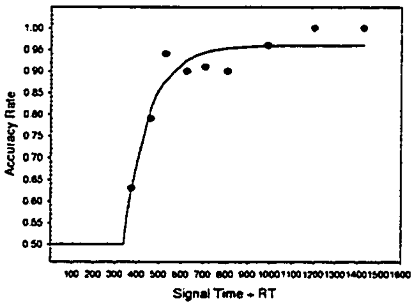
13
Intercept: 365
Rate: .0091
Asymptote: .97



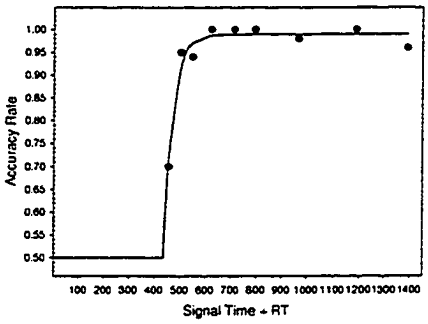
14
Intercept: 250
Rate: .0101
Asymptote: 1.00



18
Intercept: 340
Rate: .0091
Asymptote: .96

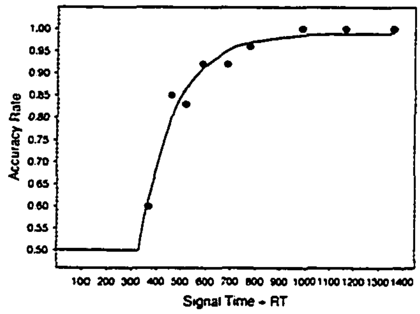


19
Intercept: 435
Rate: .0281
Asymptote: .99

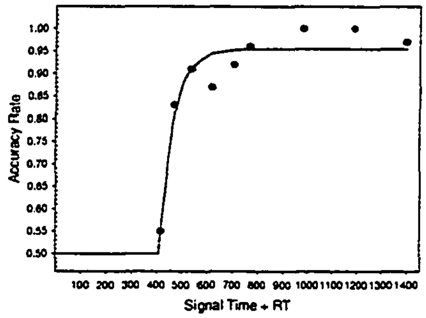


6- Long RSI, Repeat, and Incompatible

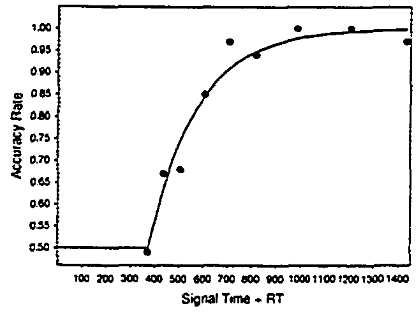
3
Intercept: 330
Rate: .0071
Asymptote: .99



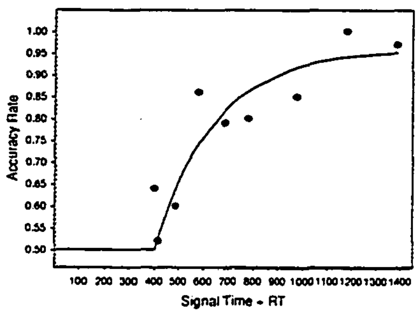
4
Intercept: 410
Rate: .0181
Asymptote: .955



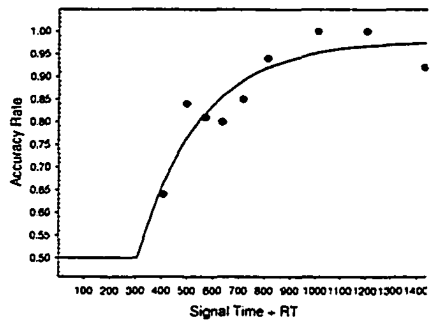
5
Intercept: 375
Rate: .0051
Asymptote: 1.00



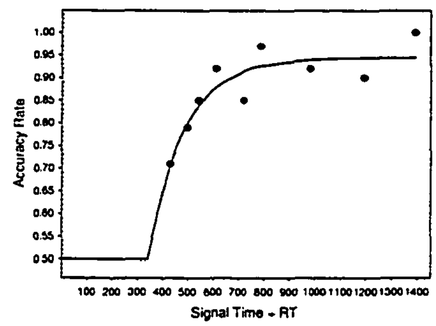
6
Intercept: 400
Rate: .0041
Asymptote: .96



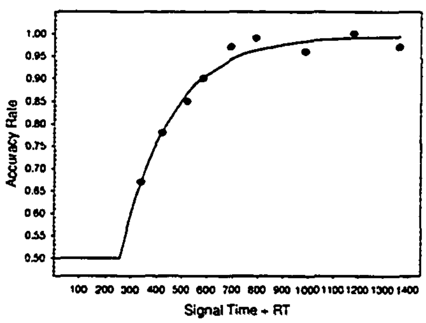
8
Intercept: 305
Rate: .0041
Asymptote: .98



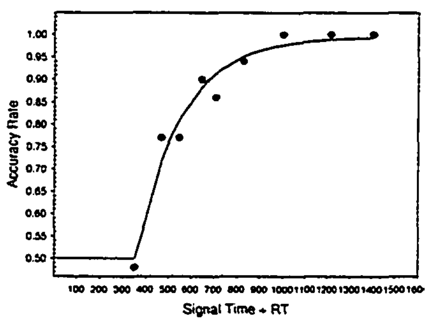
13
Intercept: 340
Rate: .0071
Asymptote: .945



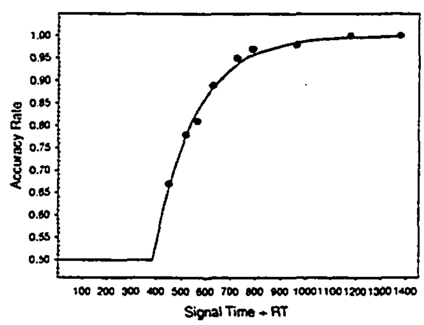
14
Intercept: 255
Rate: .0051
Asymptote: .995



18
Intercept: 355
Rate: .0051
Asymptote: .995

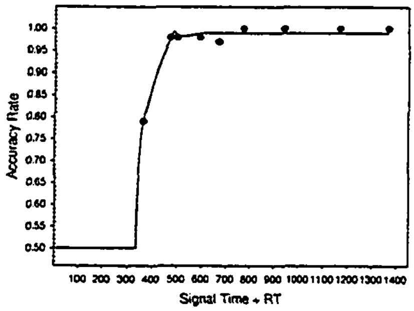


19
Intercept: 385
Rate: .0061
Asymptote: 1.00

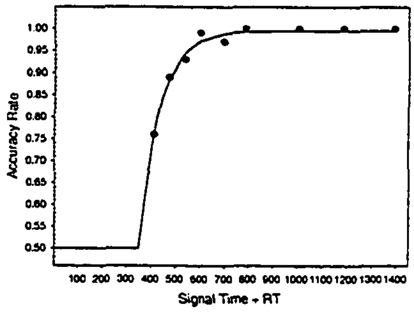


7- Long RSI, Switch, and Compatible

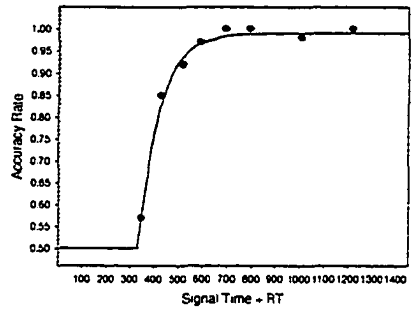
3
Intercept: 335
Rate: .0281
Asymptote: .99



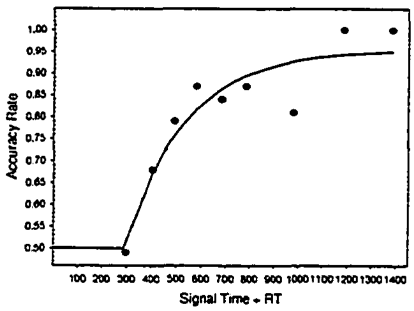
4
Intercept: 350
Rate: .0121
Asymptote: .995



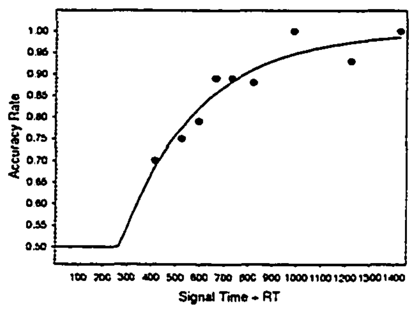
5
Intercept: 335
Rate: .0121
Asymptote: .99



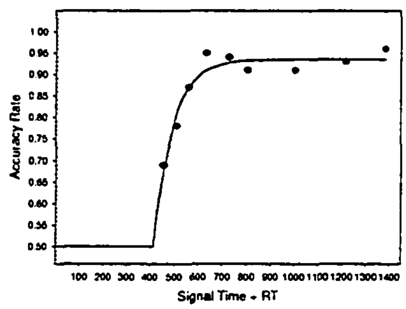
6
Intercept: 290
Rate: .0041
Asymptote: .955



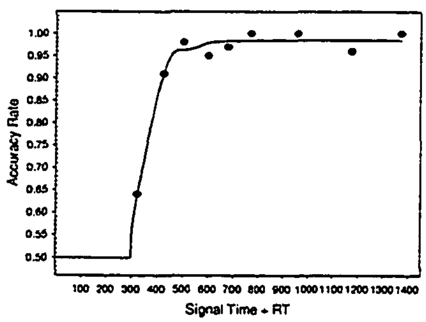
8
Intercept: 265
Rate: .0031
Asymptote: 1.00



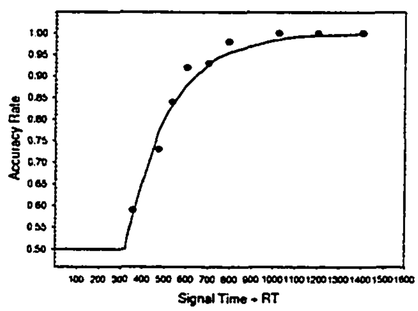
13
Intercept: 415
Rate: .0131
Asymptote: .935



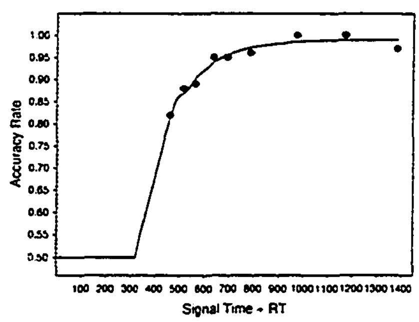
14
Intercept: 300
Rate: .0151
Asymptote: .985



18
Intercept: 325
Rate: .0051
Asymptote: 1.00

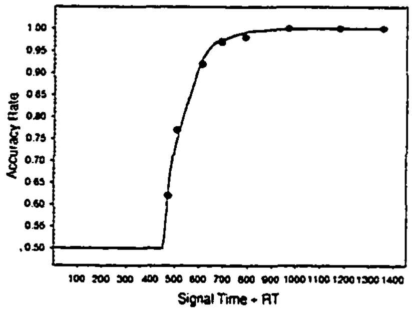


19
Intercept: 320
Rate: .0071
Asymptote: .99

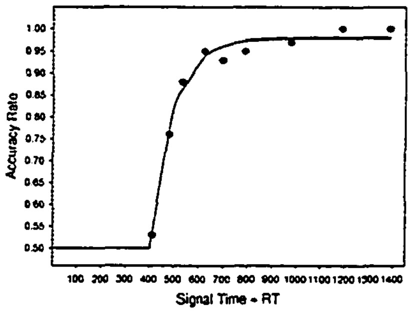


8- Long RSI, Switch, and Incompatible

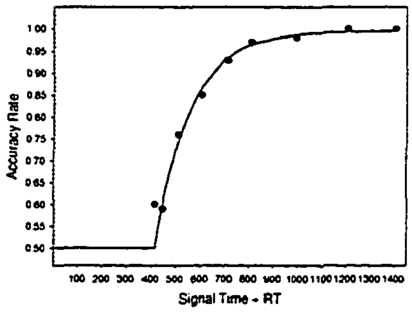
3
Intercept: 450
Rate: .0121
Asymptote: 1.00



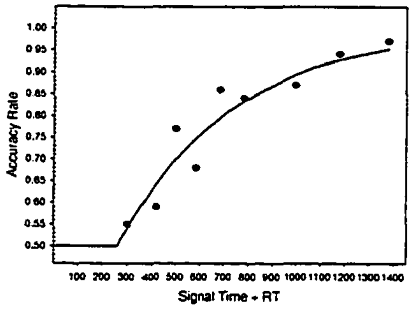
4
Intercept: 405
Rate: .0111
Asymptote: .98



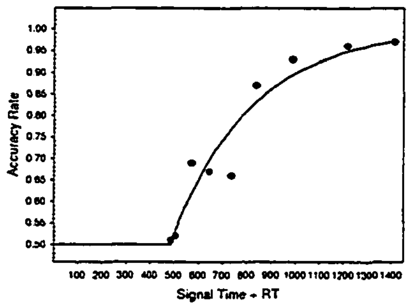
5
Intercept: 415
Rate: .0071
Asymptote: .995



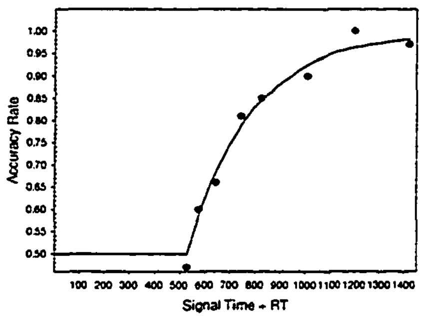
6
Intercept: 260
Rate: .0021
Asymptote: 1.00



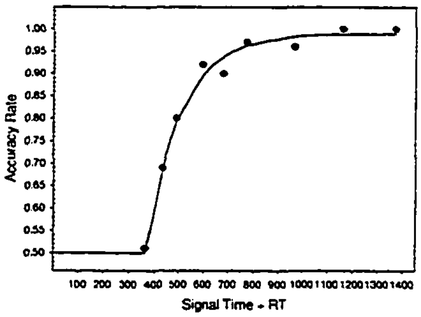
8
Intercept: 485
Rate: .0031
Asymptote: 1.00



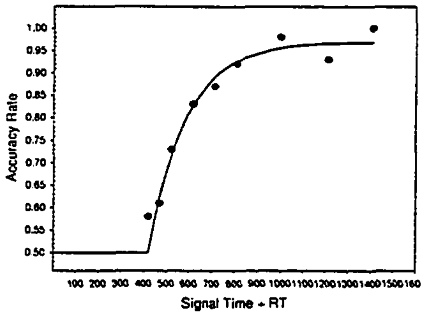
13
Intercept: 530
Rate: .0041
Asymptote: .995



14
Intercept: 365
Rate: .0071
Asymptote: .99



18
Intercept: 420
Rate: .0061
Asymptote: .97



19
Intercept: 450
Rate: .0051
Asymptote: 1.00